European Commission

Best environmental management practice for the

building and construction sector

Final Draft, September 2012

JOINT RESEARCH CENTER
Institute for Prospective Technological Studies
Sustainble Production and Consumption Unit

EXECUTIVE SUMMARY
A.1. General Aspects, Structure and Content of the Document

A.1.1 General aspects

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Legal background

On 25 November 2009, the Council and the European Parliament adopted the proposed revision of the EcoManagement and Audit Scheme (EMAS) regulation (EC) No 1221/2009, which went into force on 11 January, 2010.

One of the new elements of this revised regulation is Article 46 stating that sectoral reference documents (SRD) on best environmental management practice (Article 46(1)) shall be developed which shall contain best environmental management practices, sector-specific environmental performance indicators and, where appropriate, benchmarks of excellence and rating systems identifying environmental performance levels.

Objective of this document

In the future, the aforementioned reference documents shall be elaborated for a range of sectors identified as priorities for EMAS regulation based *inter alia* on their environmental impact and/or their suitability for EMAS uptake. The list of priority sectors is established in the communication from the Commission 2011/C 358/02 'Establishment of the working plan setting out an indicative list of sectors for the adoption of sectoral and cross-sectoral reference documents'. This SRD for the building and construction sector was compiled by the Institute for Prospective Technological Studies (IPTS), part of the European Commission's Joint Research Centre. This is a pilot SRD that may become a reference for further reference documents.

Information sources

For drafting this document, a lot of information is already publicly available from various sources including a number of comprehensive reports. That information has been considered with information collected directly from stakeholders, including construction, companies, public administrations, consultancy firms, non-governmental organisations, and technology providers. A number of site visits proved to be very useful for obtaining technical and performance data and information on economic considereations.

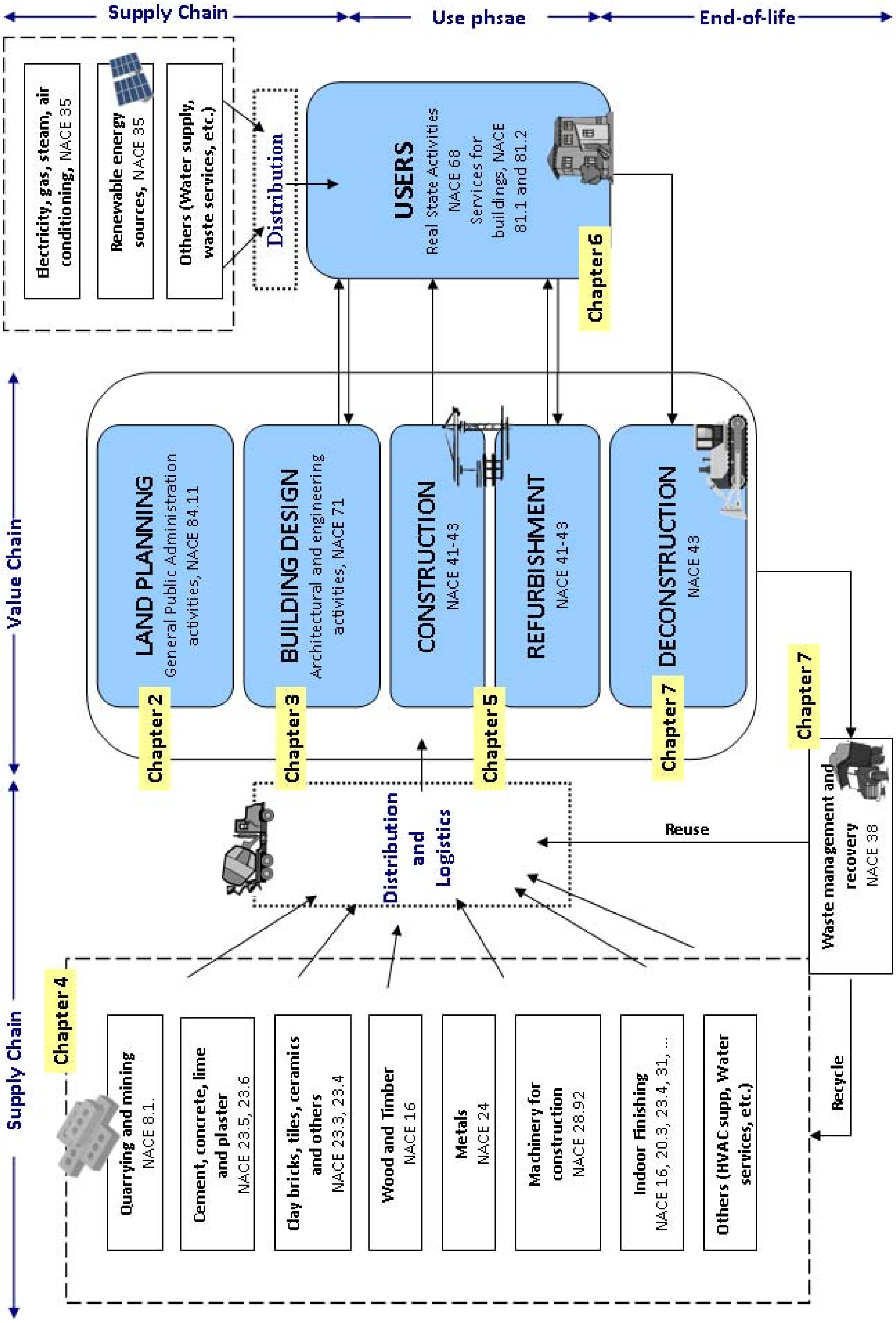
Intention of this document

EMAS is a voluntary scheme. This document is intended to support environmental improvement efforts of all actors in the construction sector. Consequently this document is not only for EMAS registered organisations but for all actors in the sector with or without a certified or registered environmental management system.

However, EMAS registered organisations, shall take into account the relevant sectoral reference document(s) when assessing their environmental performance. The same applies to the EMAS environmental verifiers when checking the requirements according to Article 18 of the EMAS regulation.

A.1.2 Structure of the document

The document covers the whole value added chain of the construction sector, from land planning to the building end of life (the *economical* life cycle) and from selection of best environmentally friendly materials to waste treatment and recycling and reuse cycles . On the basis of mass stream thinking, the following input/output scheme has been used to structure the document.



Overview of inputs and outputs of the Construction sector

The heart of the document is the 'Best environmental management practices' (BEMPs) description. Reflecting the overview above, they are grouped as follows:

- BEMPs to improve the environmental performance of the construction activitythrough better land planning and integration with urban sustainability objectives (Chapter 2)
- BEMPs to improve the building design (Chapter 3)
- BEMPs to improve the sustainability of construction products (Chapter 4)

- BEMPs to improve the environmental performance of the construction process (Chapter 5)
- BEMPs to improve operation and maintenance of buildings (Chapter 6)
- BEMPs to improve building deconstruction (Chapter 7)
- An additional chapter highlighting the links between Civil Works and building construction (Chapter 8)

The content of these chapters covers the most significant environmental aspects of the sector.

The structure to describe the techniques is very similar to the one used in the Best Available Techniques Reference Documents (BREFs) according to the Industrial Emissions Directive, which replaced the IPPC Directive with effect from January 2014.

In addition, Chapter 1 contains general information about the construction sector such as data on turnover and employment as well as the direct and indirect environmental aspects which are illustrated by means of the overview of the inputs and outputs (see figure above). In the brief Chapter 9 on emerging techniques, some techniques concerning the improvement of building design are described. Chapter 10 of the SRD provides a brief overview for micro-, small- and medium-sized enterprises. Specifically, it lists the applicability of the BEMP techniques described in this document to SMEs, and highlights any restricting factors particularly relevant to micro-enterprises and SMEs. Options to facilitate SMEs with environment-related investments are referred to.

Chapter 11 of the SRD contains concluding tables that compile the information from BEMPs description. Conclusions are drawn with respect to key environmental performance indicators and benchmarks of excellence.

A.1.3 List of Best Environmental Management Practices

A best environmental management practice, BEMP, is defined in the EMAS regulation as 'the most effective way to implement the environmental management system by organisations in a relevant sector and that can result in best environmental performance under given economic and technical conditions'. The list of BEMPs is shown in

The environmental performance of described practices has been evaluated in technical detail along with economic considerations. For this purpose, detailed technical information and data were collected and collated, which is summarised and technically described in this document. The structure of the technical descriptions of the different practices is similar to the Best Available Techniques Reference Documents (BREFs) according to Article 13 of the Industrial Emissions Directive (formerly the IPPC Directive): description, achieved environmental benefits, appropriate environmental indicator, cross-media effects, operational data, applicability, economics, driving force for implementation, reference companies and reference litreature. In the description, all management possibilities are described, i.e. as direct or indirect aspects, as the potential readers of the document are designers, local and regional public administrations, construction and deconstruction/demolishing organisations, building users, land planners, developers and verifiers with technical knowledge of the construction sites environmental management.

List of identified best environmental management practices for the building construction sector.

BEMP is to…	Described in
Land Planning	
Protect biodiversity through the implementation of local biodiversity protection strategies and action plans. For construction projects, e.g. in a city, it is required that these plans include wildlife protection during all construction stages (site clearance, site setup, haul roads, groundwork and construction).	2.2.1

BEMP is to…	Described in
Apply low impact drainage measures in the construction of new developments and in the retrofitting of existing ones to prevent and control flooding, soil erosion and pollution, groundwater pollution, establishing mechanisms to replicate as closely as possible, natural drainage of sites before development.	2.2.2
Establish water drainage monitoring systems to control water run-off, infiltration and rainwater pollution and to employ these data on the improvement of existing systems	2.2.2
Establish criteria for the green procurement of construction services, both in public or private tenders, for: • the energy performance of buildings (going beyond legislation) • the renewable energy to be produced in new or renovated buildings (going beyond legislation) • recycled content and recyclability of construction materials • environmental friendliness of construction materials and building elements • restriction on construction materials • water saving measures • ecodesign of building structure • environmental performance of the construction site • environmental capabilities of contractors • management of construction and demolition waste • water drainage and groundwater management • heating and/or cooling systems • indoor lighting	2.2.3
Take into account the mitigation of the Urban Heat Island effect through the application of environmentally friendly measures, as green roofs, the use of reflective materials, increasing the efficiency of hot pipes insulation and the use of waste heat	2.2.4
Build in brownfields, minimise the space between buildings, refurbishment of unused buildings, adding floors, improving the quality of land use, etc. to avoid urban sprawl, reduce soil sealing and avoid undesired impacts over natural spaces.	2.3
Building Design	
Use integrative approaches achieving best environmental performance and best life cycle costs.	3.4.2
Insulate and keep ari tightness avoiding thermal bridges, minimizing the heat transfer and without a significant loss of useful area	3.4.1.1
Use innovative insulation techniques for walls, as vacuum insulation, with improved environmental and economical performance	3.4.1.2
Design and use cool, brown and green roofs to improve the thermal behaviour of the building, also with a positive effect on biodiversity, water drainage performance and on the mitigation of heat island effect	3.4.1.3
Use building configuration allowing best performing glazing, maximizing gains in winter and using shading systems.	3.4.1.4
Design or retrofit HVAC system according to: • Its total integration, taking into account the envelope performance, an optimal solar gain, enhance air tightness, expected internal gains and optimised monitoring and control • The use of environmentally friendly heating and cooling systems, with proven performance in order to reduce the demand of primary energy and without cross-effects over other environmental aspects. • The optimal maintenance cycles of the system	3.4.3
Reduce the energy demand for lighting through the application of lighting strategies, daylighting and lighting devices	3.4.4.1 3.4.4.2

BEMP is to…	Described in
Use adequate renewable energy systems, if the application of best practices to reduce the demand and increase the efficiency is maximised in the design or in the planned renovation of the building.	3.4.5
Plan, design and optimise water drainage in order to improve run-off water quality, increasing infiltration and avoiding flooding risks	3.4.6.1
Plan, design and implement water saving fixtures according to best available techniques for water saving and fulfilling internationally recognised environmental criteria	3.4.6.2
Harvest rainwater, reuse it and recycle grey water, according to the applicability of these options	3.4.6.3
Prevent waste generation during construction through designing out waste techniques, as modern methods of construction, reducing extensively the environmental impact of the construction site	3.4.7.1
Prevent waste generation during deconstruction through better design and selection of materials	3.4.7.2
Construction Products	
Use environmental selection criteria for materials, products and construction elements attending to the performance of their supply chain, distribution and transportation distance, the performance during use (toxicity, release of pollutants, energy performance, noise protection and other indoor quality requirements) and the recyclability at the end of building lifetime. The performance of paints, wood and floor coverings are deeply described in the document.	4.3.1.1 4.3.1.2 4.3.1.3 4.3.1.4
Construction and Refurbishment	
Establish specific environmental management plan where all the measures to prevent, control and monitor the environmental performance is outline. It should content consents between clients and contractors, environmental risk assessment and allocation of resources. For 'Build and Design' projects, it may content preventive design measures.	5.6.1.1
Train and educate labourers on the environmental management practices	5.6.1.1
Monitor the environmental performance of the construction site, to estimate the environmental impact during design and preconstruction site and to establish mechanisms to check improvement of the environmental management performance of construction sites	5.6.1.2
Prevent and manage waste: • Site waste management plan, which includes specific actions for every type of waste, the expected amount of every type of waste, management options, allocation of resources, responsibilities definition, etc. This waste management plan should be included in the communication to stakeholders. • Separate and sort waste, diverting waste from landfill as much as possible. • Maintain or establish a waste logistics system with optimised routing to reduce the carbon footprint of its transport	5.6.2.1
Establish materials use efficiency procedures to reduce the amount of waste: just-in-time deliveries, consolidation centres, reverse logistics (where appropriate).	5.6.2.2
Use materials salvaged from deconstruction of other buildings, as metal frames, concrete structure, bricks or other ceramics. Reuse as much as possible auxiliary materials for construction sites.	5.6.2.3
Select recycled materials, with especial regard to those aggregates produced from construction waste.	5.6.2.4

BEMP is to…	Described in
Protect soil from erosion and design a temporary drainage system with pollution control for exposed land. Minimise exposed soil to wind and rainfall water and use sedimentation and filtering devices to avoid run-off water pollution: use planning strategies to reduce the costs of water management at site; use vegetative barriers, energy dissipators, dams, etc. to avoid heavy erosion.	5.6.2.5
Reduce dust by establishing a dust management plan if dust is expected to be a sensitive issue for the construction site, limit clearance of areas, spray water and apply physical and chemical barriers and control for dust generation. Monitor the effects of dust prevention plans.	5.6.2.6
Reduce disturbance to the neighbourhood, especially in sensitive areas, as residential areas or sites close to natural spaces. Reduce noise and vibration by establishing appropriate prevention and mitigation measures. Reduce night lighting by re-scheduling works when it is adequate, screens and directional lighting. Prevent odours and air emissions avoiding fires, stopping machinery not in use and keeping good practices for chemicals and fuels. Establish procedures for complaint management.	5.6.2.7
Select machinery with high energy efficiency and with low associated emissions, especially regarding to NO_x and particulate materials. Purchase or retrofit cabins to achieve best energy efficiency.	5.6.2.8
Building Use	
Install building management systems to ensure the appropriate monitoring and use of building facilities.	6.5.2.1
Monitor water consumption, detect leakages and maintain properly the water system in the building	6.5.2.2
Use environmentally friendly cleaning agents and services	6.5.3.1, 6.5.3.2
Building deconstruction	
Deconstruct and demolish building selectively, maximizing the amount of salvaged materias and the recyclability of obtained wastes	7.3.1
Use environmentally friendly deconstruction techniques	7.3.2
Maximise materials amount and applicability from waste sorting and processing	7.3.3

A.2. Environmental Indicators and Benchmarks of Excellence

A.2.1 Approach to conclude on environmental indicators and benchmarks of excellence

The conclusions on the environmental indicators and benchmarks of excellence have been derived by expert judgement of the European Commission through the JRC-IPTS, and agreed by the technical working group (TWG) during the final meeting in November 2011. This group was composed of companies, umbrella associations, verification bodies, accreditation bodies and other stakeholders. The European Commission organised and chaired the meetings of the TWG.

A.2.2 Presentation of the environmental indicators and the benchmarks of excellence

The conclusions on the environmental indicators associated with the application of best environmental management practice are compiled in the following summarizing table and the list of benchmarks of excellence is shown after the table. Organisations shall take the reference document into account when preparing the environmental statement according to Annex IV of the EMAS regulation 1221/2009. Consequently, the environmental performance can be reported using the specific indicators as described below, if they are appropriate. Some explanations should be given for the application of indicators:

- this document has been written with the basis of helping organisations or verifiers to identify relevant environmental aspects, both direct or indirect. There is no mandatory requirement on the application of best environmental management practices described in the document.
- indicators presented here are the most common used by exemplar organisations of the sector. The list has been kept short and concise and based on the indicators that companies are actually using.
- More practice-related indicators are shown in the technical description of the core text, where even more alternatives are provided.

Indicator	**Common Units**	**Short description**	**Recommended minimum level of monitoring**	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	**Example of Alternative indicators**
BUILDING DESIGN AND USE					
Specific energy consumption	kWh/m^2 yr	Energy consumption (electricity, heat from gas or others) per unit of useful area and year. Indications: Renewable energy consumption should not be subtracted or offset through CO_2 emissions. Correction factors can be used to determine the useful area depending on the final building use and typology.	Per site or equivalent and at the organisational level (aggregated value) Per main energy-consuming processes: heat, electricity for lighting, total electricityand specific processes (where applicable) and total primary energy consumption disclosed per source	Energy efficiency	Specific primary energy consumption Installed heating or cooling, W/m^2 Use of integrative approaches
Use of localised renewable energy sources	% (of total final energy demand, wether 100 % means that the building is a net zero energy building)	Renewable energy consumed from own generation at site or equivalent. Indications: Zero energy building should be considered in a yearly basis. Green purchasing should not be included, except if this purchasing is certified not to contribute to the national renewable production average)	Per site Per source of energy	Energy efficiency	Specific energy generation, kWh/m^{2}yr Percentage of alternative energy generation in excess to consumption Greenhouse gases emissions avoidance

Indicator	Common Units	Short description	Recommended minimum level of monitoring	Related core indicator according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	Example of Alternative indicators
Lighting Power Density	W/m^2	Lighting power installed to meet illumination needs per unit of area Indications • Lumens per m^2 is a good technical indicator, but the environmental performance should be measured in terms of W/m^2. • It can vary within the site (per zone) and during the day (per period).	Per site or equivalent Per zone and per day period, where appropriate (linked to lighting plans)	Energy efficiency	Specific energy consumption for lighting Specific lighting planning (y/n)
Water Monitoring	%	Percentage of building zones or units with separate water monitoring and/or relevant process for water consumption	Per process (dishwashing, swimming pools, refrigeration, etc.) Per zone (e.g. per office) or per unit (e.g. per floor)	Water	
Water consumption	L per occupant/position per day	Volume of water consumed per occupant of the building or per full position (e.g. for office and industrial buildings)	Per process (dishwashing, swimming pools, refrigeration, etc.) Per zone (e.g. per office) or per unit (e.g. per floor)	Water	When relevant, water consumption per square metre per day Sectoral approaches
Water recycling	%	Percentage of available water from rainwater or from grey water treatment being reused in internal processes	Per process Per site	Water	When relevant, installation of grey water treatment and reuse facilities (y/n)

Indicator	Common Units	Short description	Recommended minimum level of monitoring	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	Example of Alternative indicators
BUILDING CONSTRUCTION AND DECONSTRUCTION					
Specific waste generation	Weight per unit of area or representative factor (e.g. km)	Generated waste during construction phase an per square metre	Per waste type Per site	Waste	Waste sent to landfill (%) Reuse of materials and amount of recycled materials
Use of dust suppression techniques (y/n)	Dust is removed according to techniques summarized in Table 5.56	When appropriate, dust generation is avoided.	Per site	-	Estimation of dust weight and prevention efficiency when using the methodology explained in section 5.6.2.5
Use of a comprehensive monitoring system for the construction site, y/n	Site performance is monitored and benchmarked according to monitoring systems as explained in section 5.6.1.2, y/n	A comprehensive list of criteria according to section is used to control site environmental performance	Per site	All	In addition, it is recommended to add the specific water and energy consumption per site and per square metre (or per other relevant unit)
Workers are trained in environmental management aspects, y/n	-	Site workers are trained in the EMS of the company.	Per site	-	

Indicator	Common Units	Short description	Recommended minimum level of monitoring	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	Alternative indicators
CONSTRUCTION PRODUCTS					
Use of ecolabeled materials according to type I ecolabel (ISO 14024)	y/n	Use of materials bearing an ecolabel or equivalent (third party verified) can be proved.	Per material category	Materials	Percentage (w/w, EUR/EUR) of ecolabeled materials in one product category
Hazardous products are avoided	y/n	It is proved that hazardous materials to be avoided regarding to recognised third party verified schemes (e.g. ecolabel, GPP, etc) are avoided.	Per site Per material category	Materials	Degree of compliance with GPP criteria, Ecolabels or other third party verified schemes
Percentage of wood with certificates of chain of custody	%	Percentage of wood bearing a certificate of chain of custody	Per site Per wood element	Materials	

Benchmarks of excellence

A benchmark of excellence is a front-runner performance, which can be used to compare organisation current performance and their progression. They do not constitute environmental criteria to be verified according to current performance and cannot be a reason to prevent the EMAS registration of an organisation.

Organisations may report their performance using benchmarks of excellence as reference points against which an organisation can compare in order to identify improvement potentials. The document should be understood in the same way by verifiers when checking the requirements according to Article 18 of the EMAS regulation.

The list of benchmarks of excellence was agreed by the technical working group in the meeting of November 2011. More specific and alternative benchmarks can be found in the technical description of best environmental management practices.

- Building design
  - The building (new) is designed according to the Passive House standard or equivalent, with a consumption value less than 15 kWh/m^{2}yr for heating and cooling and less than 120 kWh/m^{2}yr of primary energy demand according to the methodology described in the relevant chapter.
  - The building (existing) is retrofitted according to the Passive House standard or equivalent, with a consumption value less than 25 kWh/m^{2}yr for heating and cooling and less than 120 – 132 kWh/m^{2}yr of primary energy demand according to the methodology described in the relevant chapter.
  - The building final installation for heating or cooling is less than 10 W/m^2, according to the definition of the Passive House standard or equivalent.
  - A integrative concept is used to cover building energy requirements with renewable energy sources
  - All relevant water consuming process are monitored in all building units
  - Water consumption is less than a relevant benchmark for building typology.
  - Building is designed out to prevent waste during design and for best recycling and reuse at deconstruction, using the concepts of section 3.4.7
- Building construction
  - Less than 5 % of recyclable material is sent to landfill or incineration without energy recovery
  - Dust prevention efficiency is higher than 90 % according to the methodology defined in operational data of section 5.6.2.5
  - Water use is monitored at construction sites (per source) and water drainage is properly controlled according to the practices described in section 5.6.2.5
  - Site environmental management is checked comprehensively and monthly according to a semiquantitative method across all processes
  - Environmental criteria are used in public private and private-private consents in an environmental management plan
  - All site foremen are trained according to an environmental management system
- Construction products
  - More than one product category is 100 % compliance with ecolabel criteria (type 1 ecolabel or equivalent)
  - 100 % of wood chain of custody is certified
  - Hazardous materials are 100 % avoided according to GPP or other ecolabel criteria

PREFACE

1. Status of this document

This document is a working draft of a sectoral reference document as mentioned under article 46 of the EMAS Regulation (1221/2009), concerning the Construction Sector.

2. Relevant legal background

The Community Eco-Management and Audit Scheme (EMAS) was introduced in 1993 for voluntary participation by organisations, by Council Regulation (EEC) No 1836/93 of 29 June 1993 (EC, 1993). Subsequently, EMAS has undergone two major revisions:

- Regulation (EC) No 761/2001 of the European Parliament and of the Council of 19 March 2001 (EC, 2001);
- Regulation (EC) No 1221/2009 of the European Parliament and Council on 25 November 2009.

The latest EMAS Regulation followed a large-scale evaluation of the EMAS scheme that began in 2005. This evaluation, together with input from the various stakeholders in the scheme, identified the strengths and weaknesses of the scheme and proposed options to improve the effectiveness of EMAS. Consequently, on 16 July 2008, the Commission adopted a proposal for the revision of the EMAS Regulation as part of the Sustainable Consumption and Production Action Plan (EC, 2008a). The objective of the proposal was to strengthen the scheme by increasing its efficiency and its attractiveness for organisations, and was also aimed to generate a wider influence beyond EMAS registered organisations, by encouraging these organisations to take into account environmental considerations, when selecting their suppliers and service providers.

The proposed changes gave special attention to the needs of small organisations (SMEs and small public authorities) and to the promotion of best environmental management practices. Regarding the latter, reinforced environmental reporting through the use of mandatory key performance indicators and sectoral guidance on best practice in environmental management, were added to the Regulation. Best environmental management practice and environmental performance indicators should be developed for specific sectors. This in order to help organisations better focus on the most important environmental aspects in a given sector.

The revised EMAS came into force on 11 January, 2010. This document is the first of a set of sectoral reference documents as referred to in article 46 of Regulation (EC) No 1221/2009. This document describes best environmental management practice, and includes environmental performance indicators for specific sectors and, where appropriate, benchmarks of excellence and rating systems identifying performance levels. The use of this reference document is voluntary but EMAS organisations are strongly encouraged to use them for setting up their environmental management system and for defining their environmental targets. The verifiers are required to refer to the documents as a benchmark for an effective management system. Reference documents are publicly available without any charge for use by every organisation that wishes to improve its environmental performance, irrespective of whether or not a formal environmental management system is in place.

Box: Article 46 of Regulation (EC) No 1221/2009, pertaining to sectoral reference documents

Article 46

Development of reference documents and guides

1. The Commission shall, in consultation with Member States and other stakeholders, develop sectoral reference documents that shall include:

(a) best environmental management practice;

(b) environmental performance indicators for specific sectors;

(c) where appropriate, benchmarks of excellence and rating systems identifying environmental performance levels.

The Commission may also develop reference documents for cross-sectoral use.

2.The Commission shall take into account existing reference documents and environmental performance indicators developed in accordance with other environmental policies and instruments in the Community or international standards.

3. The Commission shall establish, by the end of 2010, a working plan setting out an indicative list of sectors, which will be considered priorities for the adoption of sectoral and cross-sectoral reference documents.

The working plan shall be made publicly available and regularly updated.

4. The Commission shall, in cooperation with the Forum of Competent Bodies, develop a guide on registration of organisations outside the Community.

5. The Commission shall publish a user's guide setting out the steps needed to participate in EMAS.

That guide shall be available in all official languages of the institutions of the European Union and online.

6. Documents developed in accordance with paragraphs 1and 4 shall be submitted for adoption. Those measures, designed to amend non-essential elements of this Regulation, by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 49(3).

3. Objective of this document

In the future, the aforementioned reference documents shall be elaborated for a range of sectors identified as priorities for EMAS regulation[1]:

- Wholesale and Retail trade,
- Tourism,
- Construction,
- Public Administration,
- Agriculture — Crop production and Animal production,
- Manufacture of electronical and electric equipment,
- Car manufacturing,
- Manufacture of fabricated metal products, except machinery and equipment,
- Food and beverage manufacturing,
- Waste management,

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[1] Communication from the Commission (2011/C 358/02) — Establishment of the working plan setting out an indicative list of sectors for the adoption of sectoral and cross-sectoral reference documents, under Regulation (EC) No 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)

- Telecommunications.

In the first instance, the document on the retail trade sector, produced by the Institute for Prospective Technological Studies (IPTS), part of the European Commission's Joint Research Centre, as part of a pilot study on the development process for these reference documents, has been used as example for the development of the current construction document.

4. Information sources

Concerning environmental management and available measures to increase environmental protection and sustainability within this sector, a lot of information is already publicly available from various sources including a number of comprehensive reports. For drafting this document, that information has been considered along with information collected directly from construction companies and other stakeholders, including consultancy firms, non-governmental organisations, and technology providers. A number of site visits proved to be very useful for obtaining technical and performance data and information on economic considerations.

5. How to understand and use this document

This document is intended as a information source and a support tool for all the actors in the construction sector who intend to improve the environmental performance therein considering the whole value chain, from early planning to building end-of-life. Also, the application of this document is restricted to buildings. It has overlapping for civil engeneering works, especially for construction site management, which are summarized in a specific chapter. This document is elaborated not only for those organisations who have implemented EMAS but also for all those who have implemented any other environmental management system or who just want to contribute to increasing environmental protection and sustainability. However, for EMAS registration, the assessment of the environmental performance of the organisation concerned shall take into account the relevant sectoral reference document(s), especially regarding sector specific indicators. The same applies to the verifiers when checking the requirements according to Article 18 of the EMAS regulation.

6. Environmental indicators and benchmarks of excellence

With respect to the development of reference documents, the EMAS regulation states that they shall include environmental performance indicators for specific sectors. They are defined as follows:

An environmental indicator is '…a parameter, or a value derived from parameters, which points to, provides information about, describes the state of the environmental performance of a technique or measure'.

Environmental indicators express useful and relevant information about the environmental performance of a firm or organisation and efforts to influence performance. Annex IV, C of the EMAS regulation states that indicators shall:

(a) give an accurate appraisal of the organisations performance;

(b) be understandable and unambiguous;

(c) allow for a year on year comparison to assess the development of the environmental performance of the organisation;

(d) allow for comparison with sector, national or regional benchmarks as appropriate;

(e) allow for comparison with regulatory requirements as appropriate.

The indicators can be designed as:

- absolute indicators
- relative indicators
- aggregated indicators
- weighted indicators.

Annex IV, C foresees the use of absolute and relative (or normalised) indicators for the following key environmental areas:

- energy efficiency
- material efficiency
- water
- waste
- biodiversity
- emissions.

In the same Annex it is stipulated in relation to the previous **core** indicators that, 'where an organisation concludes that one or more core indicators are not relevant to its significant direct environmental aspects, that organisation may not report on those core indicators'.

Finally, Annex IV, C states that 'each organisation shall also report annually on its performance relating to the more specific environmental aspects as identified in its environmental statement and, where available, take account of sectoral reference documents as referred to in Article 46'. This document reviews the most significant environmental aspects of the building construction sector and for each of them describes the most relevant indicators.

An environmental indicator may be **appropriate** for a certain company, enterprise or administration but may not be for others. If an indicator can be applied to **many** companies, enterprises or administrations of **a similar** type, a benchmark may be derived from it. An environmental indicator may concern a whole organisation, a particular site, or a certain process, technique or aspect of operations. Where an organisation operates multiple similar sites, site-level environmental indicators may be appropriate (enabling comparability between the sites and from year to year). This may not be the case when comparing sites with different characteristics across organisations. However, the comparability of environmental indicators on a process-level is often possible. In addition, as the discussion of process-level data is more anonymous, the comparison of different organisations on a process-level is more acceptable. With regard to useful benchmarks of excellence, comparable environmental indicators are also required.

Depending on the sector and its individual circumstances and conditions, certain environmental indicators can be attributed with a number. As far as this quantification reflects the best performing organisations, techniques or processes, it represents the benchmarks of excellence. These benchmarks do not stand for the best of the best performing organisations, techniques or processes but represent approximately the 10 – 20 % best performers. The benchmarks of excellence are reference points against which an organisation can compare its environmental performance in order to identify improvement potentials. Verifiers can use benchmarks of excellence in the same way. The technical descriptions of best practice techniques outlining how benchmarks of excellence may be achieved can be found in the text. Based on these descriptions, the working group for the construction sector applied its expertise to conclude on appropriate benchmarks of excellence. Therefore, these benchmarks are presented as an essential part of the conclusions in Chapter 10.

CHANGES IN THIS DOCUMENT

Main changes from the previous draft are reported here according to this color code:

Black: Accepted text from the first draft document without significant and/or conceptual changes.
Blue: Added or substantially modified text from the first draft without significant and/or conceptual changes in the final draft.
Green: Added or substantially modified text from the second draft.

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Reference Document on Best Environmental Management Practice in the Construction Sector

LIST OF FIGURES

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1 GENERAL INFORMATION ABOUT THE CONSTRUCTION SECTOR AND EMAS IMPLEMENTATION

1.1 General information about the construction sector

The United Nations define construction as comprising 'economic activity directed to the creation, renovation, repair or extension of fixed assets in the form of buildings, land improvements of an engineering nature, and other such engineering constructions as roads, bridges, dams and so forth.' Construction definition includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature. The term construction usually refers to the construction of entire dwellings, office buildings, stores and other public and utility buildings, farm buildings etc., or the construction of civil engineering works such as motorways, streets, bridges, tunnels, railways, airfields, harbours and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, sports facilities etc. Although the UN definition does not exclude the work carried out by building or infrastructure owners, it is usually contracted. Often, portions of the work, and sometimes the whole practical work, can be subcontracted out (UN, 2012).

Construction activities play a major role in the socio-economic development of a country, providing building and infrastructure on which all sectors of the economy depend, which makes construction one of the most strategically important sectors.

Construction projects, particularly in building and civil engineering areas, typically take longer and include more phases than projects in other sectors, and thus involve a large number of subcontractors with various specialisations. There are many types of construction activities and a large number of actors along the whole value chain of the sector to be taken into account, and thus a variety of different organisations in the construction sector.

From an economic point of view, the European construction sector is delimited according to the European Classification of Economic Activities, NACE. The NACE classification was revised in 2008 and now includes more activities related to the construction sector which were not covered by the previous version, related to the development of building projects and the assembly and installation of self-manufactured buildings (e.g. made of metal) on site(2).

The construction sector is covered by Section F of the NACE Classification (3), divisions 41 to 43. According to NACE, the construction sector includes the complete construction of buildings (division 41), the complete construction of civil engineering works (division 42), as well as specialised construction activities, if carried out only as a part of the construction process (division 43).

Economic relevance of construction sector

The financial and economic crisis has had a very important impact on the performance of the construction sector in almost all EU Member States. Between 2007 and late 2010, the production index for construction fell by 20 %, although it has recovered to a stable level in the EU at approximately 6 % of the GDP. Nevertheless, market conditions have changed extensively in countries like Spain and Ireland over the past two to three years, with sharp falls of approximately 50 % in Spain and 70 % in Ireland (Eurostat, 2012). The construction sector accounts for more than 15.6 % of all companies in the non-financial economy, employing 11 % of the non-financial workforce, and accounts for EUR 97 300 million of tangible investment - equivalent to 9.7 % of total tangible investment. Personnel costs in the construction sector account for over 21.3 % of total costs, which is high compared to the economy-wide average of 16.1 %.

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(2) http://epp.eurostat.ec.europa.eu/portal/page/portal/nace_rev2/introduction

(3) Statistical Classification of Economic Activities in the European Community, Rev. 2 (NACE Rev. 2)

There are around 2.2 million enterprises in specialised construction activities (NACE F43), representing over two thirds of all construction activity. About 940 000 enterprises are classified as NACE F41, referring to the construction of buildings, and 99 000 are classified as NACE F42, referring to the construction of civil engineering works. Apparent labour productivity ranges from EUR 36 000 per person employed in the specialised construction activities subsector to EUR 46 000 for buildings and civil engineering sectors.

Most construction companies serve a local market and the construction sector is characterised by a large number of small enterprises and a few larger ones. Micro and small companies employ more than 71.8 % of the EU-27 construction workforce. Large companies provide employment for a small portion (12.5 %) of the workforce, which is low compared to the non-financial business economy average of one third (33 %).

In Table 1.1 a set of data for the economic and employment performance of the construction sector is shown.

Table 1.1: Country figures for the construction sector

Country	Number of enterprises, thousands	Turnover million EUR	Labour costs, million EUR	Net investment in tangible goods, million EUR	Number of unpaid persons employed	Number of employees	Apparent labour productivity, thousand EUR
European Union (27 countries)	3,285	1,910,000	364,000	n.a.	34,500	116,000	40
Belgium	75	52,000	8,900	14,000	81,000	215,000	49.3
Bulgaria	21	10,300	900	1,600	14,200	245,400	9.6
Czech Republic	157	35,400	4,000	1,200	141,000	271,000	18.1
Denmark	36	32,300	8,600	n.a.	24,000	195,500	50.7
Germany	237	170,100	48,000	3,600	211,700	1,370,000	40.3
Estonia	8	4,500	750	200	1,300	56,000	16.5
Ireland	48	32,000	6,500	840	6,200	99,000	67.4
Greece	113	16,000	3,000	660	131,000	154,000	14.3
Spain	420	341,000	58,500	13,600	435,500	1,800,000	44.5
France	438	274,000	n.a.	n.a.	n.a.	1,307,000	n.a.
Italy	635	274,000	37,200	10,000	834,000	1,180,000	40.4
Cyprus	6	3,800	900	n.a.	n.a.	37,200	54.6
Latvia	8	5,900	740	n.a.	650	89,000	14.8
Lithuania	22	6,300	1,300	500	17,000	125,000	13.3
Luxembourg	3	5,700	1,500	80	1,000	39,000	50.2
Hungary	74	17,000	1,800	500	42,500	204,000	12.6
Netherlands	100	100,300	19,300	2,000	117,000	396,000	56.9
Austria	30	40,600	10,000	830	21,000	254,000	56.5
Poland	238	62,000	7,300	2,500	260,000	670,000	19.4
Portugal	117	36,000	6,600	1,700	24,000	490,000	19.3
Romania	59	25,000	3,000	6,300	10,400	550,000	12.8
Slovenia	19	8,400	1,300	460	13,200	77,000	23.7
Slovakia	5	7,600	900	300	680	84,000	17.7
Finland	43	27,000	6,000	900	24,000	154,000	49.6
Sweden	78	47,000	12,000	n.a.	59,000	256,000	49.0
United Kingdom	293	280,000	50,400	10,300	200,000	1,300,000	70.0

N.B. Source: Eurostat Table sbs_na_con_r2

Evolution of the economic performance of the European construction sector

In this section, a number of figures are given which show some relevant aspects of the construction sector regarding its evolution in the last 10 years. EU-27 as a whole is analysed along with several reference countries for the construction sector: Spain, Germany, Ireland, Italy, UK and Sweden

- Production and contribution to the European economy (Figure 1.1 and Figure 1.2). Construction production has reduced since the financial crisis started in 2007 – 2008. For some countries, it can be said that the sector was oversized, especially in the 2005 – 2006 period for Spain and Ireland, where activity has since decreased 50 % and 80 %, respectively. In Germany the production volume has remained relatively stable over time. In France, Italy and the UK, construction activity has declined slightly, whilst in Sweden it has increased by 30 %. The contribution of construction to GDP (total value, including financial sector) is 6 % on average in Europe, and peaked at 7 % in 2007. This factor is relatively stable in Germany (4 %), France (6 %), Italy (6 %) and the UK (7 %). In Sweden, it has increased from 5 % to 6 % since 2005. For Ireland and Spain, the contribution of the construction sector reached a peak in 2006 (14 % for Spain and more than 10 % in Ireland). Then, a sharp decrease on the Irish sector due to the financial crisis reduced the GDP share of construction activity down to 3 % in 2011. Meanwhile, construction activity is still high in Spain (11.8 % in 2011).
- The extraction of raw materials and cement production parallels construction activity in every country. Cement has a high specific weight and its price is low, so transport costs are a critical factor for the supply of this raw material. The same is true for any kind of aggregate, natural or recycled, and for sand and other raw materials. Thus, cement can be considered as an indicator of national construction activity, as this material cannot be economically transported more than 200 km (EC, 2010). As shown in Figure 1.3 and Figure 1.4, cement production in the EU–27 has decreased by 50 million tonnes (about 18 % from 2007 to 2009 – a very similar decrease to that for construction activity). The same has happened for mineral extraction, which has reduced by 500 million tonnes, about 14.5 %. About 40 % to 50 % of the total reduction took place in Spain (25 million tonnes for cement and 200 million tonnes for mineral extraction) and the rest took place in France, Italy, the UK and Germany. The correlation between cement production and mineral extraction with construction activity does not fit with the Irish case, where cement production has been stable over the period 2007 – 2009.
- The construction sector employs about 16 million people in Europe in 2012, 2 million fewer than in 2008 (see Figure 1.5 and Figure 1.6). Countries most affected by this reduction are Spain and Ireland, with net employment reductions of 47 % in Spain and 64 % in Ireland, totalling over 1.5 million job losses. Other losses mainly occurred in Italy and the UK, where the number of employees declined after a small peak in 2008 – 2009. Sweden and France have increased the number of employees and Germany remains stable at around 2.5 million workers. The number of hours worked parallels the number of employees, which reflects the lack of change in the nature of contracts (part or full time positions). Nevertheless, the number of hours may be estimated to be proportional to the number of workers, so this indicator should be interpreted with caution.
- Productivity, measured in terms of Construction GDP per employee or Construction GDP per hour worked, can be observed in Figure 1.7 and Figure 1.8. GDP productivity is quite similar to the apparent labour productivity, EUR 40 000 per employee, reflected in Table 1.1, although it has varied between 40 000 and 45 000 since 2007. Germany and Italy had a stable level of productivity, even increasing slightly. Spain has had a sharp increase since 2007. The UK, Sweden and France reduced their productivities in the period 2007 – 2009, and they have recovered with different intensities in the period 2009 – 2011. Productivity in Ireland decreased by over 55 % in the period 2006 – 2009 and reached the European average in 2011. The behaviour of the productivity value per worked hour is parallel to the productivity per employee.

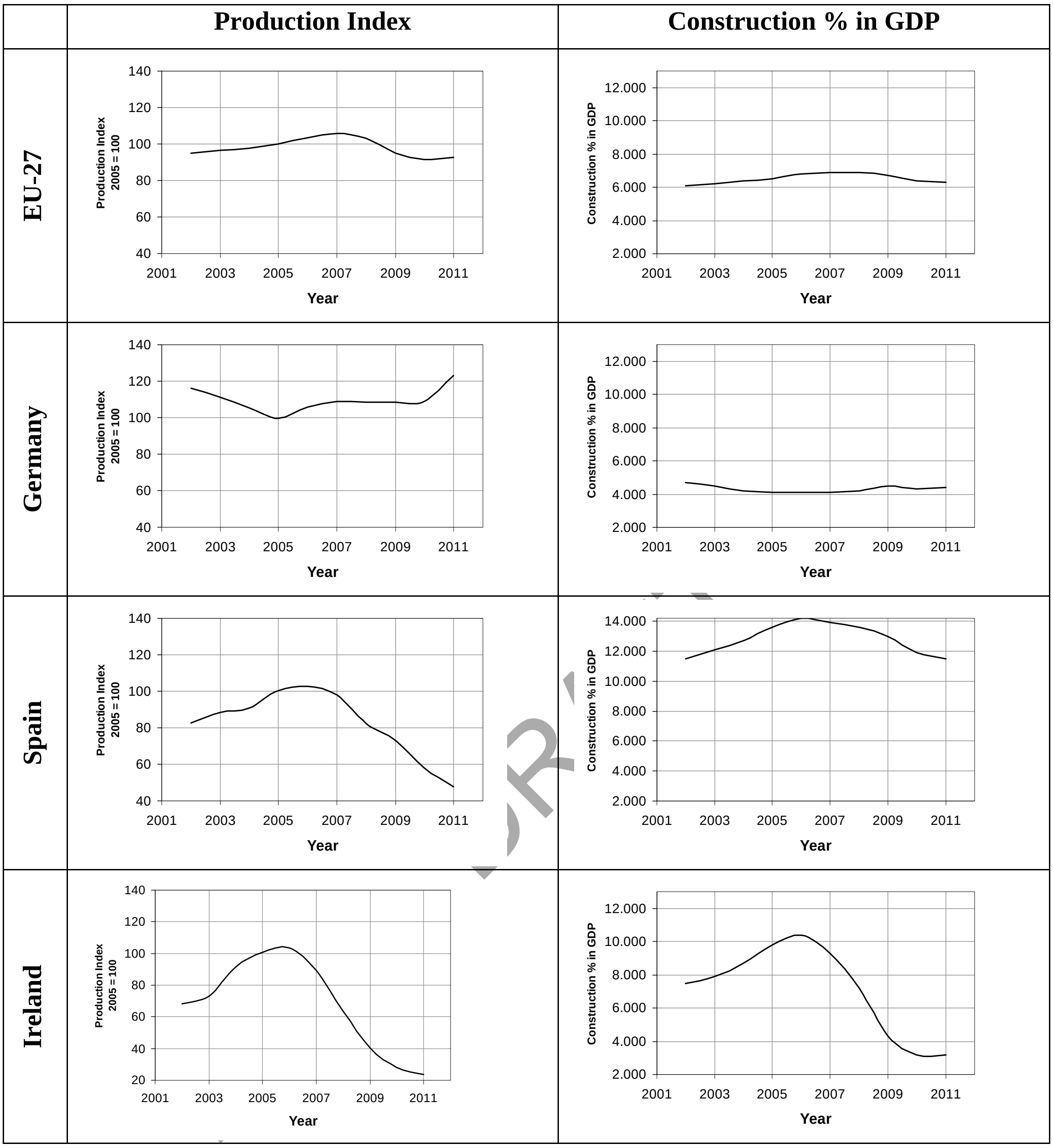


Figure 1.1: Production index of the construction sector (2005 = 100) and construction contribution to GPD: EU–27, Germany, Spain and Ireland

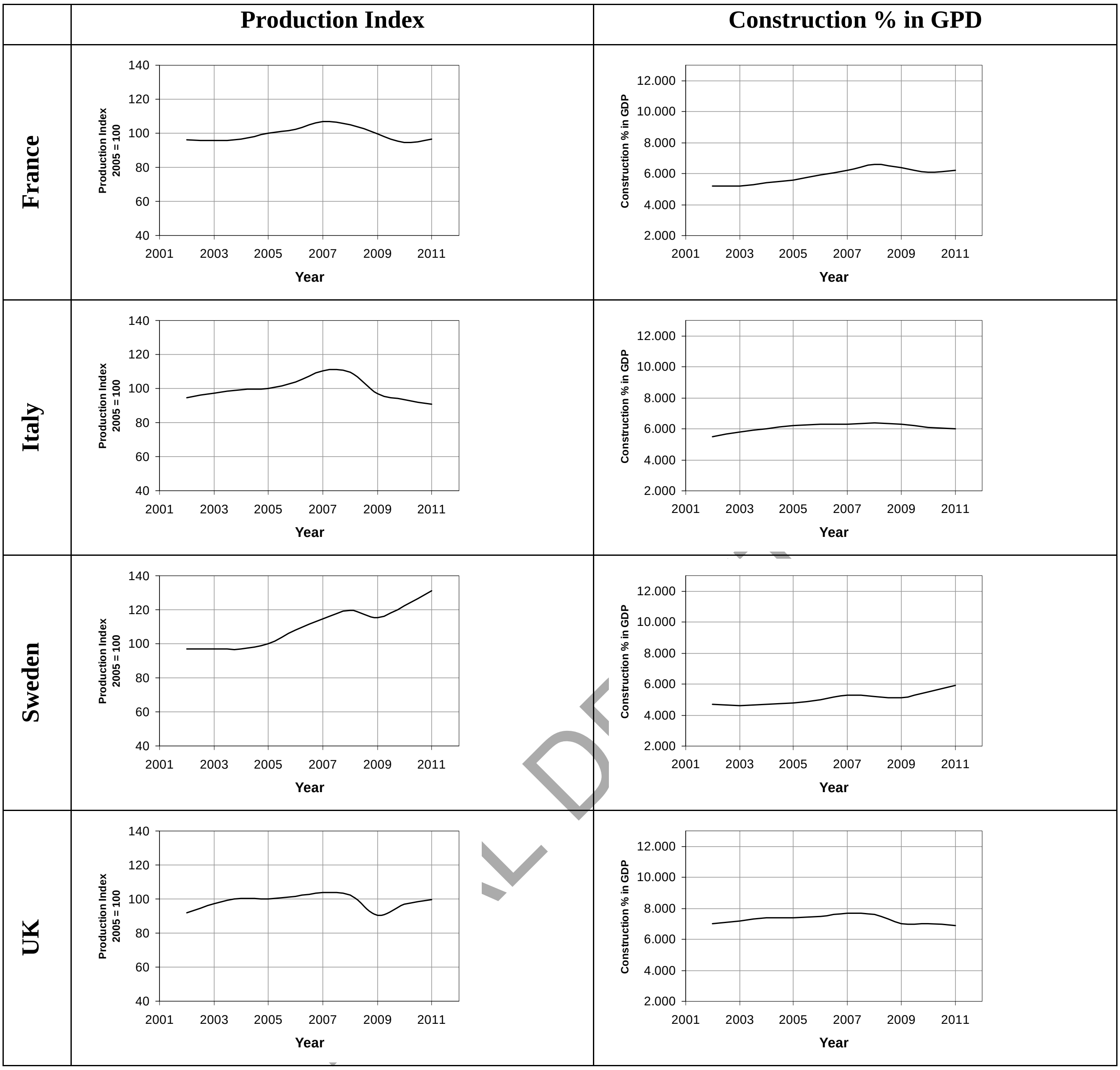


Figure 1.2: **Production index of the construction sector (2005 = 100) and construction contribution to GPD: France, Italy, Sweden and the United Kingdom**

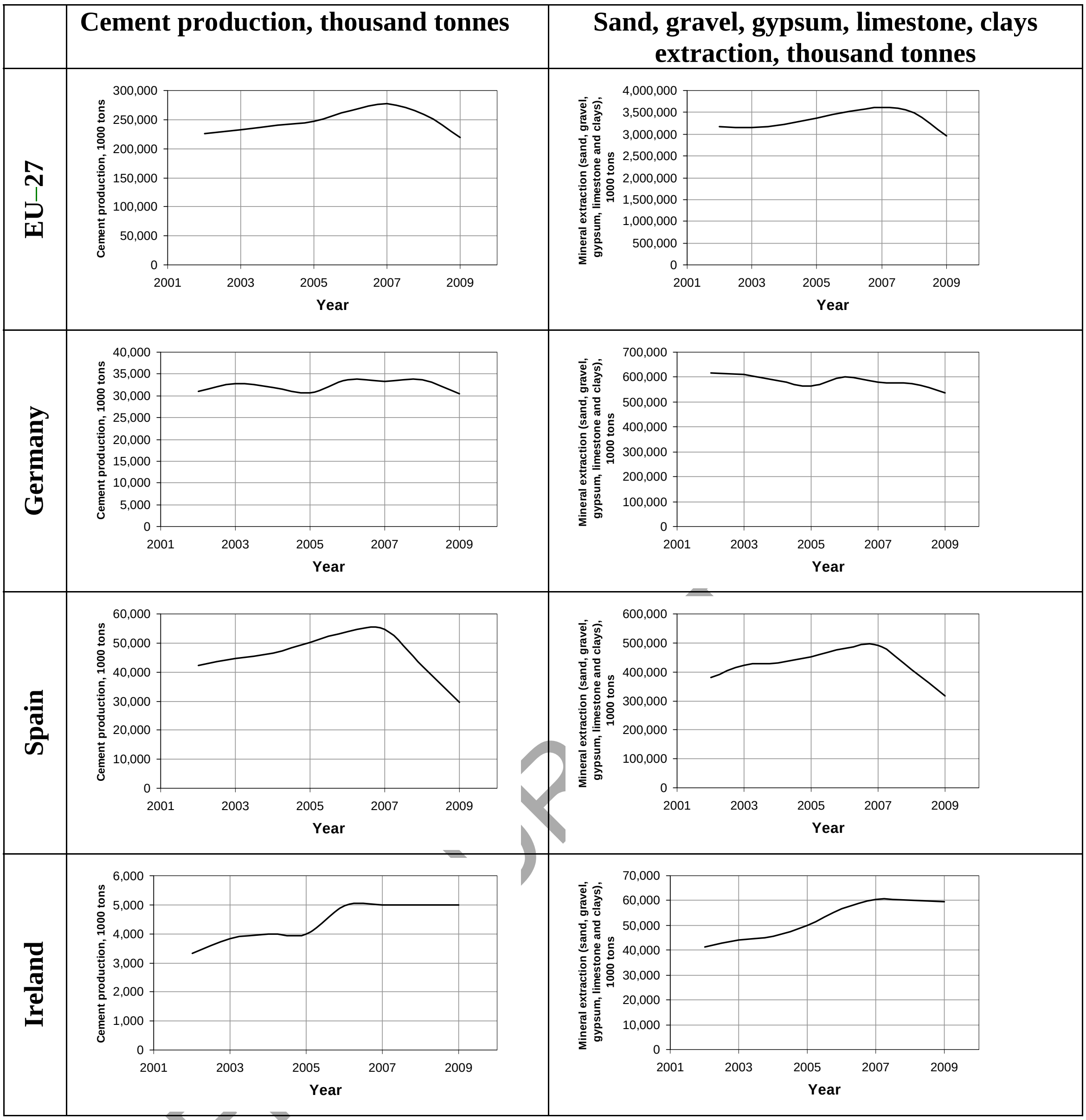


Figure 1.3: Annual cement production, thousand tonnes, and raw materials extractions, thousand tonnes, in EU–27, Germany, Spain, Ireland

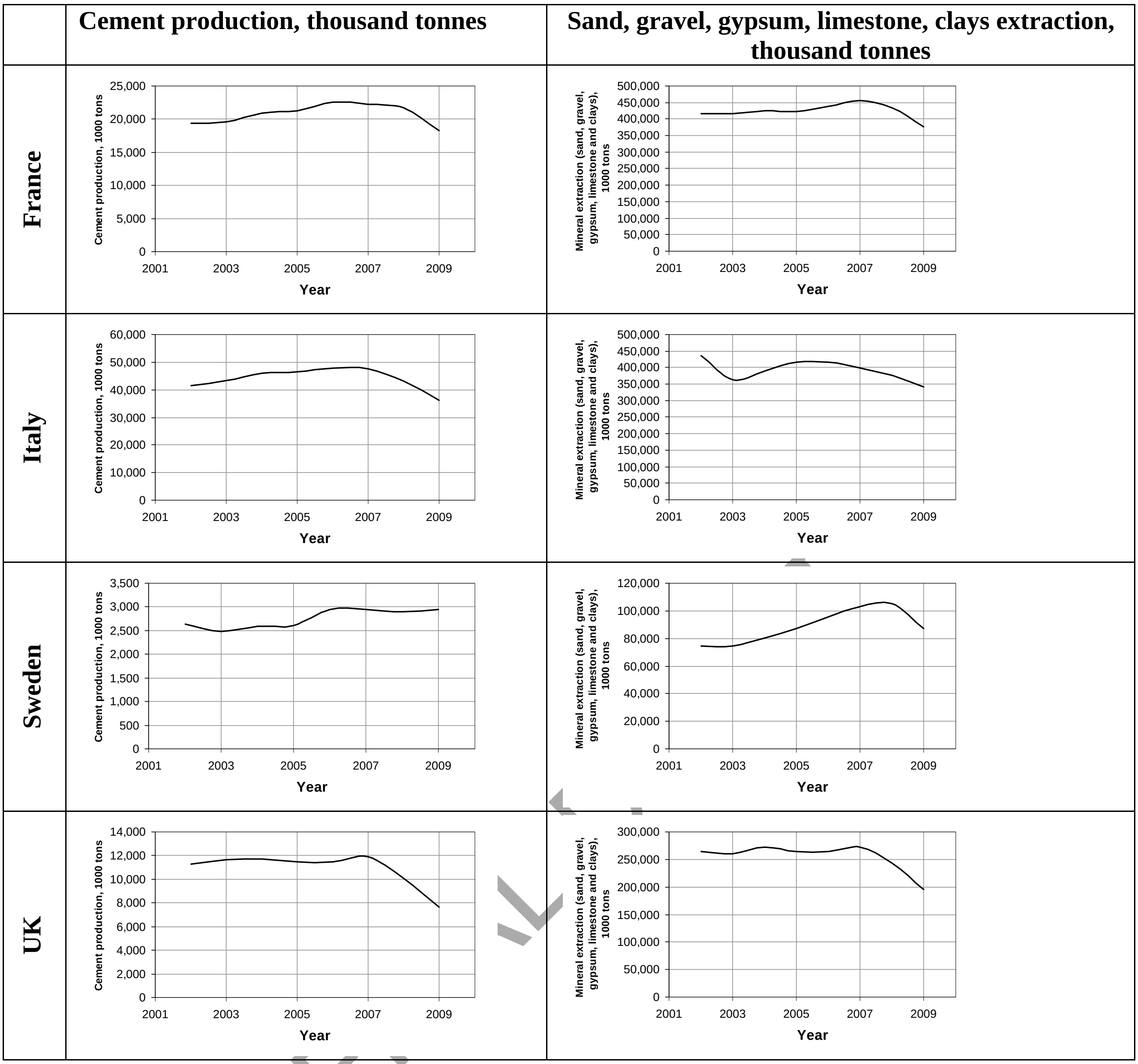


Figure 1.4 Annual cement production, thousand tonnes, and raw materials extractions, thousand tonnes, in France, Italy, Sweden and the United Kingdom

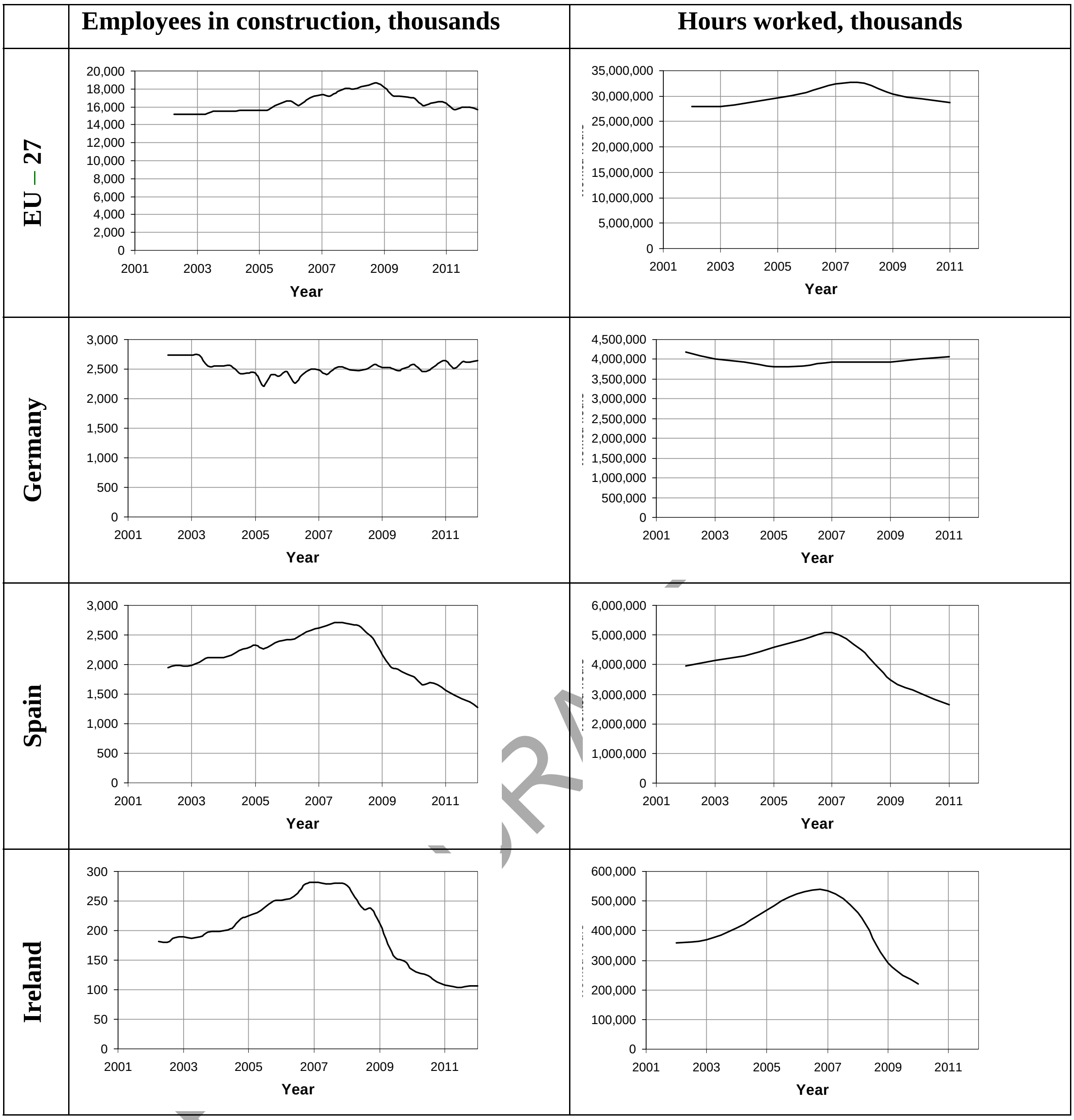


Figure 1.5 Employment and worked hours in construction sector in EU–27, Germany, Spain, Ireland

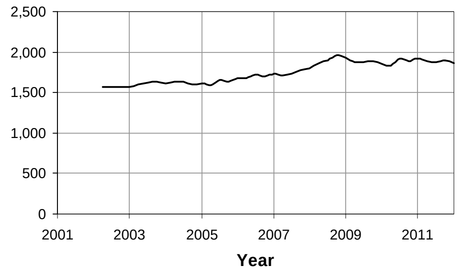
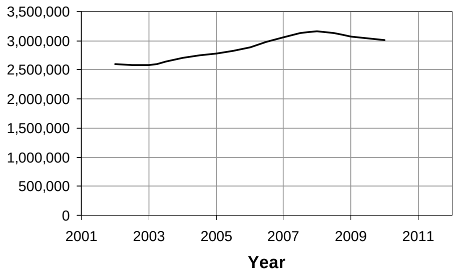
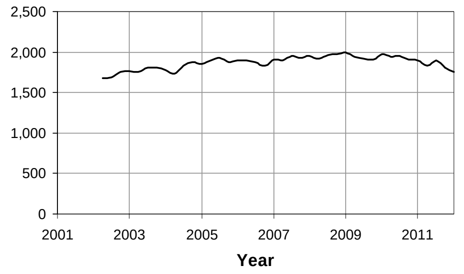
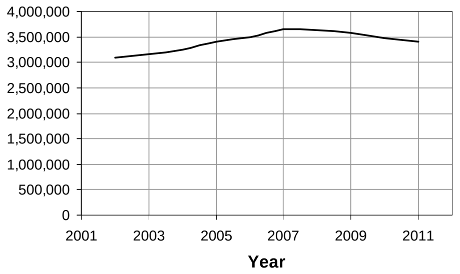
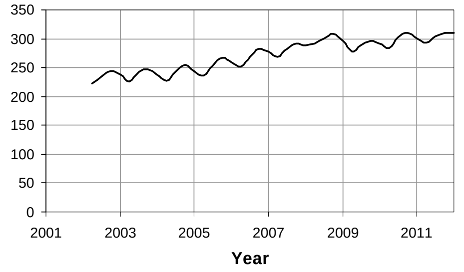
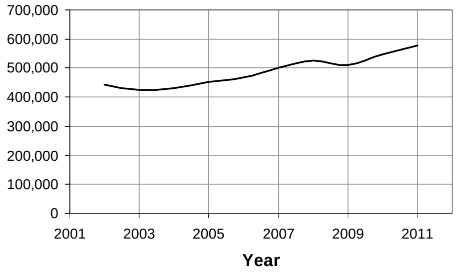
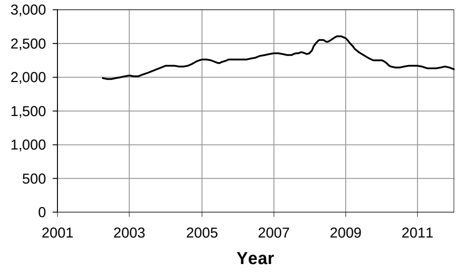
	Employees in construction, thousands	**Hours worked, thousands**
France		
Italy		
Sweden		
UK		No data available

Figure 1.6 Employment and worked hours in construction sector in France, Italy, Sweden and the United Kingdom

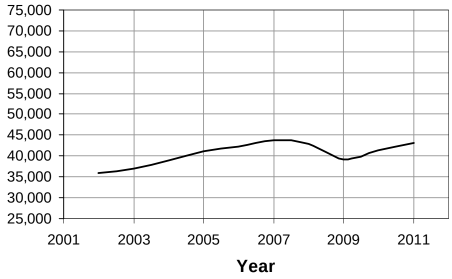
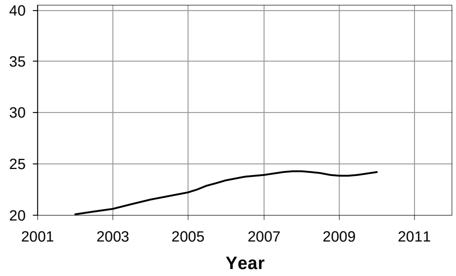
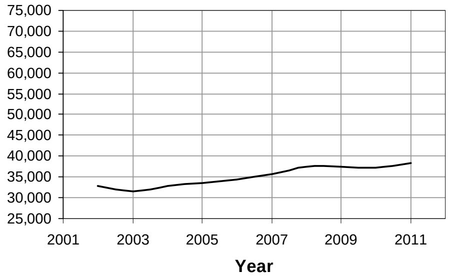
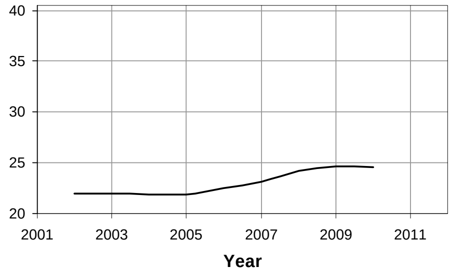
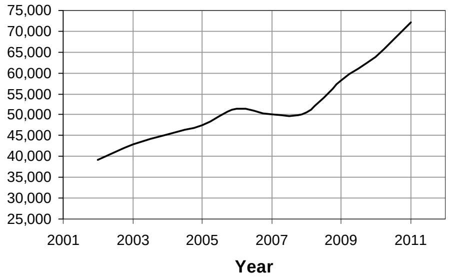
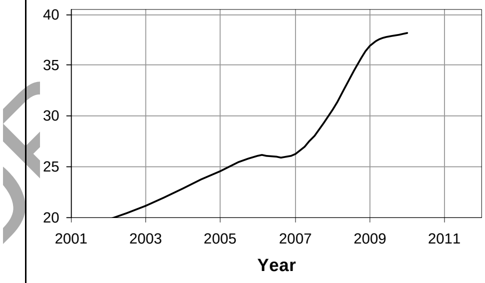
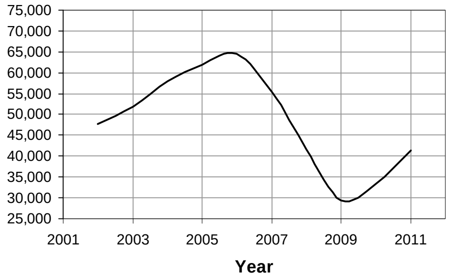
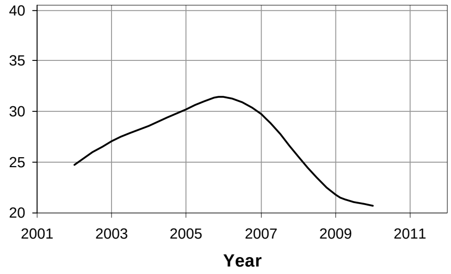
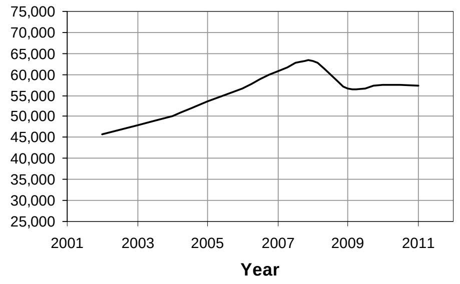
	Construction GDP per employee, EUR	Construction GDP per hour worked, EUR
EU – 27		
Germany		
Spain		
Ireland		

Figure 1.7 Construction GDP per employee and per worked hour in construction sector in EU – 27, Germany, Spain, Ireland

<table>
<tr><th></th><th>Construction GDP per employee, EUR</th><th>Construction GDP per hour worked, EUR</th></tr>
<tr><td>France</td><td>


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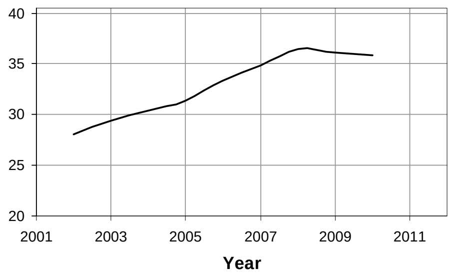

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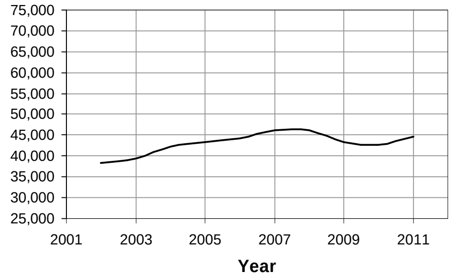
<tr><td>Italy</td><td>


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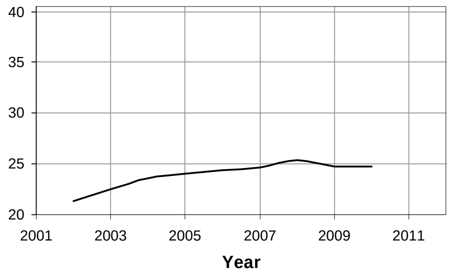
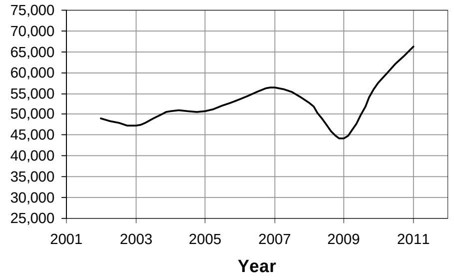


</td></tr>
<tr><td>Sweden</td><td>


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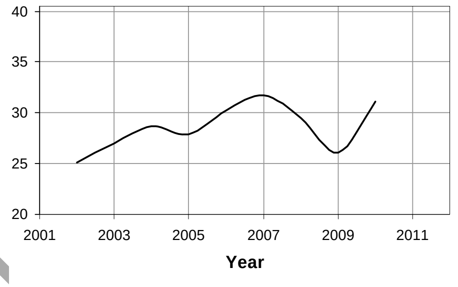

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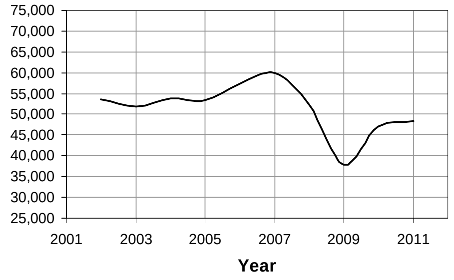
<tr><td>UK</td><td>


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</table>

Figure 1.8 Construction GDP per employee and per worked hour in construction sector in France, Italy, Sweden and the United Kingdom

1.2 Environmental aspects of the construction sector

The construction sector not only has a significant role in the EU economy, but is also a major contributor to EU energy consumption and greenhouse gas emissions. Construction activities and buildings have various impacts on the environment. The key aspects are land use, the consumption of raw materials, energy and water, the production of waste, as well as noise and air emissions, e.g. 42 % of the total EU final energy consumption, 35 % of the greenhouse emissions, about 50 wt. % of extracted materials and 22 wt. % of waste generation are related to buildings (ECTP, 2005; EC, 2007).

'Environmental aspect' is defined under the EMAS regulation (EP, 2010) as ‘an element of an organisation's activities, products or services that has or can have an impact on the environment’ and are managed differently if they are considered ‘direct’, so it is under direct control of the organisation, or ‘indirect’, if the organisation is not directly responsible but has a certain degree of influence on it. It should be noted that it is not possible to propose general *direct* aspects and general *indirect* aspects for the full sector, as the scope of the document embraces the activities to be carried out by many actors within the building sector: land planning, design, construction, refurbishment and deconstruction. Therefore, direct and indirect aspects should be defined on a case by case basis for construction organisations. The descriptions developed in this document are based on best environmental management practices to manage the most important direct and indirect aspects, with no specific differentiation on the management structure, which may be decided according to the organisation decision capabilities or to other specific requirements. Regarding the construction sector as a whole, an input-output diagram is proposed in Figure 1.9. Blue blocks are those subsectors to be covered in this document, corresponding to the value chain of the building sector. The remaining blocks correspond to the raw materials, construction products and energy production sectors. These are partially covered in the document and only for those aspects which can be influenced in any stage of the building life cycle (e.g. selection of materials, waste treatment, use of renewable energy, etc.). Figure 1.9 shows the interaction of the processes in the buildings value chain and other economic activities. This flowchart has been used to organise the main content of this reference document.

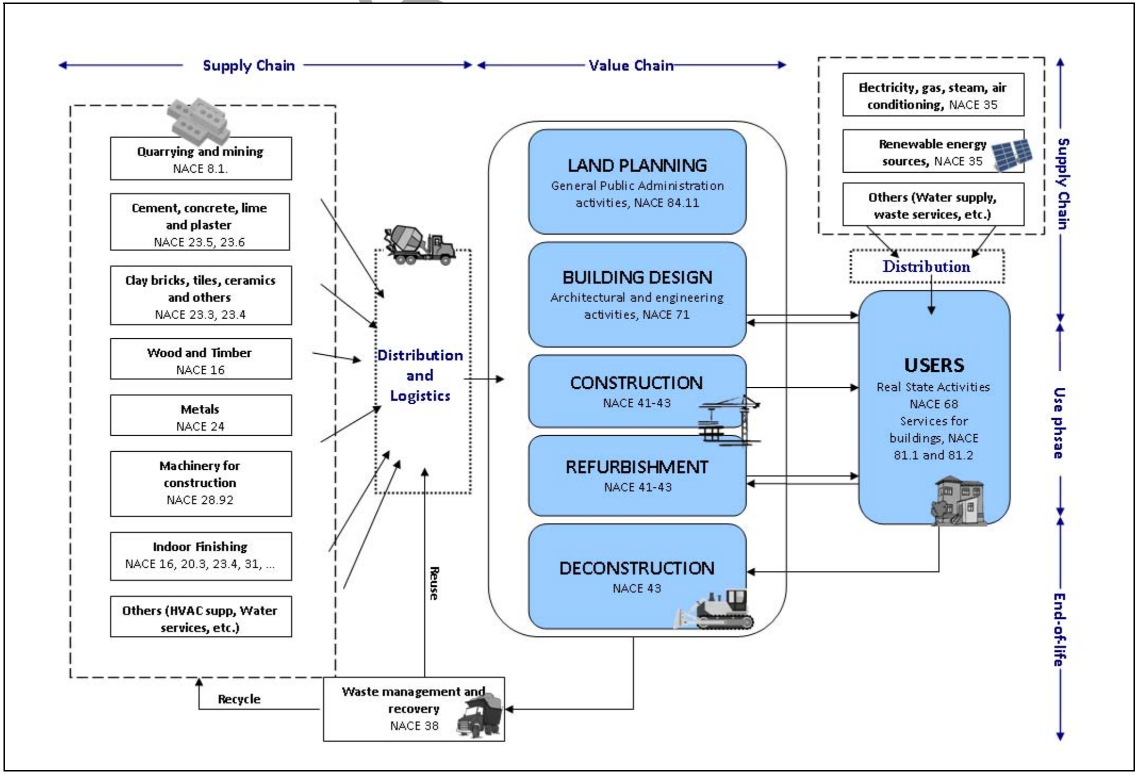

Figure 1.9: Construction document flowchart and relation to other economic activities

Not all the phases are covered in the same depth. The strategy to select best environmental management practice in this document is based on the overall environmental impact during construction or refurbishment, use phase and deconstruction activities. A short description on the scope for each building phase is explained below:

- **land planning**: this section covers the role of public administration planning authorities in considering the environmental impact of construction projects. This includes the impact on biodiviersity, resources consumption, impact on the urban environment and the importance of site selection and land use.
- **building design**: this section covers best design practices to minimise the impact of the use phase, especially regarding energy consumption. In this case, a clear push is made towards integrative approaches. Water is also considered as an important resource to be saved and also a special focus is made on the avoidable environmental impact of waste produced during construction and deconstruction.
- **construction products**: this section provides information on the existing environmental criteria for the selection of construction products, minimising the life cycle environmental impact of products and their performance during the use phase, especially for indoor finishing products.
- **construction and refurbishment:** this section covers the environmental impacts produced during construction and/or refurbishment of buildings. A special focus is made on waste management, reuse schemes, recycling flows and materials efficiency.
- **building use** is the most important phase, as it is the phase where the most important impacts are produced over the long lifetimes of buildings. Nevertheless, the most important best practices regarding the use phase may be taken during planning and design stages. In the description, special focus is applied to building management systems, cleaning services and renewable energy sources for building use.
- **deconstruction:** this sectioncovers best practices dealing with selective demolition of buildings with high recovery rates. Some recovery techniques are covered and end–of–life processing of materials described.

Although the construction sector definition covers NACE codes 41, 42, 43, **civil engineering works** (NACE code 42) are excluded from the main scope of this document. The complexity and variety of civil engineering works is wide enough to constitute a separate document. A chapter at the end of this document highlights the most important cross-cutting points that apply to both civil engineering works and building construction. Generally, the intensity and magnitude of impacts of civil engineering works are higher than for building construction projects, including the negative effects on habitats and species (i.e. biodiversity).

The relative importance of individual environmental aspects differs widely depending on the activity (Table 1.2), the building type and its life cycle phase and performance, as well as the natural environment (e.g. local climate), and finally the environmental soundness of applied techniques.

Table 1.2: Overview of the major environmental aspects and associated impacts of the construction sector.

		Planning		Development				Use	End of life	
		Project inception and briefing	Design	Transport	F.43.1.2. Site preparation	F.41.2 – 42.9. Construction activities	F43.2.–43.9. Specialised activities	Building use	Deconstruction	Recycling/ Disposal
Resource Consumption	Energy			High	Low	Low	Low	High	Low	Medium
	Water				Low	Medium	Low	High		
	Raw material					High	Low			
	Land use				High			High		Medium
Emissions to	Water				Medium	Medium		High		
	Soil				High	Medium				
	Air			High	Low	Medium	Low	High		Medium
Emissions of	Dust			Low	Medium	Medium	Medium		High	Medium
	Odour								Medium	Low
	Noise / vibrations			Medium	Medium				Medium	Low
Wastes	Construction wastes				High	High	Medium		High	Low
	Municipal–type wastes				Low	Low	Low	High		Low
	Hazardous wastes					Medium	Medium		High	Low
	Waste water				Medium	Medium	Low	High		
Others	Use of hazardous chemicals					Medium	Medium		High	Low
	Habitat and species				High	Medium				

Below, a summary list of the relevance of environmental aspects is shown, with links to chapters and sections of this document:

- **Use of energy**. Since this is the most important aspect regarding the life cycle environmental impact of buildings, this is a main topic for the whole document. Reducing the energy demand of buildings is concern in section 3, where several measures are proposed for that purpose: improving the performance of the envelope through better insulation (3.4.1.1), walls (3.4.1.2), windows (3.4.1.3) and roofs (3.4.1.4); applying integrative design concepts (3.4.2) and the description of some outstanding design premises for heating, ventilation and air conditioning systems (3.4.3) or for lighting (3.4.4). A more holistic overview of energy consumption in cities and neighbourhoods is explained in site selection and heat island effects (2.2.4 and 2.3). Embodied energy of materials and buildings as a whole is taken into account in section 4.3. The use of efficient building management systems can lead to reduced energy consumption (6.5.2.1) and the use of better energy sources is explained in section 3.4.5. Energy efficiency during construction activities is less relevant, but not negligible (5.6.2.8). In addition, emerging techniques described in Chapter 9 are focused on the energy performance of buildings.
- **Use of water**. In general, public administration can strongly influence the consumption of water by citizens and in public buildings through green procurement (2.2.3) and better water management practices regarding to drainage (2.2.2). In general, best practices for water efficiency in buildings should be described under design options, since many decisions for this aspect are taken by designers (or clients). So, water drainage systems in buildings (3.4.6.1), and water saving fixtures (3.4.6.2) are suitable for both new and existing buildings. Water recycling (3.4.6.3) are techniques more suitable to the construction of new buildings and water monitoring and management should be considered during building use (6.5.2.2). Run-off water, waterways and groundwater affectation of construction works should be considered for civil engineering works (Chapter 8) and for building constructions (5.6.2.5) as they are important for soil erosion control.
- **Use of raw materials**. The use of raw materials for construction works is regarded in a closed loop system (i.e. construction wastes can be used as raw materials after an appropriate treatment, avoiding the use of natural resources). So, environmentally friendly sourcing (4.3.1.1) should be integrated in the management system, which should accomplish objectives for the use of recycled materials (5.6.2.4), the reuse of materials (5.6.2.3) and the improvement of materials efficiency (5.6.2.2). In a closed loop system, the role of deconstruction activities (Chapter 7) and recycling plants is also very relevant. Avoidance of hazardous substances is taken into account in the environmentally friendly sourcing of materials.
- **Waste.** This issue is directly linked to the closed loop view for raw materials. The designing out waste approach (3.4.7) is taken into account within the description, as it can avoid the generation of waste during construction (3.4.7.1) or during deconstruction (3.4.7.2). The waste balance of the sector as a whole can be improved through responsible sourcing of recycled products (4.3.1.1). Best management and prevention practices are described in 5.6.2.1 and 5.6.2.2. Deconstruction best practices have a very important influence on waste generation during building end-of-life (7.3). No specific best practice was identified for hazardous waste, as it is already under strict controls and regulations.
- **Use of land and the role of public administration.** In this document, strong links are made with the public administration best environmental management practice reference document. Chapter 2 covers the main issues related to urban sprawl, use of land and the heat island effect of built environments, and refers to best practices on buildings public procurement, with links to the green public procurement of public administration regarding construction. A special focus is made on local governments. The role of public administration in construction is quite relevant: as a client for public buildings, as a regulator and as one important stakeholder to drive improvements in the environmental performance of construction sites.

- **Biodiversity**. Construction projects have the potential to impact on species and natural habitats. Habitat fragmentation occurs as the natural landscape is gradually developed and subdivided. The remaining patches of original habitat are often too small and too far apart to support the survival and reproductive needs of certain species. Other types of landscape disturbance with potential consequences on biodiversity include alterations in soil structure through compaction and changes in a site's hydrology. Moreover, the noise and light generated during the construction phase may affect feeding and breeding behaviours, which could have a negative impact on long-term population levels. Landscape disturbance caused by development can also contribute to the introduction of invasive alien species into natural habitats. Relevant sections are land planning (Chapter 2), the use of green or brown roofs (3.4.1.3), restoration of quarries (4.3.1.1) and the influence of civil engineering works on biodiversity (Chapter 2).
- **Air emissions**. The majority of CO_2 emissions of the construction sector as a whole comes directly from energy consumption during the use phase (see *Use of Energy* above). The main emissions to the environment from construction works come from dust, which can be very relevant in dry climates (5.6.2.6). Other relevant emissions originate from the use of machinery (particulate materials, NO_x, noise and vibrations, see 5.6.2.8). Disturbance and nuisances generated by construction sites are referred in a separate section (5.6.2.7)
- **Emissions to water**. Water pollution is not a major concern for building construction sites, except for those projects affecting natural waterways or where the groundwater table is high enough to require specific protective measures, usually coordinated by public bodies. Run-off water pollution should also be controlled through appropriate measures and the impact on soil should also be considered (see 2.2.2, 3.4.6.1, 5.6.2.5). During the use of buildings, best environmental management practice include the recycling of grey water (water from taps and showers, see 3.4.6.3), that can be recirculated for low quality uses (e.g. toilets).

On top of those described environmental aspects, some horizontal best environmental management practices covering several aspects at the same time are also identified and described:

- **Management**. For building construction, best practice for implementing an environmental management plan for sites is described (5.6.1.1). This overarching practice establishes objectives, sets targets, and allocates resources, etc. for the environment management of construction sites and it is a requirement of ISO 14001 on environmental management systems and for EMAS registered organisations. Other management practices are related to specific plans, such as dust management plans (5.6.2.6), waste management plans (5.6.2.1) or building management systems (6.5.2.1).
- **Sourcing**. The green procurement of materials has a wide influence on many environmental aspects of the supply chain. For instance, the use of better materials for indoor finishing (e.g. paints in section 4.3.1.2) or the sustainable sourcing of wood (section 4.3.1.3). Meanwhile, improvement of material use efficiency (5.6.2.2), reuse practices (5.6.2.3) and use of recycled materials (5.6.2.4) are also considered. In addition, green public procurement is essential also for public buildings as an example of responsible sourcing (2.2.2).
- **Monitoring**. Monitoring of the environmental performance of construction sites is considered as a best practice, when performance improvement is the main objective for the monitoring practice (5.6.1.2 and 6.5.2.1)
- **Awareness and communication practices.** The construction sector environmental performance frequently depends on the environmental practice of many subcontractors, who are usually small companies with fewer resources for best environmental management. This is an horizontal issue, described in management practices, where relevant.

1.3 EMAS implementation in the construction sector

In this section, statistics on the implementation of environmental management system registered under EMAS are shown. Firstly, the detailed classification of construction activities according to NACE codes is provided. Only construction statistics are provided, although there are many other sectors with strong involvement in the construction activity.

1.3.1 NACE codes

1.3.1.1 Subsector NACE F41: Construction of buildings

This subsector concerns the general construction of all types of building. It includes new work, repair, additions and alterations, the erection of pre-fabricated buildings or structures on the site and also construction of a temporary nature. Included is the construction of entire dwellings, office buildings, stores and other public and utility buildings, farm buildings, etc.

NACE code F41 comprises the following activities:

- NACE F41.1: Development of building projects
- NACE F41.2: Construction of residential and non-residential buildings

1.3.1.2 Subsector NACE F42: Civil engineering

This subsector includes general construction for civil engineering objects. It includes new work, repair, additions and alterations, the erection of pre-fabricated structures on the site and also constructions of a temporary nature. Included is the construction of heavy infrastructure such as motorways, streets, bridges, tunnels, railways, airfields, harbours and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, outdoor sports facilities, etc.

NACE code F42 comprises the following activities:

- NACE F42.1: Construction of roads and railways
  - NACE F42.1.1: Construction of roads and motorways
  - NACE F42.1.2: Construction of railways and underground railways
  - NACE F42.1.3: Construction of bridges and tunnels
- NACE F42.2: Construction of utility projects
  - NACE F42.2.1: Construction of utility projects for fluids
  - NACE F42.2.2: Construction of utility projects for electricity and telecommunications
- NACE F42.9: Construction of other civil engineering projects
  - NACE F42.9.1: Construction of water projects
  - NACE F42.9.9: Construction of other civil engineering projects n.e.c.

1.3.1.3 Subsector NACE F43: Specialized construction activities

This subsector includes specialised construction activities (special trades), i.e. the construction of parts of buildings and civil engineering works or preparation thereof, including activities such as pile-driving, foundation work, carcass work, concrete work, brick laying, stone setting, scaffolding, roof covering, etc. The erection of steel structures is included, provided that the parts are not produced by the same unit.

Also included are building finishing and building completion activities. Included is the installation of all kind of utilities that make the construction function as such, activities such as plumbing, installation of heating and air-conditioning systems, antennas, alarm systems and other electrical work, sprinkler systems, elevators and escalators, etc. Also included are insulation work (water, heat, sound), sheet metal work, commercial refrigerating work, the installation of illumination, and signalling systems for roads, railways, airports, harbours, etc. Also repair of the same type as the above-mentioned activities is included.

Building completion activities encompass activities that contribute to the completion or finishing of a construction, such as glazing, plastering, painting, floor and wall tiling or covering with other materials, such as parquet, carpets, wallpaper, etc., floor sanding, finish carpentry, acoustical work, cleaning of the exterior, etc. Also repair of the same type as the above-mentioned activities is included. The renting of equipment with an operator is classified according to the associated construction activity.

NACE code F43 comprises the following activities:

- NACE F43.1: Demolition and site preparation
  - NACE F43.1.1: Demolition
  - NACE F43.1.2: Site preparation
  - NACE F43.1.3: Test drilling and boring
- NACE F43.2: Electrical, plumbing and other construction installation activities
  - NACE F43.2.1: Electrical installation
  - NACE F43.2.2: Plumbing, heat and air-conditioning installation
  - NACE F43.2.9: Other construction installation
- NACE F43.3: Building completion and finishing
  - NACE F43.3.1: Plastering
  - NACE F43.3.2: Joinery installation
  - NACE F43.3.3: Floor and wall covering
  - NACE F43.3.4: Painting and glazing
  - NACE F43.3.9: Other building completion and finishing
- NACE F43.9: Other specialised construction activities
  - NACE F43.9.1: Roofing activities
  - NACE F43.9.9: Other specialised construction activities n.e.c.

1.3.2 EMAS statistics in the European construction sector

There are 169 EMAS registered construction organisations in Europe (see Table 1.3). If this number is compared to the number of construction companies (more than 3 million), the impact and the relevance of EMAS registration is minor. Most of the EMAS registered companies are Spanish (93) and Italian (38). The rest belong to Germany (18) and Czech Republic (14) and other countries (6). In total, 89 % of the registered companies are SMEs, except for the Czech companies, who are mainly big players.

Table 1.3: Structural repartition of EMAS in the EU construction sector

Country	Number of organisations	Sites	Employees	%SME
Spain	93	99	4715	95 %
Italy	38	74	1786	100 %
Germany	18	19	790	94 %
Czech Republic	14	49	10 918	36 %
Greece	1	2	3313	0 %
UK	1	14	450	0 %
Austria	1	1	192	100 %
France	1	1	16	100 %
Hungary	1	3	61	100 %
Poland	1	1	320	0 %
EU-27	169	263	22 561	89 %

N.B. *Source*: EMAS register, 2012

There are several reasons for the higher number of registrations in Spain. Mainly, third party verified environmental management systems (ISO 14001 or EMAS) are considered as a proof of environmental performance for construction companies in public tenders, so that implementation of systems compatible with ISO 14001 or EMAS has been encouraged by the public administration. In addition, subsidies were received in several regions for EMAS registration in order to improve the environmental performance of the sector.

There are far more ISO 14001 certifications for construction companies' environmental management systems. For instance, AENOR, the most important Spanish certification body, has 1810 construction companies registered as ISO 14001 certified (CACEC, 2011). The total number of issued ISO 14001 certifications for construction companies in the world are around 10 000. This number is still far from important in the context of the total number of organisations belonging to the construction sector. So, there is still a long way to go to drive environmental performance improvement through increasing uptake of EMAS or ISO 14001.

The nature of companies is also quite important. While in the Czech Republic most of the EMAS registered companies are large companies, only 10 % of EMAS registrations correspond to large companies. The rest are mainly SME companies (see Figure 1.10). In Europe, 99 % of construction enterprises are SMEs. Micro-enterprises with less than 10 employees, which account for 93 % of European construction companies, are underrepresented by EMAS with a share of only 17 % of the organisations registered by EMAS. This relatively low share of SMEs in the EMAS registers reveals the burdens for SMEs, especially micro-enterprises.

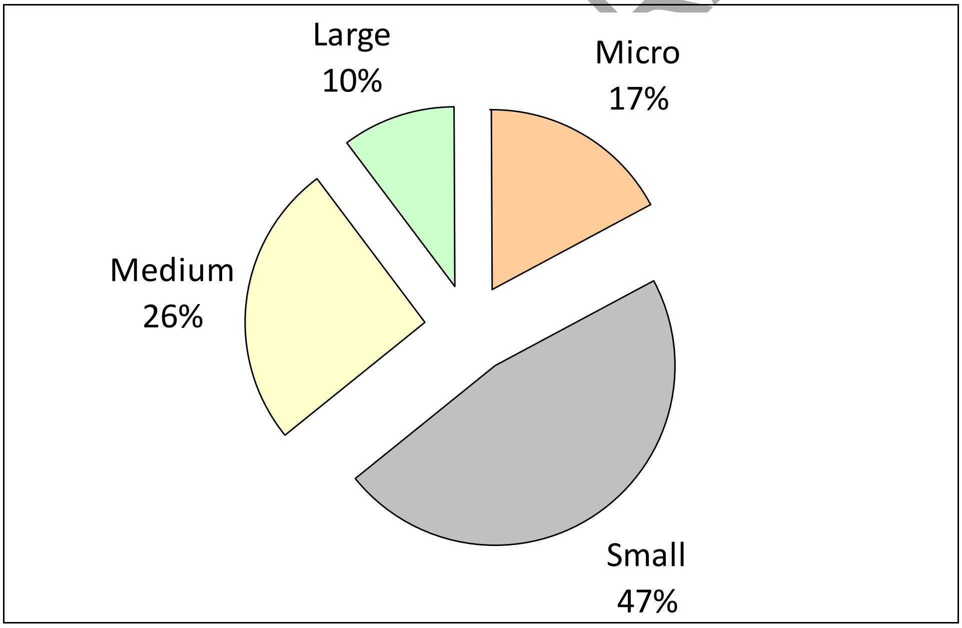

Figure 1.10: Employment size of EMAS registered organisations in the construction sector

The repartition of EMAS registered organisations by NACE code is quite representative of the construction sector as a whole, where 27 % of the construction enterprises are active in the construction of buildings; 23 % in civil engineering; and 69 % in specialised construction activities.

As shown in Figure 1.11, the main economic activities of EMAS registered organisations and sites are classified as specialised construction. Civil works account for one third of total registrations and construction of buildings for one sixth. These proportions do not vary between organisation and site registrations.

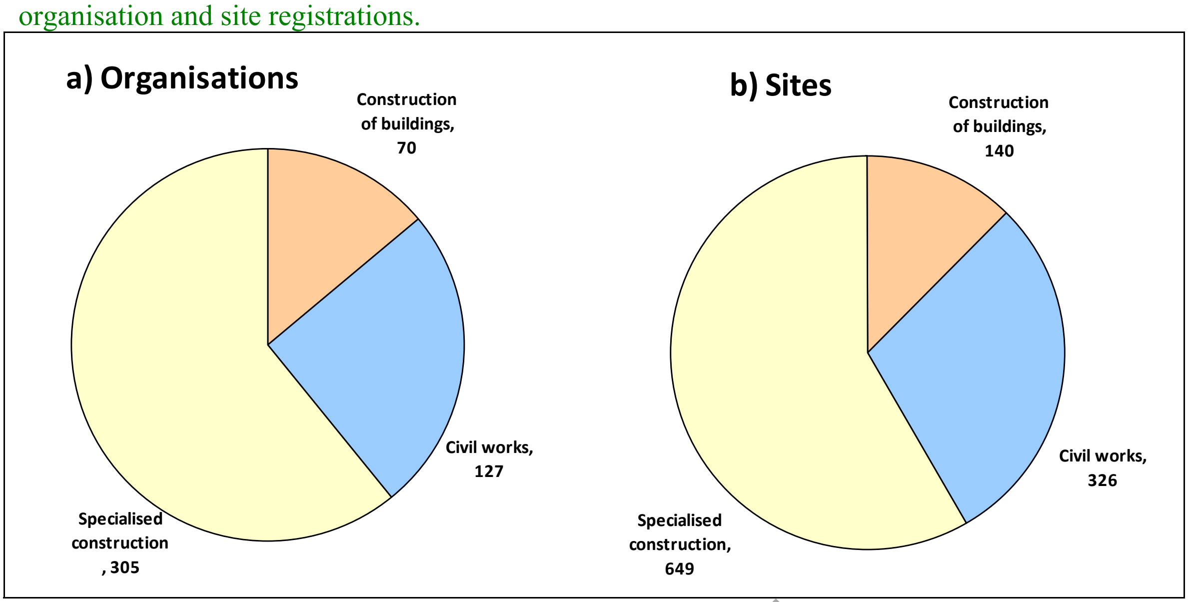

Figure 1.11: Number of organisation and sites registration per economic activity of registered organisations (note: one registered organisations can perform more than one economic activity, so duplicities are considered in the figures)

A detailed distribution of the economic activities of registered organisations and sites is shown in Figure 1.12. As shown, when analysing the detailed distribution, the highest number of registered sites and organisations corresponds to building construction. The distribution of the number of civil engineering organisations and sites per activity seem to be quite homogeneos. The highest number of sites for this subsector is the construction of utility projects for fluids. Specialised construction section (F43), especially the subsections F43.21 (electrical installations) and F43.22 (plumbing, heat and air-conditioning installation) represents a significant share of EMAS registrations for construction organisations and sites.

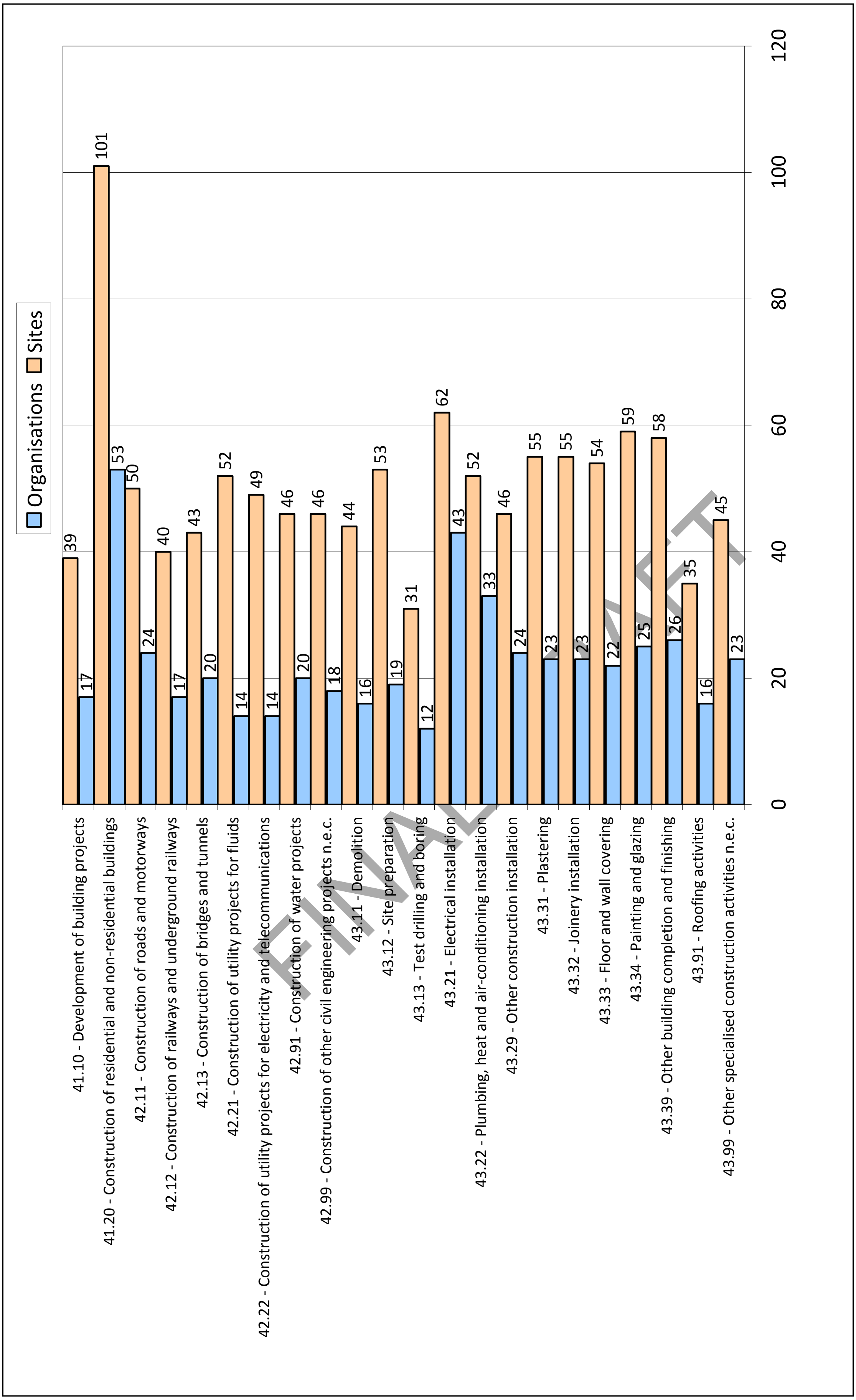

Figure 1.12: Economic activities of EMAS registered organisations and sites

1.4 References

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2 LAND PLANNING

2.1 Scope

This chapter is a non exhaustive description of the links between land planning and the impact of construction activities. The main focus is on the construction of buildings, with some specific points made in relation to civil infrastructure (e.g. green public procurement of roads). For a more comprehensive picture, it is recommended to consult the sectoral reference document on best environmental management practice in Public Administration (EC, 2012).

This chapter will include information on the role of public administration with regards to construction, but also some indications to construction stakeholders on environmental criteria, especially regarding those decisions on site selection, biodiversity aspects and the influence of building performance on local surroundings, which is represented by the heat island effect produced in many cities. Designers, developers, and public administration should also be aware of:

- the integration of urban concepts, such as biodiversity protection, in building inception and project development;
- the role of municipalities and other public administrations regarding the environmental impact of construction activity.

Note, against this background, the text of the techniques will not follow the structure of best practice descriptions for the other best practice chapters of this document (i.e. Description, Achieved environmental benefit, Environmental indicator, etc.)

Reference

European Commission, EC, 2012. Background Report for the development of the Reference Document on Best Environmental Management Practice of the Public Administration sector. Available at *susproc.jrc.ec.europa.eu* , last access on 28/5/2012

2.2 Use of urban sustainability criteria in the inception of building projects

2.2.1 Biodiversity protection

The vast majority of Europeans live in cities and towns, and the consumption of land continues apace. For example, in western Germany, the average annual expansion of built-up areas is 47 000 hectares per year, which, as an illustration, is equivalent over five years to the surface of Greater Copenhagen (EEA, 2006). Urban areas for residential and/or economic purposes (infrastructure and industrial sites) have grown in Europe by 1000 km^2 per year from 2000 to 2006. This urban land take is mostly from agricultural land, but has also reduced recreational areas and habitats for ecosystems that provide important services such as the regulation of the water balance and protection against floods, particularly if soil is highly sealed (EEA, 2006 and 2010a).

In terms of green spaces, there are two main consequences of urbanisation: first, urbanisation – particularly if done in a sprawling way – reduces green spaces outside of the city (countryside and natural areas); secondly, increasing urban populations have traditionally tended to reduce the availability of green spaces within cities themselves. In general, northern European cities tend to have more green space per inhabitant than cities in the south of Europe. Approximately, 45 million people in Europe have limited access to green spaces since they live in cities with between 2 and 13 per cent of green spaces (Fuller and Gaston, 2009).

Urbanisation can be an opportunity or a threat for green spaces and biodiversity. Seizing the opportunity demands that high quality urban green areas are mixed with dense and compact built–up zones. Proper urban design can reduce the need for additional urban land-take and fragmentation. It can, at the same time, penetrate the city with greenery and promote biodiversity. Creating and improving green areas, revitalising brownfields, greening roofs and walls, at the same time as maintaining urban density and compactness, maximises the quantity of ecosystem services delivered within cities and minimises the ecological footprint. With the right form and organisation, urban areas can provide opportunities, and not just threats, to biodiversity (EEA, 2010b).

There is a link between urbanisation and human health. So, not only do green spaces allow urban residents to escape from some of the negative aspects of urbanisation, by reducing noise and purifying the air, but they also provide benefits in and of themselves, for example, contact with green spaces has positive psychological implications. Green spaces are therefore one of the key factors in determining quality of life in cities. Green spaces also provide a range of ecosystem services that are essential to the functioning of human societies. For instance, they help improve urban air quality, attenuate storm water and hence reduce the risk of flooding, reduce the urban heat island effect and help human societies adapt to climate change. When green spaces are eliminated or altered, they lose the ability to provide these services. Alternative (artificial) ways to provide the equivalent services would be more costly and energy intensive. Green spaces are home to flora and fauna, which is not only inherently important but also provides some of these ecosystem services.

Providing green spaces and protecting biodiversity are priorities for good land–planning practicioners. The main driving forces are national strategies and policies implemented at regional/local levels, translated into local protection strategies, which promote the application of several targeted best practices. In the public administration document, four best environmental management practices are described, to be implemented at a local level:

- Setting up a Local Biodiversity protection Strategy and Action Plan, LBSAP. These plans include several elements, the first of which is an assessment of the species and habitats, or biodiversity, of the local area. Subsequently, LBSAPs assess the conservation status of these species and set targets for conservation and restoration. Finally, budgets, timelines, responsibilities and partnerships for the implementation of the strategy and action plan are set (Glowka et al., 1994 as cited in ICLEI – Local Governments for Sustainability, 2010). LBSAPs should also include cost estimates, timeplans, tasks allocation and should also consider the roles and responsibilities of stakeholders. By mainstreaming biodiversity into the regular decision making structure of a local government, LBSAPs maximise the chance of real actions being implemented.

- In the framework of protection strategies, blue green networks can be established. They consist of the development of an urban network of existing and/or restored rivers and their valleys, and green areas (agricultural areas, parks, old orchards, wastelands, degraded areas and others), as a basis for spatial planning of cities
- Another exemplar technique to be used in the framework of local biodiversity action planning is the use of green and brown roofs and green walls, as explained in Section 3.4.1.3. Urban environments are typically characterised by a lack of green spaces, breaking ecosystem connectivity. The availability of green or brown roofs can increase connectivity of ecosystems in an urban environment. Public administrations are able to regulate the use of green roofs and even the species established within this construction element.
- Limiting urban sprawl, as done in several Nordic countries, is a best practice as it allows the reduction of the urban pressure over protected green areas.

Change of land use indicator: greenfields and brownfields

ISO 21929-1:2011 proposes a list of sustainability indicators for buildings. In terms of land planning, it is important to highlight the importance of the proposed change of land use indicator, with the main purpose of measuring the change in land use caused by the development of the built environment. A list of criteria may be developed to measure this change of land use.

Therefore, *change of land use* is a sustainability indicator that measures the avoidance of reducing the area of greenfield lands through the reuse of brownfield and derelict areas, refurbishment, using infill sites and the re-development of the existing built environment according to the following definitions:

- **Greenfield** area is an area of land not covered by artificial surfaces.
- **Brownfield** area is either part of developed or urbanised land, covered with artificial surfaces and no longer used for buildings, or a part of land affected by high levels of soil pollution, requiring remediation. A brownfield area can also be ecologically valuable.

An assessment is proposed to be made on the basis of a classification that takes into account the type of reuse and the percentage of greenfield versus brownfield area. This indicator can also be used for site selection during the inception and planning phase to drive biodiversity protection.

This indicator is not only regarded as a possible indicator for biodiversity protection. It also reflects impacts on water drainage systems, the urban heat island effect and other aspects related to the allocation of resources (usually greater for greenfield sites because of higher infrastructure needs).

Examples from local governments

Integrated management systems

Implementation of an integrated environmental management system is a proposed best practice for public administration, especially for local governments. The main environmental impacts arising in cities do not remain inside municipal boundaries and the responsibility for local governments' environmental management is not limited to public buildings and administration offices. So, an integrated approach for public administrators in cities should include the administration but also city utilities and city enterprises, with a wide perspective that includes also regional influences. One example for this integrated management system can be seen for Lahti, in Finland (Lahti, 2006).

Land planning is one of the main elements of the Lahti integrated approach, with special regards to nature protection and to management of the built environment (see Table 2.1).

Table 2.1: Lahti environmental management measures and indicators for biodiversity protection and built environment management

Aspect	**Actions**	**Indicators and values**
Nature protection	Increase protection Gather information using ecological surveys Increase research on species Develop protection mechanisms for old forests Ridge nature protection areas	Natural reserve areas: 365 ha Percentage of areas protected: 2.7 % Special protection sites: 700 ha Habitats with limited natural distribution or in danger in the European Union: 17.5 ha
Built environment management	Construct new buildings with regard to cityscape and amenity Create amenities with social and cultural values, connected to environmental protection Retain valuable built environments Retain/improve traditional landscapes	Share of parks and green areas: 28 % Valuable sites protected in city land use planning: 950 ha Number of protected buildings: 61 Traditional landscapes: 26.6 ha

N.B. *Source*: Lahti, 2005 and Lahti, 2006.

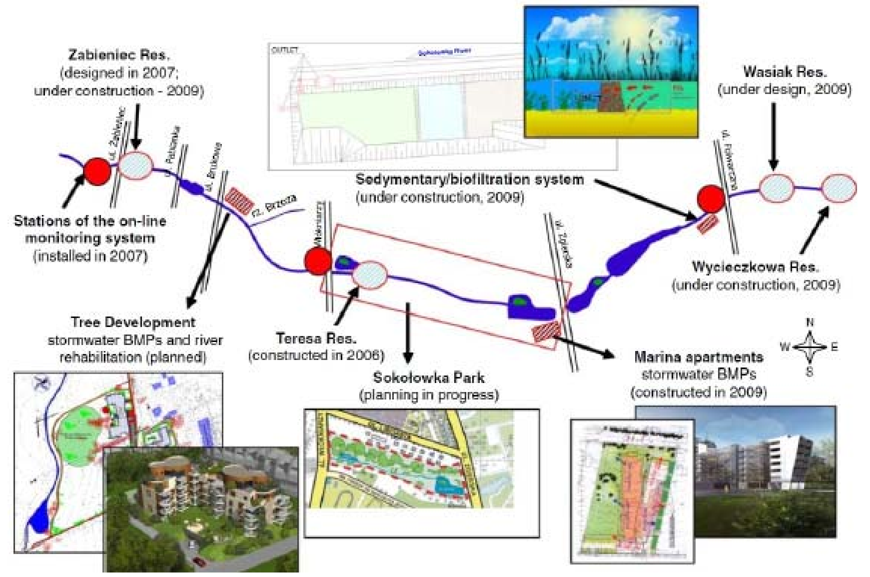
Setting Local Biodiversity Strategic Action Plans, LBSAP

Barcelona's LBSAP is expected be adopted by the City Council during the course of 2012. The main challenges addressed in the plan are the fitting in of biodiversity in a very dense urban environment, the management of habitat while taking its different uses into account and the protection of species subjected to multiple pressures. Barcelona aims to address these challenges through the following strategic lines:

- strengthening municipal leadership
- increasing knowledge applicable to conservation
- integrating criteria fostering biodiversity, from design to maintenance
- creating new nature spaces
- cconserving the city's natural heritage
- extending the commitment to biodiversity beyond Barcelona
- communicating and disseminate knowledge of biodiversity and its values
- creating opportunities for interaction with the city's nature
- fostering citizen involvement in the conservation of biodiversity
- extending education on biodiversity at all levels

Creation of Blue-Green Networks: Lodz, Poland

Sokolowka river valley was restored according to blue green networks. First, a hydrological monitoring and landscape survey was carried out (Switch, 2011). A reservoir was built and a comprehensive chemical analysis of the river basin was performed. Then, rehabilitation and development plans were implemented (see Figure 2.1).



Source: Switch, 2011

Figure 2.1: Activities developed for the restoration of the Sokolowka River

Green and brown roofs in London, United Kingdom

London's work on green roofs is strongly linked to its climate change adaptation and mitigation policies and plans; these feature for example in London's Adaptation Strategy (Greater London Authority, 2010). Although the initial push for green roofing in London was mainly centred on their biodiversity benefits, in the last few years the focus has shifted rather to the climate change adaptation benefits they provide, although some boroughs still place a stronger emphasis on biodiversity. In order to reduce the impacts of extreme weather events, the Greater London Authority has committed to increase tree cover by 5 % by 2025, to increase greenery in the centre of London by 5 % by 2030 and a further 5 % by 2050, to create 100 000 m^2 of new green roofs by 2012 and to enhance 280 ha of green space by 2012.

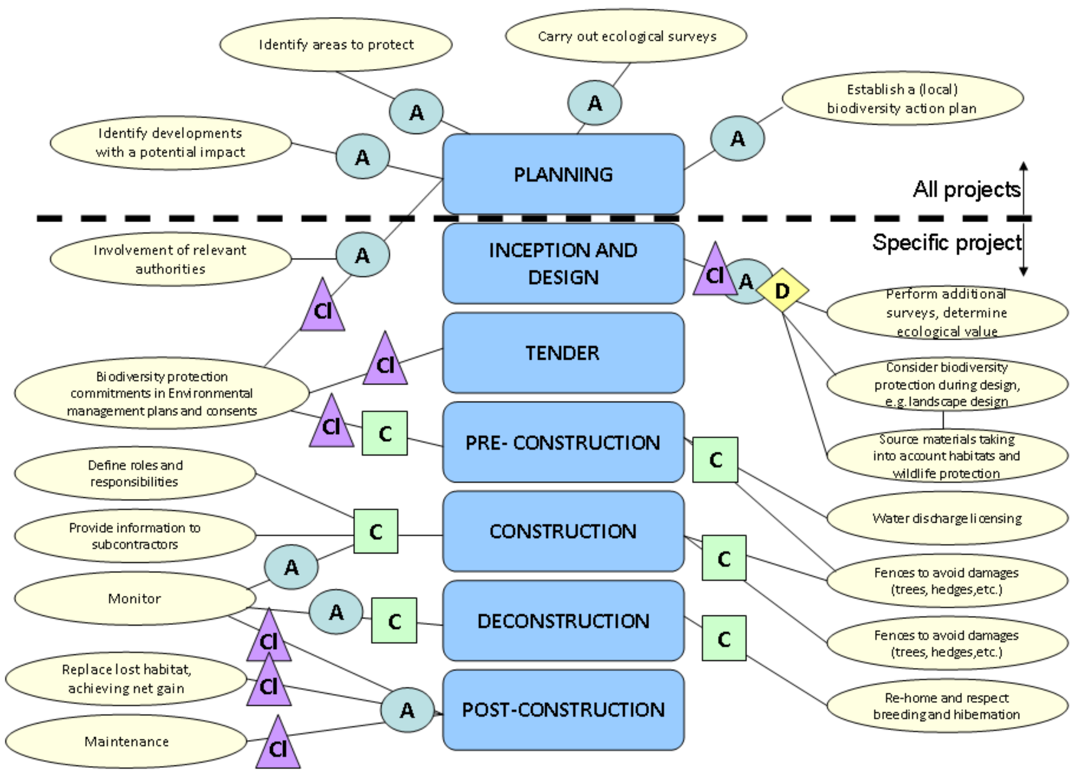
Construction projects and biodiversity protection

Construction projects usually have a significant impact on biodiversity, as there are a number of construction activities with potential adverse effects on wildlife (see Table 2.2). Those effects on wildlife should be taken into account during all construction phases. The most important one may fall under the responsibility of administrations, as they are able to regulate land use. Some identified best environmental management practices are identified in Figure 2.2, mainly extracted from Noticenature, 2006. In the figure, it is shown how different responsibilities are distributed and mainly undertaken by principal actors for each phase. Public administration should perform certain activities during the planning phase, which is common for every project, such as the identification of areas to be protected, undertaking regular ecological surveys, establishing and updating biodiversity plans and identifying those developments to be targeted to avoid negative impacts. Clients should play an active role, also during the design phase, and may have an active participation in the definition of the objectives. However, it is usual that the main responsibilities in the post construction phase are diffuse and not well allocated between construction developers or clients and public administrations. It is also important to highlight the relevant role of the information flow between all the actors, especially for the implementation of relevant measures and construction phase management. Subcontractors should be informed about biodiversity protection measures. Monitoring, maintenance and any preventive or corrective measure covered by any consent should also be properly checked.

Table 2.2: Construction activities and their potential adverse effects on wildlife

Construction activity	Implication	Effects on wildlife (examples)
Site Clearance	Removal of trees and shrubs	Loss of important species or specimens of tree or shrub that may be protected Loss of bird nests (during the bird breeding season) or bat roosts, bat commuting routes and bat feeding sites Loss of habitat for protected species Loss of important invertebrates, including those that may require deadwood habitat
	Removal of ground vegetation	Loss of habitat for protected species Loss of rare plants Loss of bird nests Killing or injury of reptiles, amphibians or small mammals Loss of invertebrates and their breeding habitat
	Removal of soil	Loss of habitat for protected species Loss of seed bank Loss of invertebrates and their breeding habitat Destruction of badger sets and other ground dwellings
	Demolition of buildings and structures	Loss of bird nesting or bat roosting areas
	Alteration of watercourses	Loss of aquatic and riparian species including fish, amphibian and plants and loss of habitats
	Infilling of wetlands/aquatic habitats	Loss of aquatic species including fish, amphibian and plants and loss of habitats
Site setup	Location of site offices and compounds	Disturbance of breeding animals
	Storage Areas	Potential for pollution of important watercourses, wetlands or other water bodies, including coastal waters through spillage or dust.
Establishment of haul roads	Rubble or concrete temporary roads constructed	Fragmentation of habitats Road kills Destruction of badger setts Contamination of adjoining habitats by dust Noise or light pollution may disturb nesting birds or other animals Change of soil pH through leaching
Groundworks	Ground investigations, foundations, excavators and piling, temporary earthworks, and tunnelling	Impacts on surface water and groundwater, which may have secondary impacts on important wetlands both on and off site Noise or light pollution may disturb nesting birds or other animals Destruction of badger sets Run-off and erosion, which may damage important habitats Potential to introduce or spread invasive plants
Construction	Concrete pours and other wet trades	Contamination of wetlands Change of soil pH through run-off

Source: DKM Economic Consultants, 2006.



A: administration, Cl; clients, C: contractors, D:designer

Figure 2.2: **Good practices in biodiversity protection during the development of construction projects**

One of the main concerns for all the actors is the main monitoring and reporting methodology for biodiversity protection. As an example, the UK Green Building Council published guidelines on the role of every actor in the management of biodiversity on construction sites (UKGBC, 2009). Some of the proposed indicators are shown below:

Biodiversity reporting indicators

UK Construction excellence impact on biodiversity

% of all applicable projects that achieved all available credits in the appropriate rating system (e.g. BREEAM)

% of projects where an ecology survey is carried out before works commence

% of projects with a Biodiversity Management Plan specific to that project

% of projects with a nominated biodiversity champion

% of direct employees with biodiversity awareness training

For singular projects, some qualitative assessment could be carried out using the following indicators:

- measures to reduce or compensate disturbance are implemented
- sighting records are kept for endangered or protected species
- the local biodiversity plan has been followed
- new habitats have been created
- a monitoring system is implemented (post-construction)
- species have been translocated
- a case study database has been consulted and relevant experts have been addressed for specific issues

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2.2.2 Water drainage in sealed soils

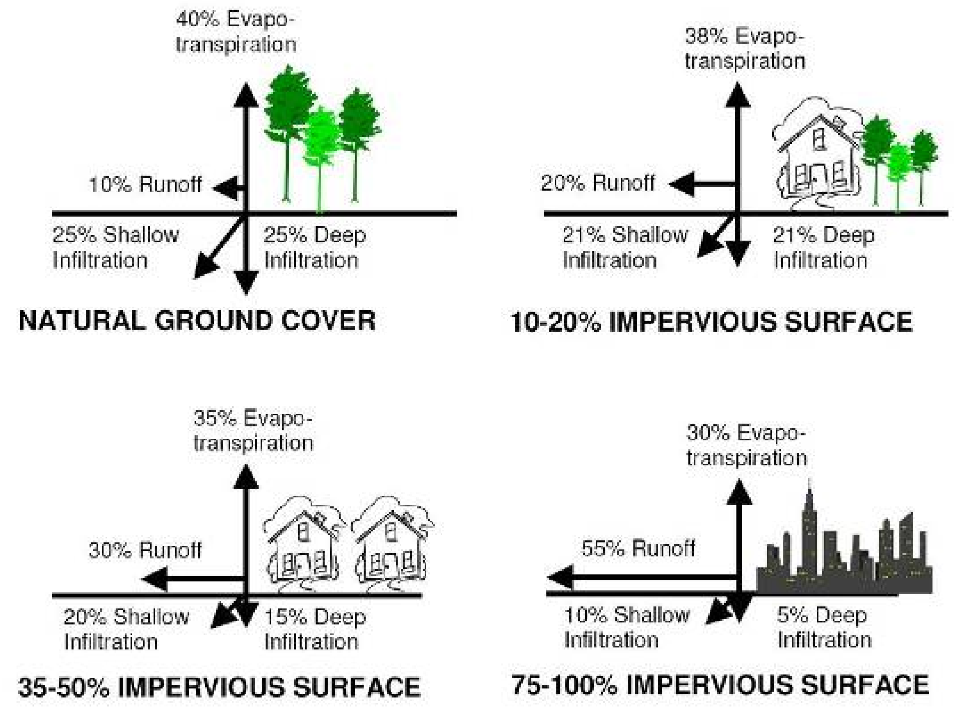
Water resources management falls under the responsibility of public administration land planners. In this document, the impact of water management activities has to be regarded from the perspective of the development of urban areas and building construction projects. The main impacts from the development of new areas and from the existing ones are soil sealing, avoiding natural drainage and increasing the amount of run-off water, which can provoke floods in heavy storm events.

Accordingly, reference should be made to the Water Framework directive, which encourages an environmentally friendlier approach for the management of groundwater, surface waters and protected areas. In general, drainage systems should be considered in local, regional and national policies, providing that:

- The drainage system is part of a holistic approach for the management of the water environment, which should be based on river basins.
- It integrates quantitative and quality objectives. Thus, all discharge activities of urban run-off will need to be managed in order to avoid damages on the receiving environment (e.g. surface waters).

One impact of urban development is the reduction of permeability of the land surface, by replacing free ground (permeable) with impermeable roofs, roads and paved zones, which have to be drained through piping systems. The phenomenon of increased impervious surface is known as land or soil sealing, which occurs not only as a consequence of the reduction of infiltration but also because of the removal of the green coverage, which avoids evapotranspiration. The European Commission defines sealed soil as 'the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)' (EC, 2011).

Figure 2.3 shows examples of different land coverage and their impact on different water flows.



Source: Dane Waters, 2009

Figure 2.3: Impact of impervious area on hydrologic fluxes

The two main potential consequences of the development of construction sites and buildings is altering water flow patterns, leading to flooding and erosion. Also, reduced infiltration decreases the aquifer recharge and changes water availability, thus risking in-stream and streamside habitats (Woods-Ballard et al., 2007)

The main impacts of construction and urban development on water natural drainage mechanisms concern water quantity and quality. The impervious surface, used for human activities, is a significant source of chemical pollution build up, when, in addition, natural filters have been removed. The main sources of chemical pollution to water quality, absorbed usually by rain water, are atmospheric deposition (from traffic or industrial activities), spillages, solid deposition in roofs, animal faeces, sediments from erosion, de-icing, cleaning, sewer and illegal disposal. The related impacts produced from these are (Woods-Ballard et al., 2007):

- Changes to stream flow: fast urban area drainage with reduced infiltration provokes the increase of run-off volumes, causing discharges orders of magnitude higher than those from natural sources.
- Changes to stream morphology: widenning channels to accommodate increased run-off would increase erosion, increase sediment in natural water ways and expose trees roots. Also, the stream bank would be eroded.
- Impacts to aquatic habitat: e.g. washing away biological communities, impacts on riparian vegetation, sedimenting solid deposits, reduced oxygen levels, reduced water quality, etc.
- Impacts on water quality: reduced oxygen levels, increased sediments, increase eutrophication, increased pollutants and toxic chemicals, etc.

In addition, climate change impacts on water resources will reduce the availability of fresh water, increase evaporation, increase the periods of intense rainfall, with higher erosion impacts, increase the amount of pollutants fed to water ways, increase flooding and increase the amount of untreated waste water discharged to the environment. Some policy approaches regarding best practice are shown in Table 2.3.

Table 2.3: Some policy approaches regarding best practices to avoid soil sealing and improve water drainage

Measure	Development
Reduction of urban sprawl (e.g. Austria)	• New spatial planning regulations to improve land use efficiency: (i) Building permits with expiration date, (ii) contracts between municipalities and land owners, and (iii) real estate funds at provincial level • New funding schemes for housing to improve intensification of settlements • 'Soil efficient' business developments
Reuse of Brownfield land (e.g. Belgium)	Brownfield Covenant: agreement between the Flemish Government and one or more private or public parties, which foresee arrangements in order to promote a smooth and efficient realisation of a Brownfield project
Protection of the best agricultural land and landscape fragmentation (e.g. Cezch Republic)	Three policy documents protect the consumption of green land inside and outside city boarders and give priority to inner urban developments, namely the building code, the act on nature conservation, and the act on the protection of agricultural land. This also improves water drainage through: • Protecting high quality soils in the outer city belt, via the act on the protection of agricultural land • Protecting of green areas within city boarders • Giving priority to the development of abandoned areas (old industrial estates) instead of developing green land
Management of flood risks (e.g. Germany)	Example in Saxony: building activities in flood risk areas were banned, retention zones were extended, soil sealing rates in flood risk area were monitored with the aim to avoid any increases in sealing, and the desealing of abandoned developed land was encouraged
Water drainage (e.g. Ireland, UK)	Proposals for a housing estate development or for the development of a large number of houses in a particular area, are required to submit a Flood Impact Assessment and proposals for a Sustainable Urban Drainage System (SUDS)

Source: EC, 2011

The use of overarching approaches can be considered as a best environmental management practice on land planning. Surface water drainage systems, developed in accordance to a sustainable development policy; managing environmental risks resulting from urban run-off and contributing to environmental enhancement, are the best examples of developed 'Sustainable Drainage Systems', SuDS, philosophy in the UK (Woods-Ballard et al., 2007). This is an exemplary approach, consisting of a three-way concept (improve water run-off quality, optimise water quantity and maximise amenity and biodiversity), replicating, as closely as possible, natural drainage of the sites before development. Apart from the evident environmental benefit, it also has a cost justification, as the need for large flow attenuation and flow control structures are effectively minimised.

The management hierarchy for water drainage management, given also by SUDS, usually refers to the techniques which should be preferred in a new development, e.g.:

- **Prevention**: good design practices and site housekeeping measures to prevent run-off and pollution, as rainwater harvesting or dust removal. Overall prevention policies should be considered a best practice technique.
- **Source control**: highly polluted or large amounts of run-off should be controlled at their source. For instance, green roofs or car parks.
- **Site control**: control of water flows on site, for instance, piping water flow to infiltration or detention basins
- **Regional control**: to send excess run-off water to a pond or to a wetland, shared by several sites.

Techniques to consider for environmentally friendly drainage systems are listed in Table 2.4 and are referred to when they improve water quality or affect water quantity. Table 2.4 also reflects the position at the management hierarchy and the main benefit to be achieved with regards to water quality or quantity control.

Table 2.4: Techniques to be considered as best environmental management practice for water drainage systems

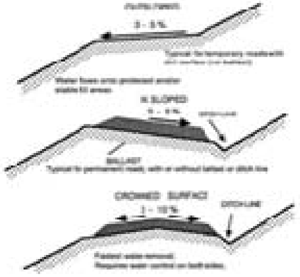
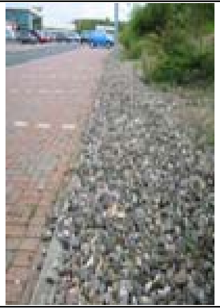
Technique	Description	Type of management	Main benefit	Picture
Water butts, site layout and management	Good housekeeping and good design practices	Preventive, source control	Increase water infiltration. Possible benefits on quality and biodiversity	
Pervious pavements	Allow inflow of rainwater into underlying construction/soil	Preventive, source control	Avoid pollution and increase infiltration	
Filter drain	Linear drains/trenches filled with a permeable material, often with a perforated pipe in the base of the trench	Conveyance, source control	Allows conveyance and detention and avoids water pollution	

Table 2.4: Techniques to be considered as best environmental management practice for water drainage systems

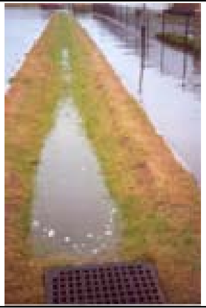
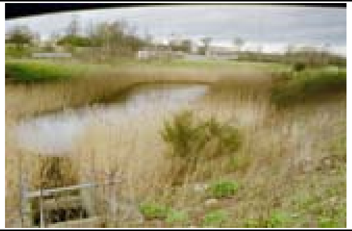
Technique	Description	Type of management	Main benefit	Picture
Swales	Shallow vegetated channels that conduct and/or retain water and permit infiltration when unlined. Filter for particulates	Conveyance, source control and site control	Allows conveyance, detention, infiltration and reduce pollution	
Filter strips	Vegetated strips of gently sloping ground designed to drain water evenly from impermeable areas and filter out silt and other particulates	Pretreats and allows source control	Improves water quality	
Ponds	Depressions used for storing and treating water. They have a permanent pool and bankside emergent and aquatic vegetation	Site control. Regional control	Detention and harvest water. Improves quality	
Wetlands	As ponds, but the run-off flows slowly but continuously through aquatic vegetation that attenuates and filters the flow. Shallower than ponds.	Site control, regional control	Detention and harvest water, improves quality	

Table 2.4: Techniques to be considered as best environmental management practice for water drainage systems

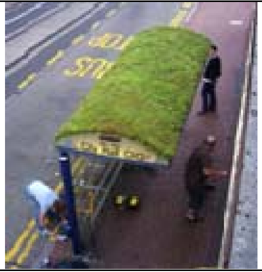
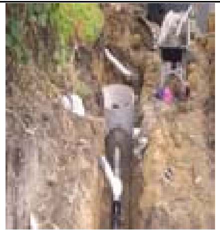
Technique	Description	Type of management	Main benefit	Picture
Soakaways	Subsurface structures that store and dispose of water via infiltration	Site control	Infiltration. May improve water quality.	
Infiltration trenches	As filter drains, but allowing inflitration through trench base and sides	Site control. Source control	Infiltration and detention. May improve water quality	
Infiltration basins	Depressions that store and dispose of water via infiltration	Site control. Regional control	Detention and infiltration. May improve water quality	
Green roofs.	Vegetated roofs reducing run-off volume and rate	Site control. Regional control	Detention	

Table 2.4: Techniques to be considered as best environmental management practice for water drainage systems

Technique	Description	Type of management	Main benefit	Picture
Bioretention areas	Vegetated areas for collecting and treating water before discharge downstream or to the ground via infiltration	Site control. Source control	Detention and infiltration. Improves water quality	
Sand filters	Treatment devices using sand beds as filter media	Pre treatment and site control	Detention and improves water quality	
Silt removal devices.	Manhole and/or proprietary devices to remove silt	Pre-treatment	Improves water quality	
Pipes and storage.	Conduits and accessories as conveyance measures	Conveyance and site control	Conveyance and detention	

Performance of selected case studies

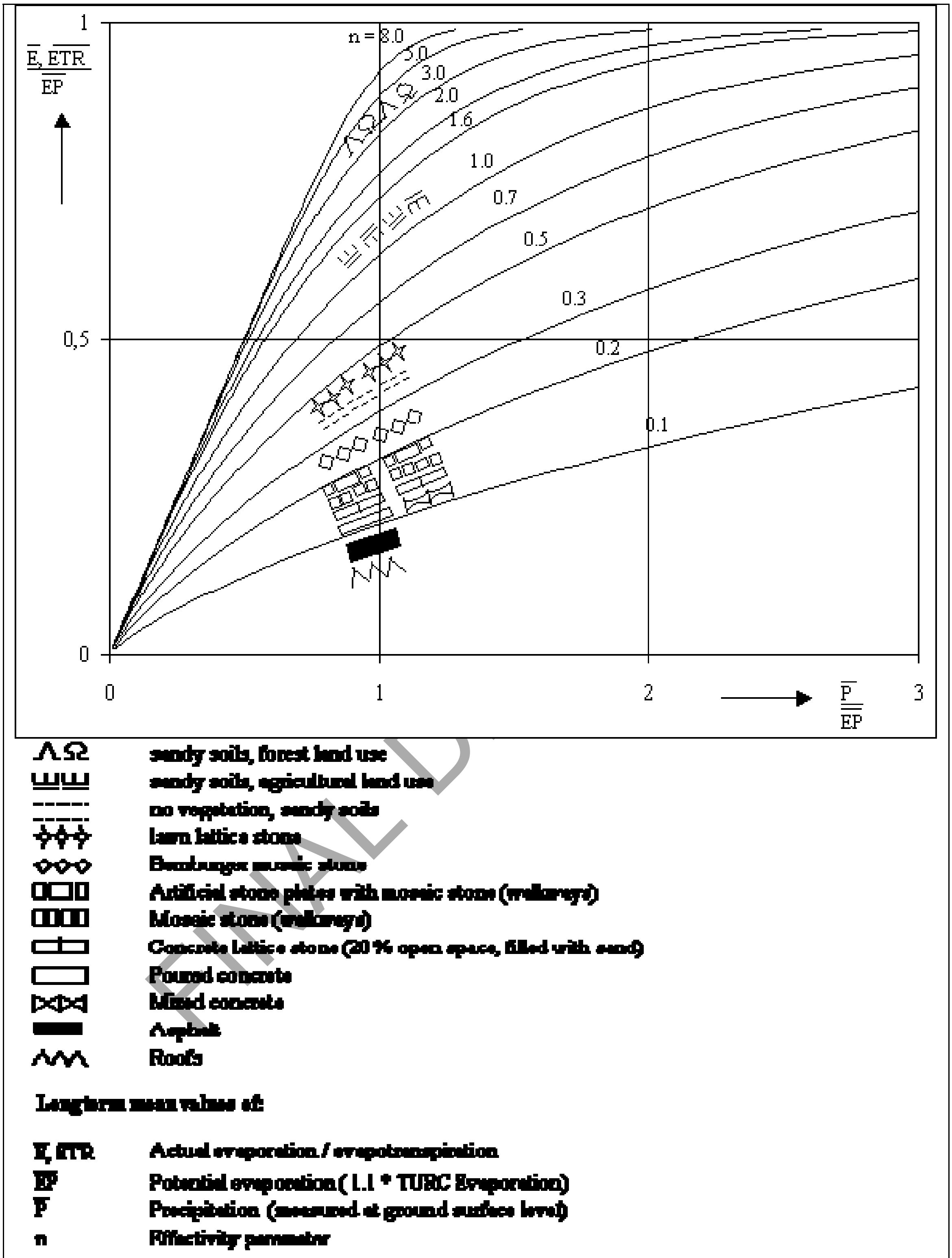
Berlin management of Rain and Waste Water

The city of Berlin can be considered exemplary on the development of its monitoring system for the management of rain and waste water and on the adoption of measures to prevent and correct surface run-off water. For rainwater drainage, an extensive analysis, including modelling, detected that 55 % of the total received rain water (about 478 million m^3 in 2009) is evaporated, while the rest, 216 million m^3, is available as run-off. Nevertheless, 149 of those 216 million infiltrate to the ground, due to the degree of sealing. The rest is recovered by a sewerage system (20 in a combined treated system sewage-rainwater and 47 in a separate system). To evaluate the performance of the water drainage system in the city, a model was established that requires 25 input parameters to be controlled in 25000 sections of the city (Berlin, 2007). The model, called ABIMO, calculates the evaporation rate and derives total run-off and surface run-off from collected data, calculating the water balance for the whole region.

To understand how the model works, there are several definitions to be provided:

- **Total run-off** is the difference between long-term annual average precipitation values and real evaporation.
- **Real evaporation** for a site is calculated from the amount of precipitation, the potential evaporation (depending on the climate characteristics) and the storage capacity of the evaporation area.
- **Usable field capacity** is a difference of the humidity or water content values for field capacity and of the permanent wilting point. So, it reflects the amount of water that the soil is able to store without producing damage to the plants.
- **Groundwater net consumption** is negative run-off values and only occurs when there is low precipitation in a certain area and the water table has low depth. As plants, here, are fed by groundwater, evaporation produces a negative value for run-off.
- **Surface run-off** is the total run-off that drains into the sewage system (separated or combined).
- **Seepage** is the difference between total run-off and surface run-off and, thus, corresponds to the basic contribution to new groundwater formation.
- The **infiltration factor**, F, is the fraction of water that is actually percolated by the terrain and is not possible to catch as surface run-off.
- The **effectivity parameter**, n, is a measure of the storage capacity in an evaporation area, being dependent on the intensity that the real evaporation approximates potential evaporation. So, high values of the effectivity parameter are reached for sandy soils, while roofs are considered to have a very low effectivity parameter due to very low storage capacity, where total run-off very close to surface run-off.

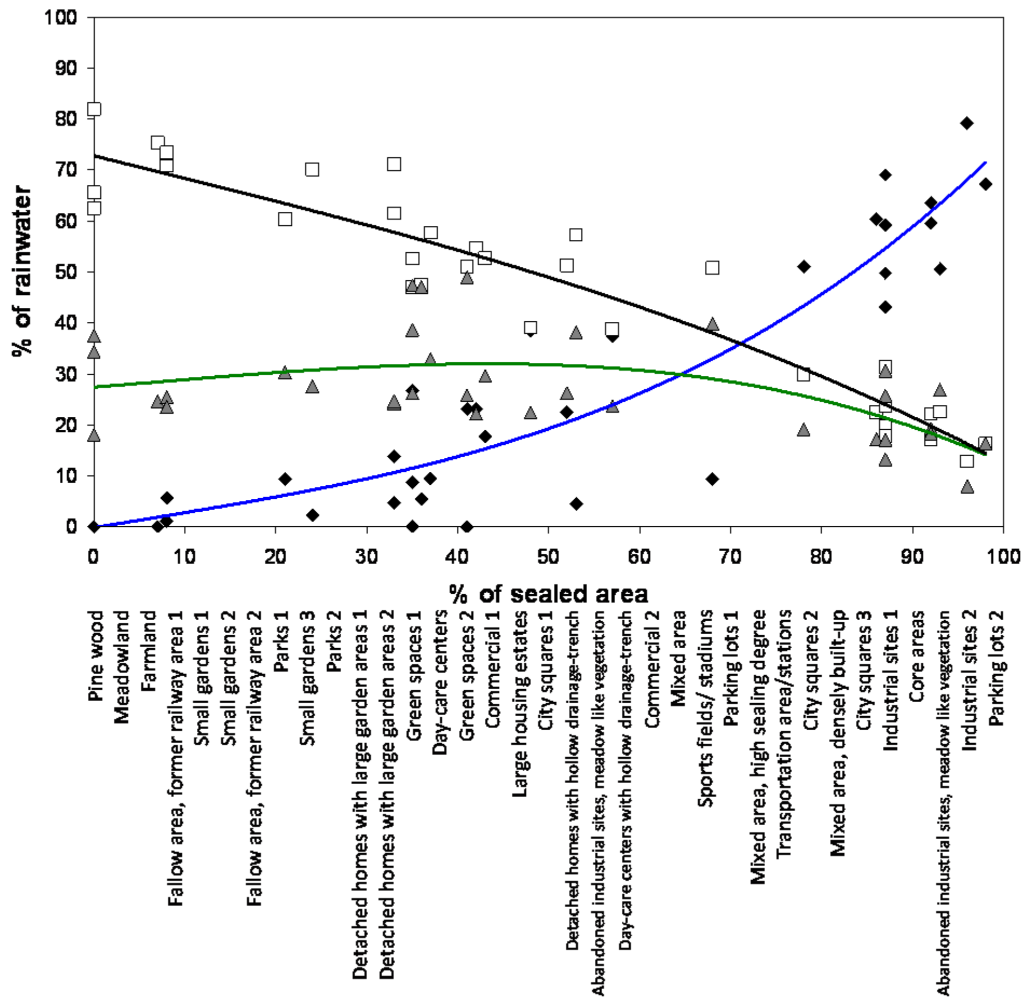
The performances of sites are measured with the Bagrov equation for several effectivity parameters of surfaces. The Bagrov relation describes the nonlinear relation between precipitation and evaporation according to site characteristics. This relationship is represented in Figure 2.4.



Source: Berlin, 2007

Figure 2.4: **Representation of the Bagrov Equation for selected values of n (effectivity parameter) for different land uses or soil types**

Taking into account all the factors described above, the model becomes useful to determine the storage quality of a particular site. This is determined by the use for: impervious area, vegetation-free surface, agricultural, etc. In Berlin, a full set of data on the water drainage quality of sites is available. In Figure 2.5, the percentage of rainwater to different fates (as run-off, evaporated or infiltrated) is shown for different degrees of sealing. It can be observed that when the sealing degree of surfaces is increased, the water run-off increases, thus increasing the need of installing water collection devices. Also, it is noticeable that, for some of the sites with similar uses, water drainage performances are quite different only because of the different degrees of sealing.



◆ % of run-off water; □ % of evaporated water;▲ % of infiltrated water; —— trend line of run off water; ——trend line of evaporation water; ——trend line of infiltrated water

Figure 2.5: Run-off water performance in Berlin for different sealing degrees

Finally, and as an example of the comprehensive monitoring system, the city is developing water maps for different soils and land use, as shown in Figure 2.6. This not only reflects best practice, but can drive flood risk assessment and the introduction of prevention or corrective measures, allowing for the best water drainage performance.

Legend on surface run-off rate (mm/year) 🟧 <50; 🟨 50 – 100; ▭ 100 – 150; 🟩 150 – 200; ▭ 200 – 250; 🟦 250 – 300; 🟦 300 – 350; 🟦 350 – 400 ■ > 400

Figure 2.6: Berlin surface run-off map (example)

Sustainable Drainage Systems: SuDS

SuDS application to cities and neighborhoods in the UK has an important number of examples, which can be seen on the CIRIA (Construction Industry Research and Information Association) webpage. These case studies report the results from the application of several techniques in new or existing developments. Below, two examples are given:

Large residential development in Elvetham Health (Hampshire). In this residential area with several services (school, retail outlet, park, sports, etc.), 63 ha of land were used with a housing density of individual houses of 30 per ha (Figure 2.7). One third of the site was provided with soakaways for deep groundwater level zones and swales and ponds for transporting and storing water, reducing run-off and infiltrating as much as possible: in total, 14 detention basins, 1 pond and a number of soakaways and swales. The scheme collects run-off discharging into swales, and then it is sorted in a retention pond, with two levels of treatment (filtering and sedimentation). The final retention pond collects all the drained water and is considered an amenity inside the park (CIRIA, 2012a). The design rate is 7 litres per second per ha without flooding in a 30 year return period event. Economically, it represents an advantage, as there are estimations on the increase of value by 10 %. The main environmental benefits were affected by cross effects; e.g. the construction process compresses soil and reduces the infiltration capacity, changing design premises. Nevertheless, water flooding was perfectly controlled, although water quality was less than desired, due mainly to the income of drainage from a road close to the site.

Source: CIRIA, 2012

Figure 2.7: Water pond in Elvetham Health

London 2012 Olympic Park – public open space. The Olympic development in London covers 250 hectares in a formerly industrial development and, also, with a significant fraction of contaminated sites. For the development, many SuDS system were installed. Porous asphalt strips collect the run-off and, finally, drain away to watercourses. Rainwater harvesting was installed and wetlands were built.

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2.2.3 Green public procurement for construction

Public administrations are important consumers in Europe: they spend approximately EUR 2 trillion annually, equivalent to some 19 % of the EU gross domestic product. By changing the decision making process on public procurement, they are able to drive industry to develop more environmentally friendly products and services. According to the European Commission (EC, 2008a), Green Public Procurement (GPP) is defined as ‘a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured.’ The Commission is developing some GPP guidelines for the development of greener procurement within public administration, through a voluntary instrument (EC, 2012a)

The Commission identified a number of priority products for the development of green procurement guidelines. The first item in the priority list is ‘Construction (covering raw materials, such as wood, aluminium, steel, concrete, glass as well as construction products, such as windows, wall and floor coverings, heating and cooling equipment, operational and end-of-life aspects of buildings, maintenance services, on-site performance of works contracts)’ (EC, 2008a). Environmental criteria, according to this scheme, have been developed for the following products (in bold, products relating to the building and construction sector under the scope of this document):

1. Copying and graphic paper
2. **Cleaning products and services**
3. Office IT equipment
4. **Construction**
5. Transport
6. Furniture
7. Electricity
8. Food and Catering services
9. Textiles
10. Gardening products and services
11. **Windows, Glazed Doors and Skylights**
12. **Thermal insulation**
13. **Hard floor-coverings**
14. **Wall Panels**
15. **Combine Heat and Power** (CHP)
16. **Road construction and traffic signs**
17. Street lighting and traffic signals
18. Mobile phones
19. **Indoor lighting**

In addition, the GPP work programme of the European Commission establishes that environmental criteria will be proposed by 2013 for heating systems and buildings.

For public administration, the construction of new buildings and the renovation of existing ones represent a major share of annual expenditure, possible as high as or higher than 50 %. In addition, the running costs of publicly owned buildings represent a high share of the annual operational costs of any public administration. Therefore, one of the most relevant set of environmental criteria is for construction services to be purchased by public administration (point 4 in the product list above).

The set of criteria should be established for the full life cycle of the building, from inception to the implementation of building services (Figure 2.8)

Source: Adapted from EC, 2008b.

Figure 2.8: Construction process scheme for the proposal of environmental criteria in the GPP scheme

The set of environmental criteria refer to the most important environmental aspects of a building (EC, 2008b):

- Energy
    - Energy consumption (heating, cooling, hot water, ventilation and electricity)
    - Passive house and low energy house concepts
    - Use of renewable energy
    - Monitoring the energy performance
- Building materials
    - Exclusion of certain building materials
    - Use of environmentally friendly materials
    - Long life cycle and material efficiency
    - Specific criteria for materials: wood, iron, etc.
- Waste management
    - Waste prevention
    - Recycling and reuse of materials
- Water Management
    - Water saving installations and rainwater/grey water use
- Other
    - Transport and noise control

Criteria are divided into Core Criteria (designed for a minimum verification effort or cost increase for purchasers) and Comprehensive Criteria (for best environmentally friendly construction products, even if additional administrative effort is required).

Finally, the set of GPP criteria for construction are shown in Table 2.5(EC, 2008b).

Table 2.5: Comprehensive environmental criteria for construction green procurement from the European Commission GPP scheme

Set of criteria	Description	Comprehensive Criteria
Subject matter	Construction of a building able to fulfil the environmental criteria	1. Exclusion of certain contractors (those who have repeatedly acted against environmental legislation)
		2. Experience of the architect in environmental construction
		3. Technical capacity to undertake the necessary environmental management measures in order to ensure that the construction works are executed in an environmentally friendly way
Energy performance	Increasing the energy efficiency of the building through reduced demand and efficient technologies	(Opt 1) Use of energy performance standards (e.g. those described in Section 3.4.2)
		(Opt 1 and 2) Final building user has been trained on the energy efficient use of the building
		(Opt 2) Localised renewable energy use
		(Opt 2) Energy consumption fulfils a benchmark, e.g. less than 15 kWh/m^{2}yr heating demand.
		(Award) Innovative energy efficient building services
		(Award) Lower energy consumption than demanded in certain specifications
Building materials	Use of most environmentally friendly options for materials	Exclusion of certain materials, regarding to the content of hazardous substances
		Timber from legal sources
		Volatile Organic Carbon (VOC) emissions do not exceed the values outlined in EN ISO 16000-9 to 11
		For renovation, steel cleaning should not be done with silicon blasting agents
		(Award) Use of construction materials and products complying with certain environmental criteria
		(Award) Use of materials from renewable raw materials
		(Award) Thermal properties of insulation materials are met
		(Award) Sustainable forestry sources
Water saving installations	Reduction of water consumption	New sanitary and kitchen water facilities must be equipped with the latest water saving technology
		A number of urinals and toilets use waterless technologies
		(Award) Rainwater and grey-water use
Contract performance clauses	Additional performance clauses to be met by contractor	Use of LCA in design
		Compulsory blower door test
		Book keeping
		Transport and recycling of building materials
		Waste reduction and management

N.B. Source; EC, 2008b.

The GPP criteria set proposed by the EC constitutes a voluntary approach to guide public administrations in their procurement. Municipalities and other public organisations are able, then, to adapt these guidelines to their own circumstances. Within the sectoral reference document for best environmental management practice in the public administration sector (EC, 2012b), a number of examples are described for green public procurement schemes in several governments, especially at local level. Regarding the implementation of GPP criteria in the procurement of construction works, the policy approach of the city of Frankfurt can be regarded as exemplary. The implementation of best practice by Frankfurt city council took place long before the EC criteria were published. By 2010, the city had already built 800 new dwellings, two schools and two kindergartens in accordance to the Passive House standard, totalling 100 000 m^2. A resolution was implemented to make every new building or those buildings under the influence of the local government to be built under the Passive House standard. According to Neumann, 2010, the implementation of the passive house approach in Frankfurt is a combination of 'proven, economic techniques' driven by the motivation and commitment of architects, construction companies and the local government (Neumann, 2010; Stadt Frankfurt, 2007). More info on the application of the Passive House standard can be found in Section 3.4.2.

In addition to the Passive House resolution, the City of Frankfurt also developed some rules for the procurement of construction works, which go considerably beyond the guidelines published by the Commission (Linder, 2011). Frankfurt City's guidelines are called 'Guidelines for Economic Construction', as the final objective is the minimisation of annual total costs (capital, operational and environmental costs) over the entire duration of the building life cycle (i.e. planning, construction, operation, deconstruction and disposal) based on life cycle analysis and a minimum quality standard. This concept represents a comprehensive approach, reflecting the municipality's responsibility for the construction, use and disposal costs associated with public building stock. Cost minimisation over the long term is achieved, which can be considered as the main driver for the application of best environmental management practice in this case. One of the main examples for this kind of procurement is the Riedberg School, explained in detail under 'Operational Data' in Section 3.4.2. The city detected that half of the energy consumption of its buildings arose in public schools, so the early projects addressed the efficiency of school construction.

Frankfurt's 'Guidelines for Economic Construction' provide guidelines for better construction performance and are mandatory for every new public construction. For instance, for materials, the rules are the following:

- The products and materials used must be low in pollutants and solvents, be odourless, and not cause allergic reactions. Buildings must at least comply with the category of 'low pollution' as defined in Appendix C of DIN EN 15251.
- The following construction materials must not be used:
    - Components and by-products made of tropical, subtropical, or boreal timber without FSC certification (Forest Stewardship Council, www.fsc-deutschland.de, MB 2561 of December 8, 1989)
    - The following components made of polyvinyl chloride (PVC): flooring, wallpaper, windows, door profiles, cables, and tubing (MB 525 of February 16, 1990).
- Synthetic mineral wool must be completely sealed off from indoor air and must comply with the criteria for biosolubility (RAL GZ 388).
- All design steps must be taken to protect wood. Chemicals should be kept to a minimum in protecting the wood. Indoors, chemicals should not be used to protect wood.
- Construction materials should contain as little formaldehyde as possible. Wood products and composite boards must fulfil the requirements for the Blauer Engel (RAL UZ 38 or RAL UZ 76).
- Solvents should not be used or at least kept to a minimum in substances used to treat surfaces, such as paint and adhesives (powder coating, firing, etc.). If substances containing a small amount of solvent have to be used, they should have an environmental label for 'low pollution' (such as RAL UZ 102, RAL UZ 12a, RAL UZ 113, www.blauer-engel.de – also see 3.2 Ventilation).
- Bitumen coatings and adhesives with GIS code BBP 40-70 cannot be used (www.gisbau.de).
- Epoxide resin products with GIS code RE 4-9 cannot be used.
- Polyurethane resin products with GIS code 20-80 cannot be used except for performance classes B and C (ZDB memo on composite sealants).
- DD varnishes with GIS code DD1 and DD2 cannot be used.

In addition to the procurement of construction services, municipalities can also drive environmental improvement through the application of environmental labels or schemes for neighbourhoods, as is the case for BREEAM, DGNB and LEED. Nevertheless, a best environmental management practice in this regard is to require the active involvement of the public administration in the procurement of construction services, possibly using the requirements and benchmarking criteria of these schemes.

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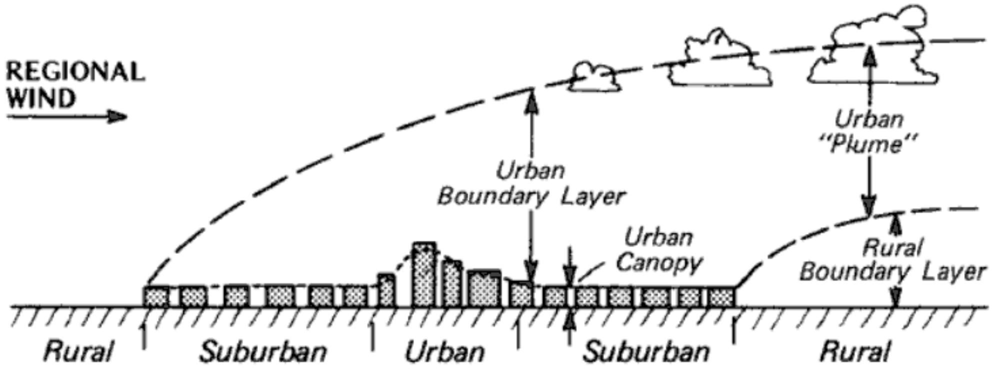
2.2.4 Reducing the Urban Heat Island effect

Description of the Urban Heat Island

Urbanisation may have some benefits. Transportation requirements are minimised and energy use per capita is reduced. But it negatively impacts the environment mainly by generating concentrated pollution and modifying the physical and chemical properties of the atmosphere and the covering of the soil surface, creating nuisance and discomfort for people. Urban heat island (UHI) is taken as a cumulative effect of all these impacts. It is considered as a specific issue directly related to the built environment in cities. Construction activity in the urban environment has a direct influence on the UHI effect. The definition of UHI is the rise in temperature in man-made areas, which can be from 1 to 3 °C during the day and up to 12 °C during the night. There are two types of UHI (EPA, 2009):

- Surface UHI, produced because of the heat absorption of materials in the built environment, where the temperature of the surface can be higher than air temperature because of radiation. This effect is very important during summer days.
- Atmospheric UHI: produced because of warmer air in urban areas compared to cooler air in the surroundings. Two layers of atmospheric UHI are distinguished by Oke, 1976. The urban canopy layer is where the local processes of urban activities take place - *where people live*. The climate is dominated by the nature of the surroundings, such as the albedo, emissivity, thermal properties, and building orientation. The other layer is the urban boundary layer, where climate may be affected by the presence of an urban area (Ng et al., 2012) – *from the tops of trees and roofs up to the point where the urban landscape does not affect temperature*. The most common typology is canopy layer urban heat islands and is more important after sunset. Figure 2.9 shows the schematic representation of the two layers of the urban climate.



Source: Oke, 1987

Figure 2.9: Urban atmosphere two layer scheme

Usually, natural surfaces are composed of vegetation and moisture-trapping soils. A significant part of the heat is used for the evapotranspiration process to release water vapour. This contributes to cool the air in the surroundings. Urban areas are built environments(4) where a high proportion of water resistant materials, usually non-reflective, substitute the natural cover. This built environment tends to absorb a large proportion of the radiation, which is released as heat. According to EPA, 2009, natural surfaces are able to reduce the run-off of surface water by up to 10 % through evapotranspiration (40 % of total water) and by 50 % through infiltration. The water balance in built environment is drastically different: up to 55 % of water run-off.

Main factors causing UHI are:

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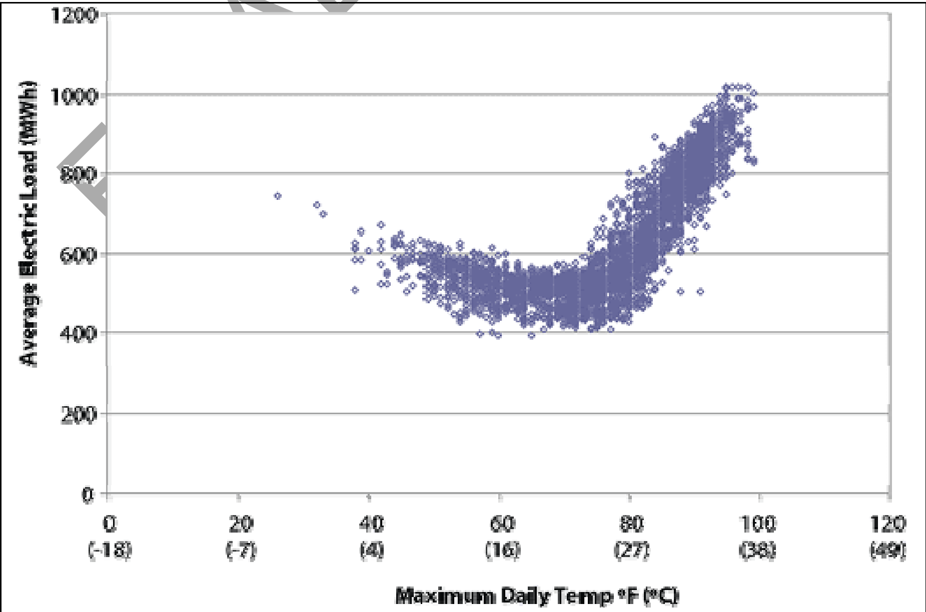
(4) According to the definition of McClure and Bartuska, 2007, the built environment is everything humanly made, arranged or maintained to fulfil human purposes (needs, wants and values) to mediate the overall environment with results that affect the environmental context.

- reduced vegetation in urban regions, which reduces cooling by evapotranspiration and shading
- properties of urban materials: they absorb solar energy, heating the surface and the air above
- urban geometry: the height and spacing of buildings inside a city affect the amount of radiation received and released as heat. The position of buildings can produce urban canyons that reduce the sky view factor and impede the escape of the reflected radiation
- anthropogenic heat emissions: heat loss from buildings, hot air and gases from vehicles, heat released in condensation of refrigerants and any source of waste heat
- weather: cities with clearer skies are more likely to create an urban heat island effect
- geographic location: large water bodies and mountains influence wind patterns in the surroundings and, therefore, the formation of urban heat islands

UHI has a significant negative impact, from the influence on surroundings of a small number of buildings to the huge impact caused by big cities (Ng et al., 2012). The main impacts produced by the UHI are:

- increased energy consumption: while urban environments can lead to better energy distribution and minimisation of energy consumption for transport, the increase of energy demand for space cooling during summer can be high (Figure 2.10).
- in addition to air emissions associated with increased electricity consumption, high air temperatures can increase the rate of ground level ozone formation – in particular the reaction rate of ozone formation from NO_x and VOCs is increased.
- human health and comfort is affected, through contribution to some respiratory difficulties, heat stroke and other heat related diseases.
- water quality may be degraded by thermal pollution. Some studies have shown that run-off water has a temperature 11 to 17 °C warmer than in nearby rural areas (EPA, 2009). This water temperature increase affects all aspects of aquatic life.



Source: Sailor, 2002 with data courtesy of Entergy Corporation

Figure 2.10: Electrical load of buildings in New Orleans vs. maximum daily temperature

Urban heat island mitigation techniques and strategies

The main option to reduce the urban heat island is to increase the amount of trees in cities. This may have a benefit for the microclimate of cities by:

- Increasing shading and avoiding solar gains
- Reducing temperatures of building façades and surfaces
- Reducing dry-bulb temperatures by evapotranspiration (i.e. water evaporation from plants reduces the temperature of a volume of air in the surroundings)
- Increasing latent cooling due to the addition of moisture to air through evapotranspiration

Other passive techniques can be useful to reduce the amount of radiation absorbed by cities. This is the case of cool, green and brown roofs (see Section 3.4.1.3) and the use of reflective materials (cool pavements and paints). Other techniques relate to 'active' technical options: increasing building energy efficiency for heating and cooling, reducing heat loss, waste heat recovery from exhaust air and from refrigeration processes, transport impact mitigation activities, etc.

A comprehensive compendium of mitigation measures can be found in Table 2.6 and Table 2.7, as proposed by Yamamoto, 2006.

Table 2.6: Mitigation measures to reduce anthropogenic heat releases

Mitigation Measure	**Scale**	**Period**	**Administered by**
Reduction in anthropogenic heat releases			
Improving the efficiency of energy-using products	Individuals	Short term	Individuals, companies, local governments
Improving the efficiency of air conditioning systems	Buildings	Short term	Individuals, companies, local governments
Improving the heat insulation and the envelope of buildings	Buildings	Medium term	Individuals, companies, local governments
Greening of buildings and adoption of water retentive materials	Buildings	Short term	Individuals, companies, local governments
Improving the reflectivity of walls and roofing materials	Buildings	Short term	Individuals, companies, local governments
Traffic control measures	Cities	Medium term	Individuals, companies, local governments
Introducing district heating and cooling	Districts	Medium term	Local government, companies
Using waste heat and untapped energy (e.g. groundwater, geothermal, etc.)	Various	Medium/long term	Local government, companies
Using renewable energy	Buildings and cities	Short term	Individuals, companies, ocal governments

Table 2.7: Mitigation measures of the urban heat island

Mitigation Measure	**Scale**	**Period**	**Administered by**
Improvement of artificial surface covers			
Improving the reflectivity and water-retentivity of paving materials	Cities	Short term	Local governments
Greening of cities	Cities / Individuals	Medium term	Individuals, companies, local governments
Greening of buildings and adoption of water-retentive materials	Buildings	Short term	Individuals, companies, local governments
Open Water Spaces	Cities	Medium term	Local governments
Improvement of urban structures			
Optimising buildings' orientations	Cities	Medium term	Local governments
Improving land planning (more green spaces)	Cities	Long term	Local governments
Creating eco-energy cities (integration of energy uses)	Cities	Long term	Local governments
Recycling-based society	Cities	Long term	Local governments

Many of the techniques shown in the tables above are developed in other parts of the document, as they correspond to technologies being proposed at inception, the design phase or at other building life cycle phases. When a single local government, project developer or a designer wants to reduce or mitigate the urban heat island effect, correct strategies should be implemented, mainly driven by public administrations. So, a sole optimised building is not enough and joint strategies should be implemented. For this, the public administration role is highly relevant. According to EPA, 2009, several strategies to mitigate the UHI are available for local governments (Table 2.8).

Table 2.8: Heat Island Reduction Strategies

Voluntary Efforts	Demonstration Projects Incentives Urban Forestry Programmes Weatherisation (building adaptation) Outreach and Education Programmes Awards
Policy Efforts	Procurement Resolutions Tree and Landscape Ordinances Comprehensive Plans and Design Guidelines Zoning Codes Green Building Programmes and Standards Building codes Air Quality Requirements

All the measures of Table 2.8 are identified by the US EPA as they are being applied in the United States to mitigate the Urban Heat Island effect of their cities. Voluntary efforts are those strategies implemented by local governments, industries, residents or designers without any regulatory framework. Demonstration projects are those designed to analyse and show the performance of several techniques, promoting new technologies and encouraging relevant local business. Lessons learned from this type of project can be used to set incentives (cheap loans, tax reductions, grants, etc.) for local communities. Urban forestry programmes are very important for large cities, as urban greening is the main technique to cool cities. In Table 2.8, the weatherisation term is used to refer to any technique focused on increasing the energy efficiency of residential buildings of low-income families at no cost to those families. Educational programmes and awards are very important to help e.g. on the proper planting and maintenance of trees and to highlight innovation of public and private sectors. Policy efforts include mitigation strategies in policies and regulations, such as voluntary procurement guidelines, building codes, regulations, etc.

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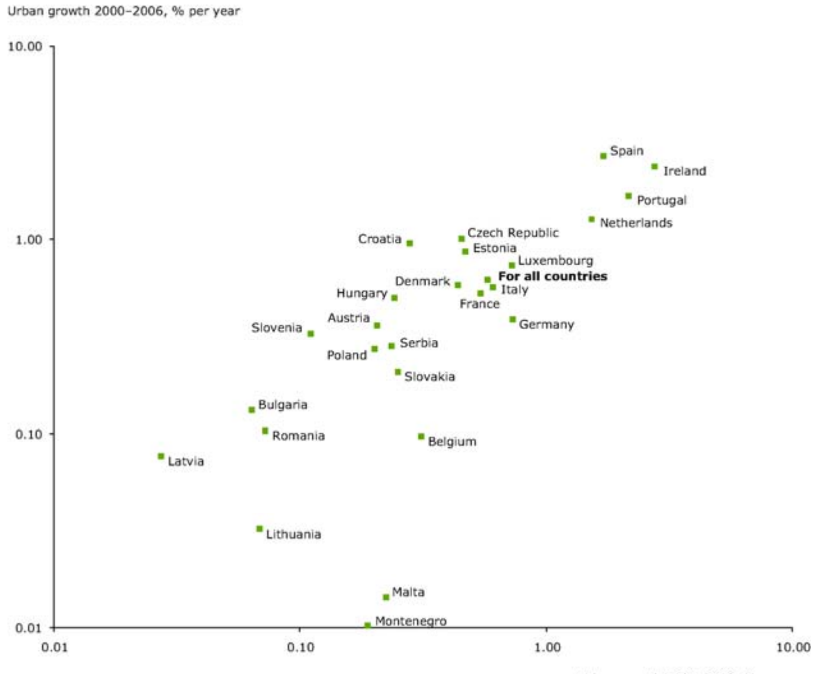
2.3 Site selection, land consumption and urban sprawl avoidance

Land take usually refers to the conversion of open space or farmland to residential, commercial, office, traffic or other developed land uses. Whereas arable land can be easily converted to more valuable ecosystems, there are only a few examples for renaturation of built land. In general, urban land take is increasing due to the expansion of economic activities rather than residential areas. During the period 2000 to 2006, the growth rate per year of urban land take (for infrastructure and construction sites) was more than twice the growth rate of the urban population, and had accelerated compared to 1990 – 2000 (Figure 2.11).



Source: EEA, 2010

Figure 2.11: Growth of land take for urban residential and other economic purposes in selected European countries

Land take for urban development has a number of environmental impacts (EEA, 2010):

- soil sealing, so soil resources are lost due to the covering of land for housing, roads or other construction work. This impact is mostly irreversible.
- loss of space for habitats and ecosystems, losing their water regulatory potential, which is harmful if soil is highly sealed.
- generally, lower population densities require more energy for transport and heating or cooling. On the other hand, consequences for quality of life are higher in densely populated urban environments, where noise, air pollution and the lack of ecosystem services produce a higher effect.

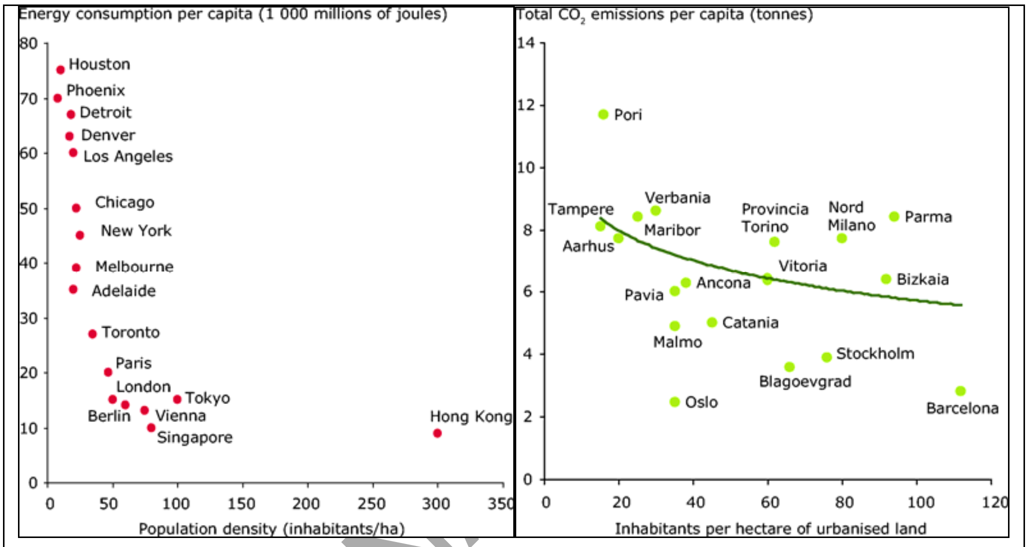
In general, land use for construction and buildings leads to a degradation of soil, in particular if sealed, and compromises its natural functions which include (Thematic Strategy for Soil Protection SEC(2006)620):

- provision of food, biomass and raw materials
- platform for human activities and landscape
- archive of heritage

- habitat and gene pool
- storage, filtering and transformation of substances, including water, nutrients and carbon.

Another aspect of land consumption is habitat fragmentation, for example by roads. This leads to isolated gene pools, with the risk of species extinction and effects on micro-climate via heat-island effect when soils are sealed. Soil sealing also affects the water cycle via increased run-off and decreased infiltration and evapotransparation by plants. Overall, land consumption has therefore considerable negative environmental impacts related to e.g. non-renewable resource consumption, groundwater formation and quality, and biodiversity.

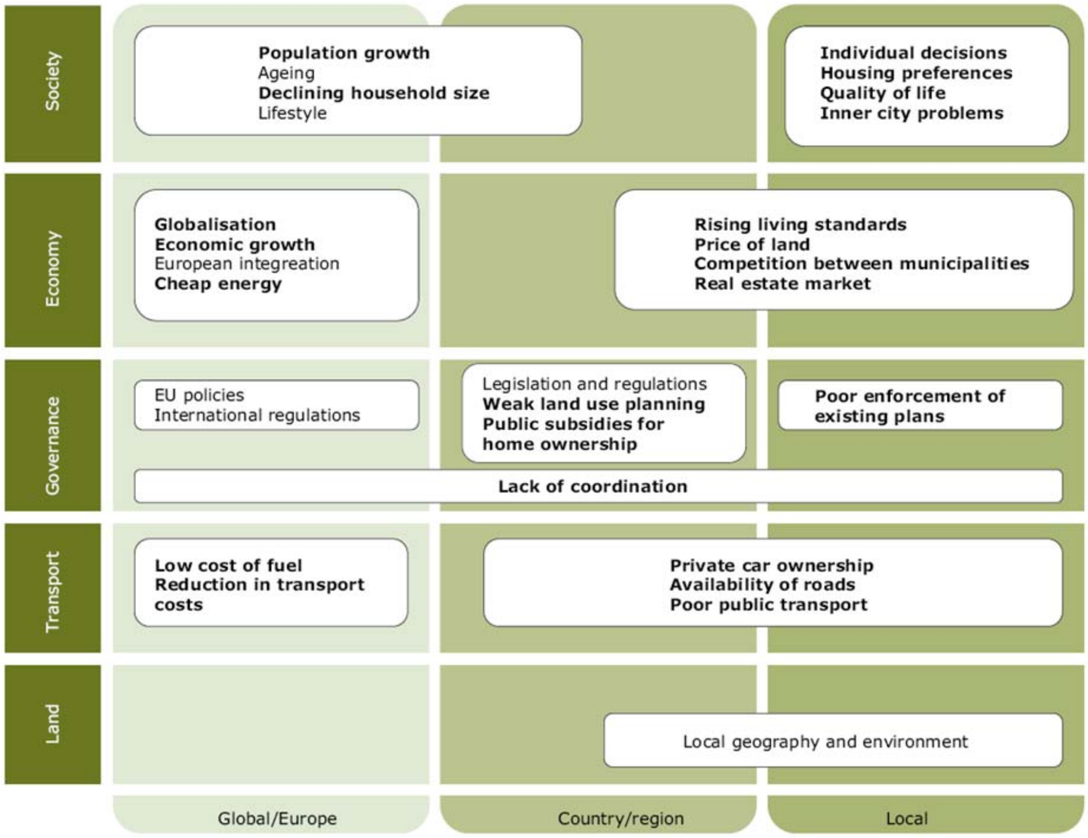
Land take is also often associated with urban sprawl, i.e. the spreading of cities towards their outskirts, with low population density, high car-dependency and high segregation of land uses. Urban sprawl contributes to increased the traffic volume and the related emissions, as well as resource consumption. Therefore, cities with a high population density are more energy-efficient than sprawled cities, which are responsible for more CO_2 emissions (see Figure 2.12), (Newman and Kenworthy, 1999)



Source: EEA, 2006

Figure 2.12: Population density and CO_2 emissions, selected cities

A number of urban land take drivers were identified by EEA, 2006 and shown in Figure 2.13.



Source: EEA, 2010

Figure 2.13: Drivers of urban sprawl in Europe

Sustainable land use management aims to reduce land consumption and protect the soil and its functions. The main strategy behind sustainable land use management is to encourage a higher density of urban areas and to reduce negative impacts as far as possible, e.g. by choosing areas for developing zones with low soil fertility and low ecologic value. This strategy enables a reduction of land consumption and does not require investment in building additional infrastructures, e.g. streets, sewerage system, for new residential projects. This approach involves making use of fallow land and spaces between buildings, reconstructing or converting vacant buildings or structures, in order to obtain denser urban areas, e.g.:

- revitalisation of brownfields(5) (this may also lead to the remediation of polluted abandoned areas and reduce land consumption; brownfield areas are often in central locations making them potentially valuable)
- closing of spaces between buildings
- refurbishment of obsolete buildings, e.g. old farm houses, garages etc.
- dividing large building plots to allow the construction of new buildings on the plot
- adding floors to existing buildings
- improving the quality of land use, e.g. converting unused street areas into building plots

These potentials can be activated by a number of measures, e.g.:

- identification of spaces for densification in urban areas, e.g. using aerial photographs(6)
- discussion with building owners about their willingness to sell parts of their building plot
- using internet tools to foster a market for spaces between buildings etc.

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(5) Definition made by ISO 21929-1:2011

(6) http://www.raum-plus.info/

- sensitisation of both building owners and parties interested in constructing a building about advantages of densification.

For new building zones the following should be considered

- reducing the size of new building plots as far as reasonable
- planning aiming to minimise areas for streets

Recommendations regarding density and types of habitations for different levels of sustainable urban settlement (see Figure 2.14) are:

- A density between 50 and 80 habitations/ha enables mixed functions and the implementation of district equipment, the development of collective parking strategies and the implementation of collective energy management forms (e.g. district heating).
- A minimal density of 100 habitations/ha in sustainable cities allows the implementation of public transport system, public parking infrastructure, public equipment and a functional mixture.

Figure 2.14: Left: Eco housing estate [25-40 habitations/ha], Center: Eco-district [50-80 habitations/ha], Right: Sustainable city [min. 100 habitations/ha]

In general, densification may produce a number of environmental benefits:

- Densification reduces the non-renewable land and soil consumption associated with urban sprawl. It also reduces (but does not eliminate) the consumption of raw materials such as gravel and those needed for example for the production of concrete or asphalt. Reducing urban sprawl allows soil to perform its water and carbon absorption functions, and helps reduce degradation of water quality associated with storm water run-off from sealed surfaces. Reduced urban sprawl also helps preserve groundwater recharge, hence reducing water scarcity.
- The changes in lifestyle associated with urban sprawl, which see increases in single-person households, also increase the consumption of resources because multiple-person households consume fewer resources such as water, energy and consumables, per person. Increased energy consumption is also associated with low population density areas whose sprawl reduces the energy efficiency of distribution systems.
- Densification typically allows for increases in public transport usage which counteract the prevalence of cars in sprawling urban areas, and create reductions in fossil fuel consumption and associated greenhouse gas emissions. Fossil fuel use in sprawling areas is not only due to private car transportation but also to fuel consumption linked to the conveyance of goods and waste. Finally, compact cities where people can more easily move around on foot, by bike or using public transport will be more resilient to fuel cost increases.
- Reducing urban sprawl allows for the preservation of natural areas, intrinsically important but also vital because of the importance of ecosystem services. Negative

impacts of sprawl are particularly evident in ecologically-sensitive areas such as coastal zones, for example in the Mediterranean, which is considered to be a biodiversity hotspot.

- Limiting urban sprawl into agricultural land helps not only preserve the soil and biodiversity values of these, but also avoids the transfer of agricultural activities to less productive or more elevated areas – which, respectively, require more fertilisers and irrigation and lead to increased soil erosion.

Stockholm is an example of city development avoiding urban sprawl. Since the 1980s, Stockholm has managed its growth emphasising the development of areas within the city's boundaries rather than allowing growth, at the city's fringe. This new approach has been stimulated by important population growth combined with the realisation that Stockholm's green and blue spaces needed to be actively preserved from sprawl. This densification has been called 'building the city inwards' or 'city healing', where the former has been the paradigm for the City Plan of Stockholm since 1999. Many policies, such as Stockholm's City Plan proposed to build on semi-central industrial land and save green space due to environmental concerns and 'Not-In-My-Backyard' effects (Ståhle & Marcus, 2009).

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3 BUILDING DESIGN

3.1 Scope

This chapter provides information about design considerations for buildings that may constitute best environmental management practice, from the inception phase to redesign activities, during new buildings construction or building renovation[7].

The document aims for an integrated view of construction activity, with a multi-actor and multi-stage approach, so cross-links between different chapters of the document will be established. For the building design chapter, the scope is focused on the main environmental impacts where design has a strong influence: energy, water and waste. Indoor air quality is covered related to the environmental aspects of material selection processes. Health-related issues, e.g. noise and vibrations are not covered. Designing out waste, as a design practice, has a direct influence on the life cycle environmental performance, so it is covered in this chapter. Users' behaviour is also excluded, although its influence is mentioned where appropriate. This factor seems to be more suitable for a sectoral approach, i.e. by developing best practices guidance for other sectors: this is the case of building techniques gathered in the reference document on best environmental management practice of the retail trade sector (EC, 2011).

3.2 Introduction

The Energy Performance of Buildings Directive (EPBD) defines a building as an object, as it ‘means a roofed construction having walls, for which energy is used to condition the indoor climate’. European standard EN 15643-1:2010 defines a building as ‘construction works that has the provision of shelter for its occupants or contents as one of its main purposes and is usually enclosed and designed to stand permanently in one place’. So, a building is regarded, usually, as an unmoveable object, which provides shelter or a conditioned indoor environment to occupants. Classical architects' concerns are economy, utility, durability, and comfort (EPA, 2009). New and enhanced definitions may be needed to define the interaction of the building and how designers should take it into account. The green building approach is a good example of this. The definition of green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle, from siting to design, construction, operation, maintenance, renovation and deconstruction (EPA, 2009). So, it is not only the building, but where the materials come from, how these are produced and transported, how it is built, how it is used and how it is retrofitted, refurbished or demolished (Figure 3.1)

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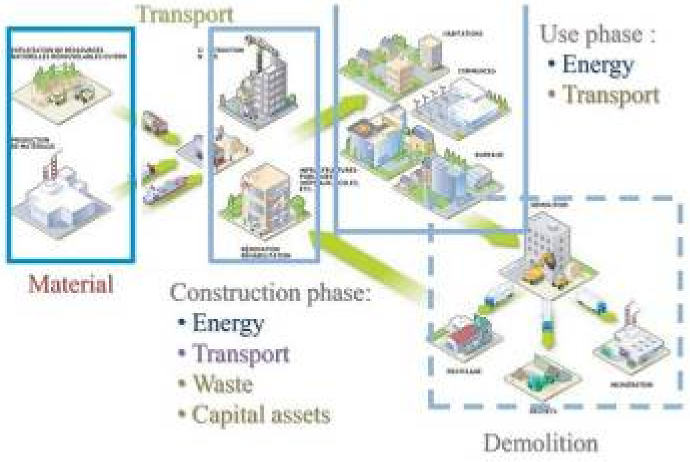
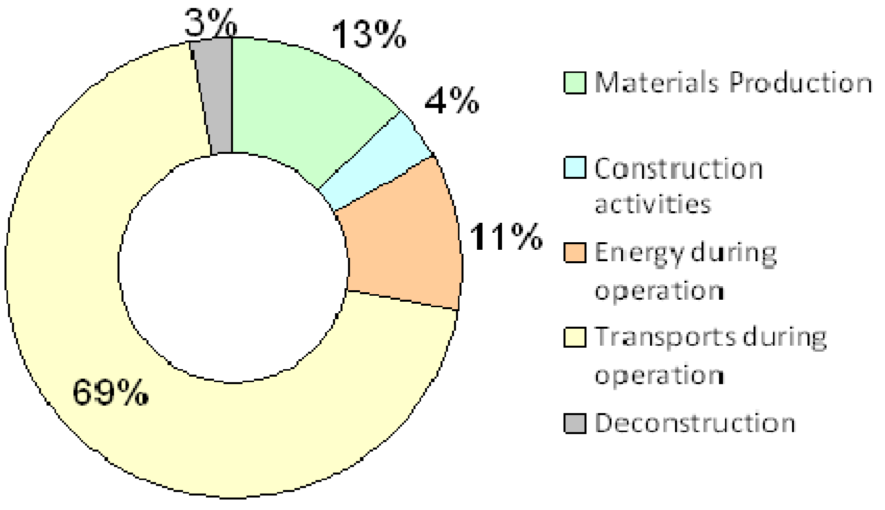
[7] As agreed by the Technical Working Group, this sectoral reference document has an actor oriented approach and, as a consequence, the division of the document is made in the following chapters: land planning, design, construction products, construction and refurbishment, building operation and maintenance and building end-of-life. Chapters are drafted to be stand-alone documents. So, strong linkages and overlapping may provoke the repetition of the same information across the whole document.



Source: Utopies, 2005 as adapted by Saheb, 2011.

Figure 3.1: Disclosure of the carbon footprint of buildings in a flowchart perspective

Desai, 2011, stated that what is usually defined as the impact of a building or the environmental footprint of buildings is not accurate. The real environmental impact is produced by the people living, working or using buildings. Many single measures can be applied to lifestyle, which are not costly and have huge reduction potential of environmental impact. For instance, the cost of mitigating one tonne of CO_2 by retrofitting one house to Passive House concept is 430 times higher than the reduction potential of a green transport programme (e.g. car-sharing among neighborhoods). The 'One Planet Communities' programme establishes an ambitious target by applying an integrative approach to lifestyles, including buildings among other aspects. For example, an outstanding design of an office building (from the energy and carbon footprint point of view) performs in line with the chart of Figure 3.2 during the use phase. Transport needs of users are huge because no other access than private transport is possible and the average travel distance is long, due to the lack of planning or the inappropriate site selection, thus producing an undesirable high environmental impact. So, best performing buildings should be designed with the broadest achievable integrated approach[8].



Source: Saheb, 2011

Figure 3.2: Carbon footprint of a building during 40 years (example)

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[8] Integrated approach for building design means any design activity oriented to achieve the best performance, taking into account all the elements with a significant influence in the life cycle of the building. For instance, an energy integrated approach would minimise the energy demand of the building by searching for the optimal design solution, which performs an appropriate combination of all relevant elements: envelope, ventilation, heating, air conditioning, cooling, internal processes, etc.

Although behavioural aspects are essential to understand the performance of a building, they are not in the scope of the present document. The main objective of this chapter on building design is to propose best practices for building design but taking into accout the entire life cycle of the building. The long service life of buildings makes any decision about its design to affect their environmental performance also in the very long term. A main barrier for long term decisions is that the building and construction sector has had a traditional behaviour, fragmented in too many professional groups and this business structure does not facilitate the dissemination of innovation (PB, 2010). In this regard, regulartors are starting to take the initiative and prioritise best building practices, taking into account the whole life cycle, in order to reduce the environmental footprint of the sector. Important economic barriers are seen in this phase, since the payback period, especially for retrofitting measures, is too long and requires subsidies to be economically accepted. Also, split views and interests are a main barrier of the sector. The clearest example of this is the owner/tenant split (UNEP 2009).

The way design practices and environmental performance are interconnected is a complex issue. Thunshelle et al., 2007, describe the intricate relationship between building design and its energy performance, where several views and perspectives have to be taken into account: the architect wants to implement their vision, which usually corresponds to functionality and aesthetic quality; the user requires high comfort levels, consultants want to implement new technology applications, the developer wants to minimise or optimise the investment, and the constructor wants to build easily and economically. The extension of this concept to all the environmental aspects is compatible: designers decide not only about the energy performance, but also about the quality, typology and amount of materials to be used. Location and use will have a strong influence in resources efficiency, not only regarding the building but also to the occupant's environmental behaviour. This is why many authors regard buildings not as an object but as a service to a user.

This document takes into account the whole life cycle and the value chain of buildings, as all of them have a relevant impact. For building design, best practices and approaches for better design are considered. Lifestyle approaches are outside of the scope of this document.

There are a large number of actors and stages in the construction activity. For them, many best practices documents are currently available, especially for the construction stage. This huge amount of information is contributing to create some awareness in the sector, but no commitment is usually required from construction companies, designers, developers, clients or users to implement them. Best practice guidance documents are frequently produced by public administrations, but the public administration itself does not take them into account for the procurement of their own buildings.

Many of them have been used for this document, although the scope of these documents differs, from the scope of this one, in that:

- Commonly, the focus of these documents is made only on one environmental aspect. For design practices, they usually refer to energy efficiency of buildings.
- The design concept, inception, and project briefing is usually not considered, and the customer is usually not addressed on these guidance documents. From the understanding of this document, best environmental management practice on project briefing, land planning and the role of public administration should always be taken into account, covering also the best construction process, the best use phase and the best deconstruction, the *need* for the building, the *location* of the building and the *role* of the client. So, best environmental management practices have to be assessed from the multi-actor and multi-stage approach.
- Design guidelines focus on the environmental aspects of the use phase and usually consider only the more important aspects of life cycle assessments. This approach usually neglects construction phases, which may produce very important and local environmental impacts.

- Construction guidelines usually refer only to the construction process, with very few references to the design phase. This is a single-actor approach, where the construction company is regarded as a service provider and the design is usually never questioned.
- Construction guidelines are frequently called best practice documents, but most of the times, they only cover *correct* practices, i.e., they provide guidance to fulfil legislation and, sometimes, they only provide guidance to fulfil the requirements of a certification scheme without looking at the real performance on site.

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3.3 Background information

3.3.1 Definitions and conceptual approaches

The technical background and the description of several best environmental management practices relies on several concepts and approaches for buildings design. Most of them are explained in the description corresponding to the best practice. Nevertheless, some of the most important overarching concepts are defined in following subsections. Coverage is not fully comprehensive and is focused on areas requested by the technical working group for the development of this document.

3.3.1.1 Integrative and process approach

Practices to be regarded as 'best' are to be decided based on an integrative approach. This concept means that best environmental performance is assessed for the building as a whole. Designing in an integrative manner means that all building elements are optimised to achieve overall best performance. For example, this is quite relevant for the design of the building envelope and for the heating ventilation and air conditioning (HVAC) system: both elements cannot be designed separately, as the performance of the insulated envelope has a significant effect on the size and demand for the HVAC system. In the integrated design of several building elements, prioritisation may also be regarded as a best practice, e.g. energy demand reduction may be a priority for building design.

On the other hand, best practices are defined for processes, but, usually, the benchmark of excellence may be established on overarching indicators. For instance, best practices for ventilation would help the building to reach a benchmark on the total primary energy demand. In other chapters, as in construction and refurbishment, the complexity of processes make itimpossible to define a single best practice for every process and, therefore, 'activity' is preferred as the term to define multiple processes. For example, waste management is an activity since many single processes and procedures are gathered under this activity: site planning, resources allocation, segregation, collection, reverse logistics, reuse, etc.

Often, the text refers to different building typologies using the term sub-sector approach. This is not a new term, as it is commonly used under the Sustainable Building and Climate Change Initiative of the United Nations. It is employed frequently to different building users and building typologies, with varying designs. This would imply that benchmarks of excellence for different building users or 'sub-sectors' may be different. This means that hotels, residential, retailers building will have different benchmarks of excellence.

Passive design is one of the most important integrative approaches used for the development of the document. Other example of the overarching integrative concept is designing out waste, which is linked with other parts of the text.

3.3.1.2 Use of the life cycle approach for the environmental performance assessment of buildings

Design is considered to be the main element influencing the environmental performance of every further stage (construction, use and deconstruction). Nevertheless, the design is usually conditioned by a customer or by a project developer, defining the project brief, or a private or public company with a restricted budget. Best environmental options should be considered even from project inception. Extra investment for a better environmental performance is much higher if environmental requirements are established in further stages. Thus, this document, which comprises the best environmental management practice of the construction sector, should cover design options to produce construction works with the best environmental performance. For that purpose, some background information on the life cycle approach in design is given on ecodesign, environmental rating schemes and environmental standards.

There are, usually, two approaches to the life cycle of a building:

- environmentally: from raw materials acquisition to building decommissioning and waste treatment and recycling
- social and, especially, economical approach: from project inception to the decommissioning or de-construction (even to the legacy that is left behind once the building has been demolished or disposed of).

When a building is ecodesigned, the environmental impact of the whole life cycle should be considered. Ten generic rules are commonly used for ecodesign practices, which need to be implemented and specifically defined for a certain application:

1. The use of toxic substances should be avoided. When toxic substances are necessary, close loops should be arranged.

2. Consumption of energy and resources has to be minimised for production/construction and transport phases.

3. Product weight should be minimised by using high quality materials and structural features, whenever possible and negative effects on flexibility, strength and other functional qualities are foreseen.

4. The product use phase should minimise the demand of energy and resources.

5. Repairing and upgrading of products/elements and, especially, of system-dependent products/elements, such as the technical building equipment, has to be supported.

6. The promotion of long lifetimes of products is important, especially for products with major environmental influences outside of the use phase.

7. Construction products and elements can be protected from dirt, corrosion and wear by investing in better materials, treatments for surfaces and structural arrangements. At the same time the maintenance of the product/element is reduced and its life might be extended.

8. Upgrading, repair and recycling should be prearranged through the use of modules, manuals and labelling.

9. Upgrading, repair and recycling should be promoted in avoiding alloys and using simple, recycled and not blended materials in a small amount.

10. Connection components should be used as little as possible. When they are necessary the durability of these connection components, such as screws, adhesives, welding, snap fits, geometric locking, need to meet the lifetime of the major product/element.

Several systems have been developed to measure, evaluate and certificate the performance of buildings regarding certain sustainability aspects, especially those referred to environmental aspects. Some of these systems can be applied in the design phase, as they provide guidelines for the design of different building types, and others are also applicable in the use phase and can promote transparency of the environmental performance of buildings, e.g. related to energy efficiency. Table 3.1 gives a sample of existing building rating systems applied in Europe. Other initiatives and projects focus on single environmental aspects. For instance, the open house project aims at establishing a common European basis, in the form of a technical platform and open assessment methodology, to make the planning and construction of sustainable buildings transparent and applicable (Open House, 2010). Similarly, the Sustainable Building Alliance (SBA) is doing so on an international level (SBA, 2010). The Energy Efficiency in European Social Housing (E3SoHo) project aims to inform inhabitants of European social housings about their energy consumption and opportunities to reduce this consumption by up to 25 % using information and communication technologies (ICT) (E3SOHO, 2010). Energy efficiency is also the focal point of the DENA efficient house quality mark, making energy-efficient houses recognisable in Germany (DENA, 2010).

Table 3.1: Building rating systems applied in Europe

System Name	Country of origin	Applied in
BREEAM	UK	Several European countries
BREEAM.nl	The Netherlands	The Netherlands
BNB	Germany	Germany (federal buildings)
DGNB	Germany	Germany, several European countries
HQE	France	France
LEED	US	Several European countries
Minergie	Switzerland	Switzerland, France

The rationale for these environmental rating schemes is that best solutions for buildings are never obtained on a component-by-component basis, but from the optimisation of the system as a whole, by an interdisciplinary project team assesses identified environmental impacts during the whole life cycle. Then, even from the inception of the building project, it is important environmentally important to establish ambitious targets regarding the environmental performance of the building, not only during its use phase, but also during construction and deconstruction. These schemes usually give an award or a label to best performing buildings, mainly assessing several performance characteristics during the whole life cycle. They are often focused on the energy performance during the use phase, but, in order to get the maximum qualification, other aspects, such as materials, water use, comfort, indoor air quality can be considered. When assessing the sustainability of a project, aspects such as the economic performance and social issues are also considered. According to Utopies, 2009, these labels also develop the definition of buildings not as objects but as integrated elements of the urban ‘ecosystem’, looking also at the interaction of buildings with their surroundings. Table 3.2 shows a summary of the main schemes addressing the environmental performance of buildings.

The European Commission is developing an Ecolabel for Office Buildings. At the moment of preparing this document, criteria are still being drafted. The purpose of this pilot project is to develop an EU Ecolabel that awards the best environmental performance buildings and green public procurement criteria to promote environmentally-friendlier public and private consumption. As for any other label, the EU Ecolabel for office buildings will allow consumers to identify environmentally friendly buildings easily and will allow manufacturers to show and communicate to their costumers that their products respect the environment.

Table 3.2: Comparative analysis of building labels (adapted from Utopies 2009)

Certification	**HQE**	**BREEAM**	**LEED**	**MINERGIE ECO**	**GREEN STAR**	**CASBEE**
Origin	France	UK	USA	Switzerland	Australia	Japan
Year	1993	1990	1999	1996	2003	2001
Building type included						
Office	Yes	Yes	Yes	Yes	Yes	Yes
Retail	Yes	Yes	Yes	No	No	Yes
Industry	Yes	Yes	No	No	No	No
Residential	Yes	Yes	Yes	Yes	No	Yes
Education	Yes	Yes	Yes	Yes	No	Yes
Hospitals	Yes	Yes	Yes	No	No	Yes
Others	Yes	Yes	No	No	No	No
Neighborhoods	Yes	No	Yes	No	No	No
Life cycle stages included						
Inception	Yes	Yes	Yes	Yes	Yes	Yes
Construction	Yes	Yes	Yes	Yes	Yes	Yes
Use	Yes	Yes	Yes	Yes	No	Yes
End-of-life	No	Yes	Yes	No	No	Yes
Categories included	14	15	34	1	50	80
Site	Yes	Yes	Yes	No	Yes	Yes
Indoor environment	Yes		Yes	No	Yes	Yes
Energy	Yes	Yes	Yes	Yes	Yes	Yes
Materials and resources	Yes	Yes	Yes	Yes	Yes	Yes
Water	Yes	Yes	Yes	No	Yes	Yes
Transport	No	Yes	No	No	Yes	No
Health	Yes	Yes	No	Yes	No	No
Comfort	Yes	No	No	Yes	Yes	No
Management	Yes	No	No	No	Yes	No
Quality	No	No	No	No	No	Yes
Aestetics	No	No	Yes	No	No	No
Functionality	No	No	No	No	No	Yes

The establishment of environmental criteria for buildings is not an easy task when comparing the performance of buildings and requires a consistent methodology. A new set of standards has been developed at the European level by the technical committee 350 of CEN (European Committee for standardisation) for the sustainability assessment of buildings and for the development of EPD, environmental product declarations, for building components. Early released texts are EN 15643-1, which defines the general framework, and EN 15643-2, which defines the framework for the assessment of the environmental performance. The standard 15643-1 states that this suite of standards does not set benchmarks or levels or performance, so the usability of this document would focus on the establishment of common methodologies. Neverthless, these standards do not give any valuation method for the environmental impact and lack a comprehensive approach to buildings, making these standards have a narrow applicability in the identification of best practices. For instance, the comparability of the performance of buildings, in a quantitative way, is restricted to functional equivalencies including:

- building type
- pattern of use
- relevant technical and functional requirements (regulations, client's demands, etc)
- required service life.

So, it may be considered that the comparison between existing buildings is quite restricted, although this standard may be very relevant in the comparison of design options.

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3.3.1.3 Low, zero, plus and life cycle zero energy buildings

The development of high performing buildings with very low energy demand has become widely accepted in the construction of new buildings. This was started with elements improvement, but this led to very expensive concepts where every element was improved in isolation (Feist et al., 2005). Some voluntary standards, e.g. the Passive House, seek for the lowest energy consumption within a cost-efficient approach. Then, the energy demand of this type of building could be easily balanced with renewable energy, following the standard definition of zero energy buildings. A zero energy building (ZEB) is a building with a high level of energy efficiency but with an energy demand equal to or less than the energy production from renewable energy sources on site. A positive energy building (PEB) is, therefore, one with higher renewable energy generation than demand. The performance of ZEB or PEB is calculated on an annual basis, so the building may require net energy in winter periods and produce net energy in summer periods. So, the overall annual balance is equal or less to zero. Therefore, the mainstream terminology often includes the term 'net energy'.

The ZEB/PEB approach is considered a natural progression from demanding standards, e.g. a Passive House design plus renewable energy production. A ZEB/PEB can be designed using mature technology. Long payback periods are foreseen, although the life cycle costs would be always the lowest for optimal ZEB/PEB, so this concept is often used as lighthouse or pilot projects where no economic restriction is foreseen. According to Kolokotsa et al., 2010, there are a large number of techniques to integrate into a ZEB/PEB:

- improvement of the envelope
- innovative shading devices (automated/seasonal devices)
- improved air tightness and ventilation
- high efficiency heating and cooling devices
- use of renewable energy sources
- implementation of efficient energy management, monitoring and control systems.

Autonomous buildings, producing the energy they consume and storing it for further use, may be considered best practice in very specific situations, but, from the life cycle perspective, the use of net energy concept and feeding excess production to the grid seems to be more appropriate.

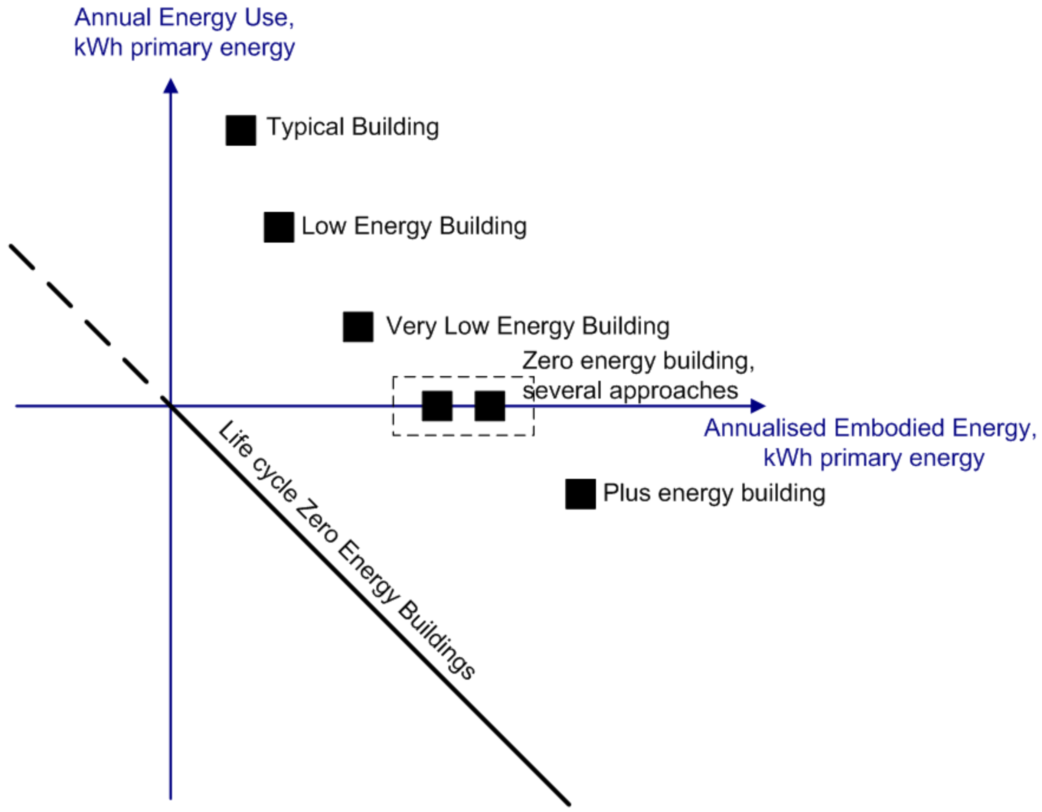
Another useful term is the Life Cycle Zero Energy Building, LC-ZEB, which can be defined as that building 'where the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building lifetime' (Hernández and Penny, 2010). So, a LC-ZEB would account for all embodied energy input of materials used in the construction of highly efficient buildings. Therefore, optimal energy consumption optimisation should take into account the increase of embodied energy when assessing the overall performance of final design. Although this definition is quite ambitious, it is quite relevant for the definition of the annual life cycle energy, as the sum of annual energy use and annualised embodied energy:

$$\text{Annualised life cycle energy, ALCE} = \text{Anual energy use (AEU)} + \text{Annualised embodied energy (AEE)}$$

So, the introduction of an improvement in a design or in a building may be assessed by its impact on the ALCE parameter. For instance, Hernández and Penny, 2010, proposed the use of the net energy ratio, NER, defined as:

$$NER = \frac{AEU_1 - AEU_2}{AEE_2 - AEE_1}$$

So, it is assumed that a change from design 1 to design 2 produces a reduction in the AEU value and is likely to increase AEE. The ratio between the variation of both parameters may be higher than 1, so net energy is saved in the overall life cycle (ALCE decreases); or lower than one, which would mean an increase of the overall life cycle energy of the building. Figure 3.3 shows how AEU and AEE may vary for several building typologies.



Source: Hernández and Kenny, 2010.

Figure 3.3: **Annual energy use and annualised embodied energy examples for several types of best performing buildings**

This life cycle approach for the building design of buildings is considered in many of the environmental ratings schemes and ecolabels for buildings. Nevertheless, several disadvantages should be overcome for the application of this concept:

- lack of data in existing databases, the lack of accuracy and the varying burdens for some LCA studies.
- in order to evaluate the variation of the NER for a building system, there is a high dependence on where the initial or starting situation is placed. In fact, this factor seems quite relevant for retrofitting but not easy to define for new designs.

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3.3.1.4 Designing out waste

Designing out waste is the design process that considers waste prevention and minimisation as key elements of the design optimisation process. There are five key principles that design teams may use to avoid or reduce wastes (WRAP and RIBA, 2012):

- Design for reuse and recovery: this involves recovering materials and reusing excavated material or wastes generated. This principle is mainly focused on civil engineering projects or building projects with a high amount of excavation material.
- Design for off-site construction: for instance, to use large precast concrete components to reduce construction time and wastes. This decision can only be made during the design stage.
- Design for materials optimisation: this involves using fewer materials without changing design principles or quality. It considers minimisation of excavation, standardisation and dimensional coordination.
- Design for waste efficient procurement: this involves considering all wastes generated and how they may be reduced by modifying conventional design
- Design for deconstruction (see 3.3.1.5): this is considered less relevant for costs, but it has a strong influence on the environmental performance of building's life cycle.

References

WRAP, Waste Resources Action Programme, and RIBA, UK Royal Institute of British Architects, 2012. Designing out waste: a design team guide for buildings. Available at www.wrap.org.uk, last access on 20/2/2012

3.3.1.5 Design for deconstruction and reuse

Deconstruction is the selective dismantlement (in contrast to demolition, Section 7f) of building components, aiming at their direct reuse or recycling of components and materials, i.e. ‘construction in reverse’. Design for deconstruction (DfD) and reuse is a way of designing a building to maximise its flexibility to adapt to multiple owners and lengthen its lifespan and avoid wasteful renovations. It also ensures that a building can be disassembled and parts reused for closing the loop after becoming obsolete. For achieving an optimal reuse of the building and its design so that it can be efficiently mined as a source of reusable materials, several preconditions should take place. These are generally called design for deconstruction (DfD) or design for recycling. Whereas the latter is more focussed on materials, especially on avoiding those which are difficult to recycle, and on easy separation, DfD is often used for all technical (industrial design, architectural technology, structural engineering, building maintenance), material and management (documentation of used materials and joints etc.) choices at the design stage. In this meaning, DfD is often used together with similar concepts like design for:

- adaptation
- disassembly
- reuse
- recycling
- reparability
- product recovery, and
- end-of-life.

As these concepts are all connected, some of the greatest benefits of DfD can be during a building’s lifetime, or actually extending a building’s useful lifetime. Measures for achieving this are, for example, simple construction methods with accessible separable joints (mechanical fasteners instead of glue), durable high-grade materials, standardised materials and documentation of construction methods. In summary, DfD is a design approach aimed at achieving environmentally responsible buildings, by accounting for the future deconstruction of a building (Hurly and Hobbs, 2005).

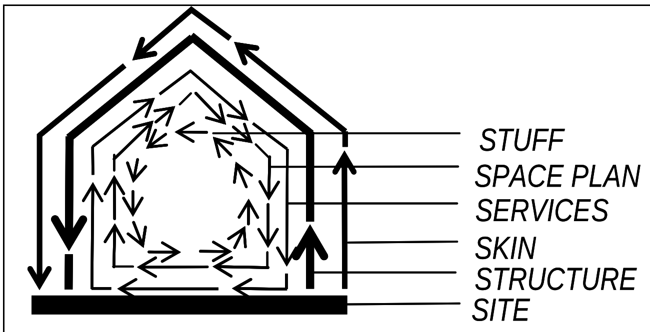
As a summary of DfD principles, the following list gives some general strategies (Guy and Ciarimboli, 2005; Scheibengraf and Reisinger, 2006; Hurley and Hobbs, 2005; Shell et al., 2006):

- construction design:
  - maximise clarity and simplicity
  - minimise building complexity
  - provide access to components/assemblies (windows, etc.)
  - ensure that buildings are conceived as layered according to their anticipated lifespans
  - design buildings to be adaptable to different occupancy patterns in planning, in section and in structural terms
- accessible information:
  - construction drawings & details
  - identification of materials and components
  - structural properties
- materials:
  - precautionary materials selection (recycled and recyclable materials preferred)
  - use durable materials worth or feasible for recovery
  - minimise number of different materials
  - avoid composites of dissimilar materials
  - minimise toxic materials, parts containing hazardous materials should be easy to remove
  - code and mark all materials
- assemblies:
  - minimise number of components (fewer, larger elements)
  - minimise number of fasteners (fewer, stronger fasteners)
  - use mechanical fasteners in lieu of sealants and adhesives
  - simplify connections (if two parts cannot be recycled together, make them easy to separate)
  - make connections visible/accessible
  - separate building layers or systems
  - disentangle utilities from structure
  - use modular building components/assemblies
  - consider independent (self-supporting) assemblies
  - design for serviceability.

One issue relevant for several of these specific strattegies is the representation of a building as composed of different layers, which are in a constant change (see Figure 3.4). The faster changing layers, such as the space plan layer are contained by the less flexible layers, as the structure, and some friction can appear between them. For example if a space plan configuration of a building cannot be implemented because the structure does not allow it, this causes premature obsolescence of the building. For avoiding these problems, the idea of buildings having different layers with individual cycles for use and wear has to be considered. These layers were defined as follows by Brandt, 2005:

- site: outlasts the life of the building
- structure (foundation and load-bearing elements): can last 30 – 300 years
- skin (building envelope, frame, exterior finishes, glazing): can change for repair or appearance every 25 years approx.
- services (utility, HVAC systems, elevators): major replacement every 7 – 15, their embeddedness can cause demolition of a building

- space plan (division of space, cabinetry, interior finishes): changes vary depends on commercial setting being overhauled every 3 years to much longer life in residential buildings
- stuff (furniture, appliances): can change daily to monthly.



Source: Brandt, 2005

Figure 3.4: Stewards Six Ss showing the layers of a building

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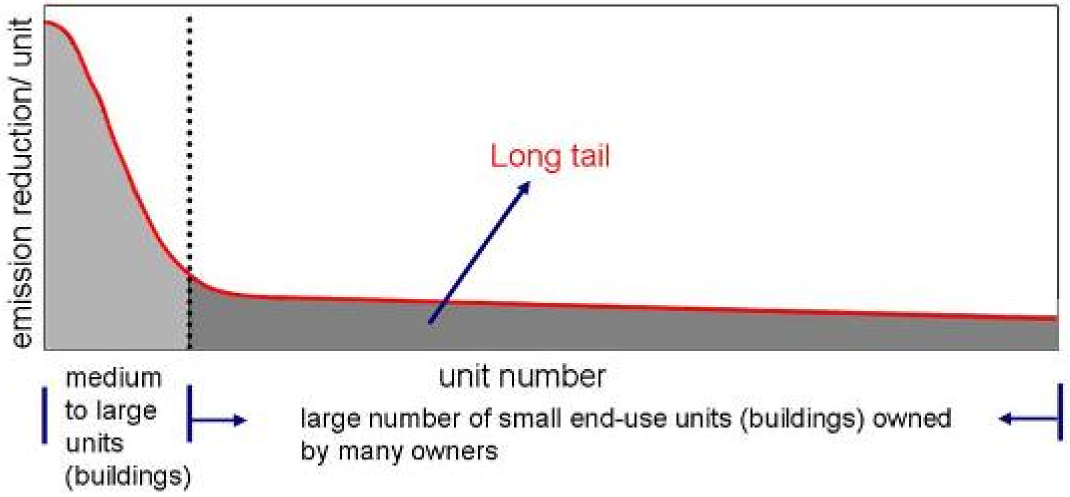
3.3.2 Life cycle environmental relevance of building design

In the description of techniques and in its further applicability, the environmental potential description made by UNEP for buildings should be taken into account (Figure 3.5). While, medium to large buildings have huge improvement potentials, the building sector is characterised by a large number of small end-use units owned by many owners (residential buildings). The long tail of small residential buildings has strong links with public administration, as regulators and as promoters of best design practices.

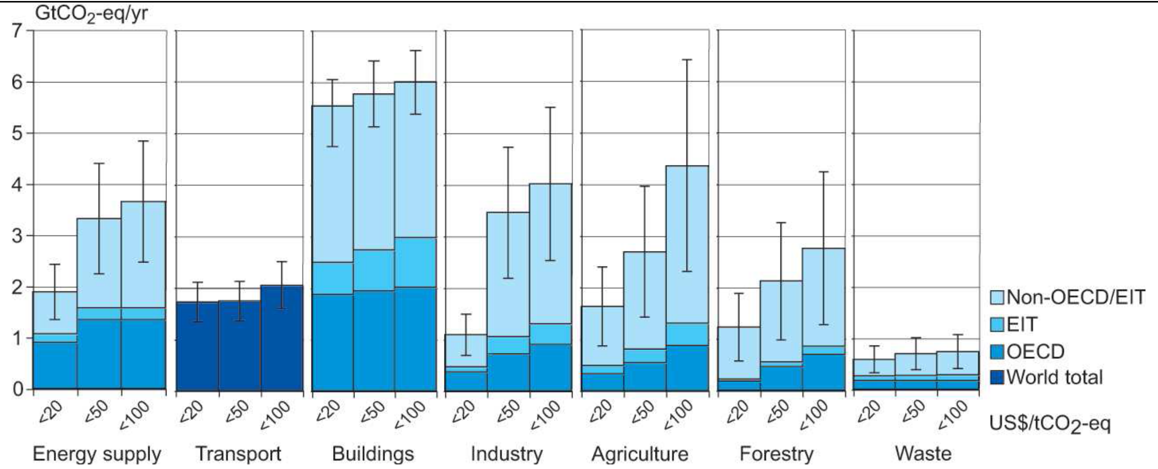


Source: Hinostroza et al., 2007 as adapted by UNEP, 2008.

Figure 3.5: Environmental reduction potential for buildings

The Green Economy report of UNEP for buildings (UNEP, 2011) states that the building sector has an oversized environmental footprint. Also, the construction sector is responsible for the consumption of more than one third of global resources and contributes to the generation of 40 % of total waste volume in the world, 40 % of energy consumption and 30 % of overall carbon footprint. According to Desai, 2011, it may constitute an error to allocate impact to buildings, as this impact is really produced by the people living there. A clear example is given: while retrofitting of houses using passive solar measures can cost more than EUR 130 000 per tonne of CO_2 saved, the cost of car sharing among neighbours is less than EUR 300 per tonne of CO_2. Thus, environmentally-friendly building design should be regarded as one required element for environmentally-friendly living.

Figure 3.6 was developed by the Intergovernmental Panel on Climate Change (IPCC, 2007). This figure shows how the building sector has the highest potential for greenhouse gas reductions. In fact, UNEP states that it is proved that with proven and commercially available technologies, the energy consumption of buildings during its use phase can be cut by 30 % to 80 % (UNEP, 2009)



Source: IPCC, 2007

Figure 3.6: **Carbon dioxide emission reduction potentials of several sectors**

In the assessment of improvement potential, the main environmental aspects to be considered for buildings are energy performance, building materials, waste management, water management and all those related to transport and noise control (EC, 2008). For this, the concept 'environmental construction' is used frequently for techniques addressing the environmental impact of construction works in all phases of the life cycle of a building, including planning, design, construction, renovation, use and deconstruction, and, wherever possible, to be considered in a subsectoral approach, identifying different building user requirements and behaviour. Taking this into account, this chapter has been drafted looking more deeply in the energy and water performance of buildings. Designing out waste techniques are covered, although the main techniques addressing wastes are covered in the construction and deconstruction sections. Building materials selection is covered in a separate chapter.

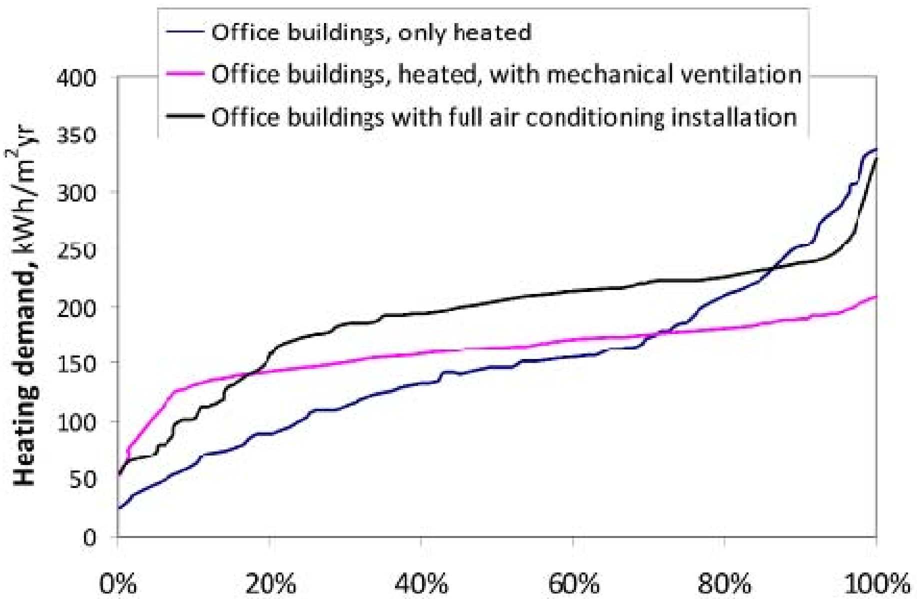
The IMPRO study for residential buildings (Nemry et al., 2008) states that the main environmental impact in the life cycle of buildings is produced during the use phase, due to energy consumption. This aspect can be measured as primary energy demand and greenhouse gases emissions. The main life cycle impacts are proportional to the impact produced by the energy consumption (acidification, eutrophication, etc.), so the life cycle energy consumption (also including the energy of the production phase of materials) can be considered as a good approximation to the life cycle impact of a building (IBO, 2011). Table 3.3 shows the results for the energy consumption per square metre and year. Usually, isolated single family houses have greater energy consumption, especially for colder climates. Multi family houses and high rise buildings reduce considerably the environmental impact of buildings. The remaining impacts have a proportional relationship to the primary energy consumption. These results are based on modelling and simulation of the energy demand of buildings. For the real thermal performance of residential buildings and energy saving behaviour, the difference between Nordic countries and the rest of Europe is reduced. A Eurima report assessed the performance of EU countries and reveals that northern countries perform better than Mediterranean countries (Boermans and Petersdorff, 2007).

Table 3.3: **Life cycle energy consumption of several types of residential buildings for three climates**

	Total Life Cycle Energy Consumption, kWh/m^{2}yr		
Climate	Warm	Moderate	Cold
Single Family House	329	539	670
Multi Family House	173	344	427
High-rise Buildings	98	224	273

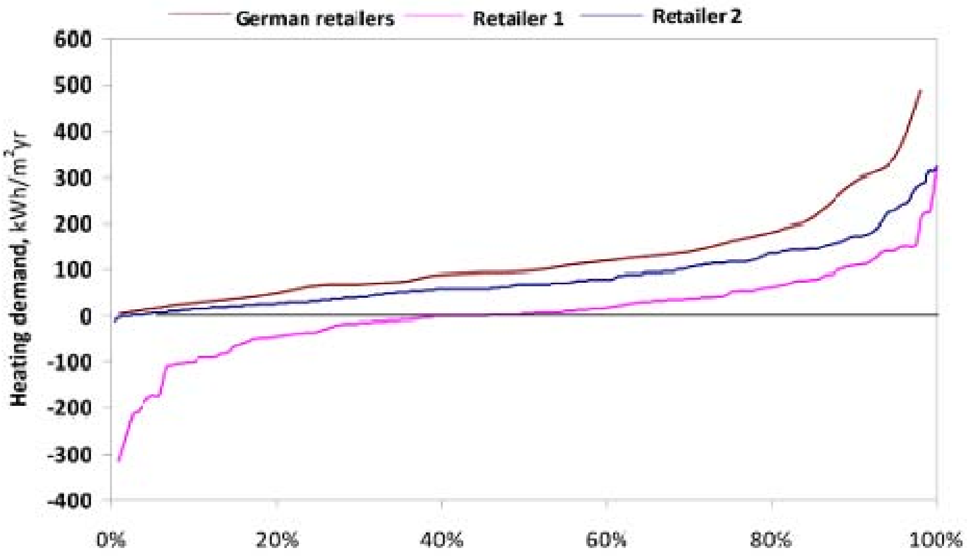
The use of energy was extensively studied by Arge Benchmark for German commercial buildings (Arge Benchmark, 2009). In the figures below, the heating demands of several typologies of buildings are shown. Heat demand in buildings is a good indicator of the thermal design of those buildings and, also, shows differences depending on the specific uses of energy that may occur. Electricity use can be a valid indicator of specific needs of each type of building.

Below, from Figure 3.7 to Figure 3.15, heating energy demand is disclosed per type of building: office, retailers (food, non-food and others), bars, restaurants, cinemas, hospitals, sports facilities, airports, train stations, parkings and hotels.



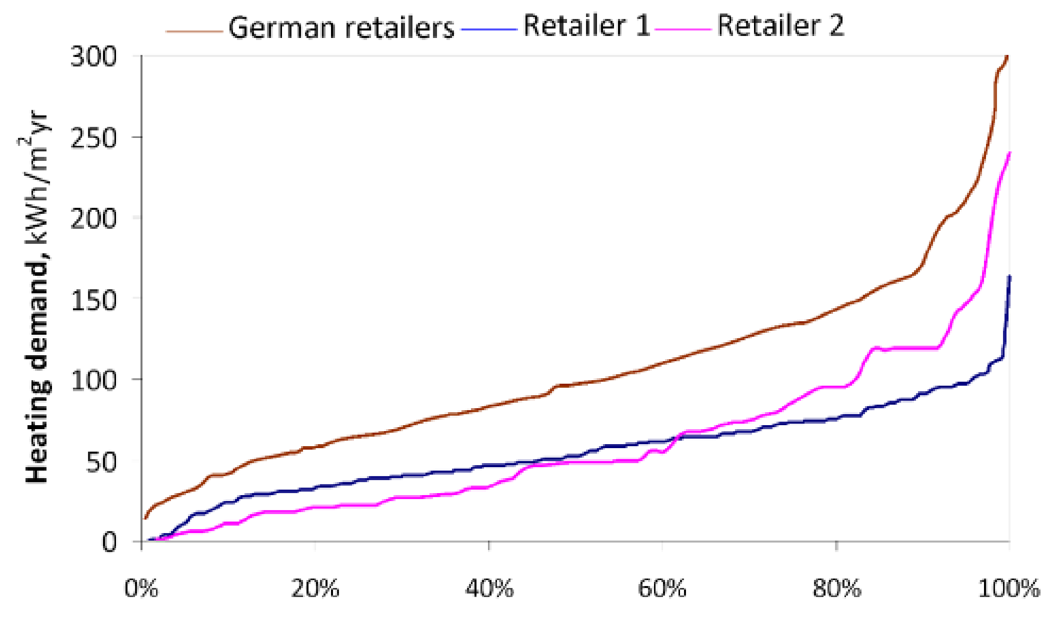
Source: Arge Benchmark, 2009

Figure 3.7: Heating demand vs. cumulative frequency of office buildings in Germany



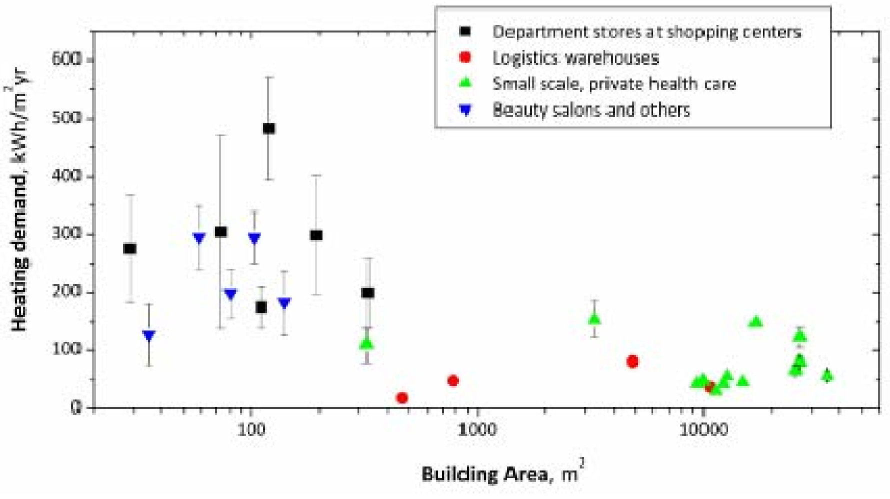
Source: Arge Benchmark, 2009 and EC, 2011a

Figure 3.8: Heating demand vs. cumulative frequency of food retailers buildings



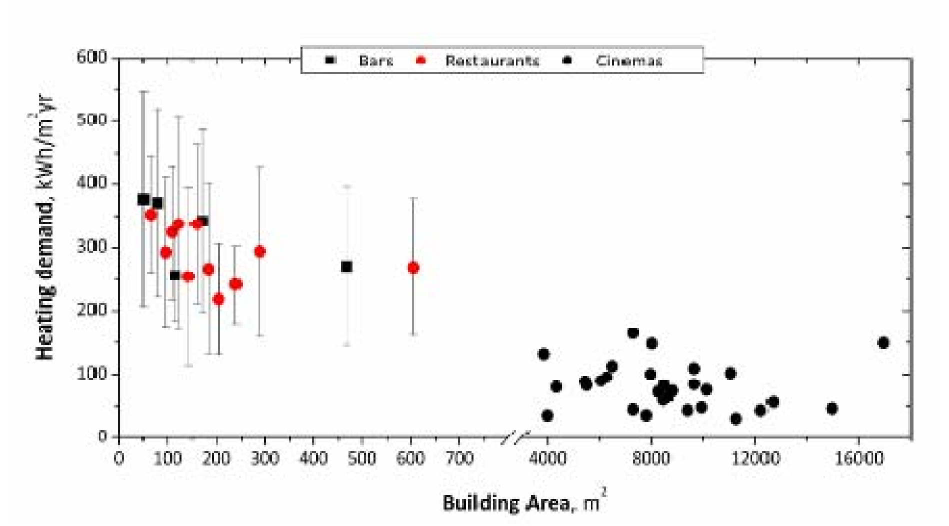
Source: Arge Benchmark, 2009 and EC, 2011a

Figure 3.9: Heating demand vs. cumulative frequency of food retailers buildings



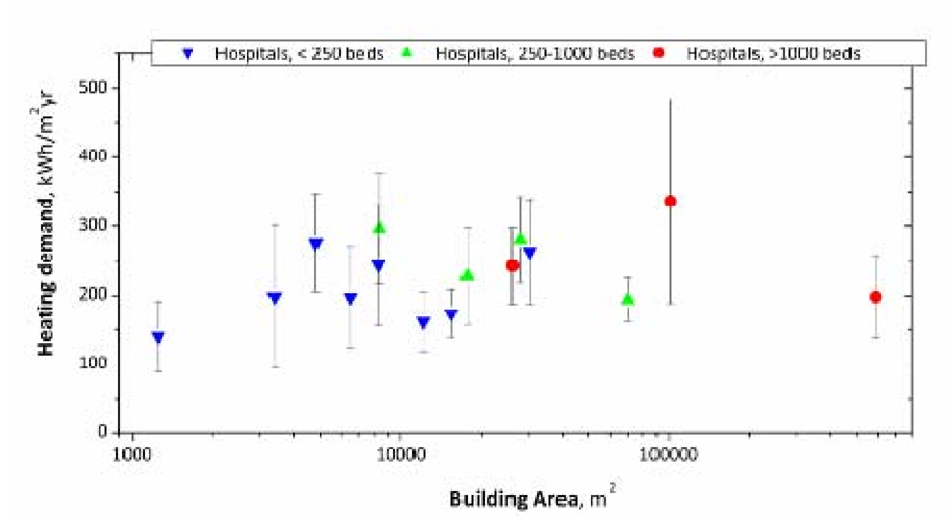
Source: Arge Benchmark, 2009

Figure 3.10: Heating demand vs. area of several retail-type buildings



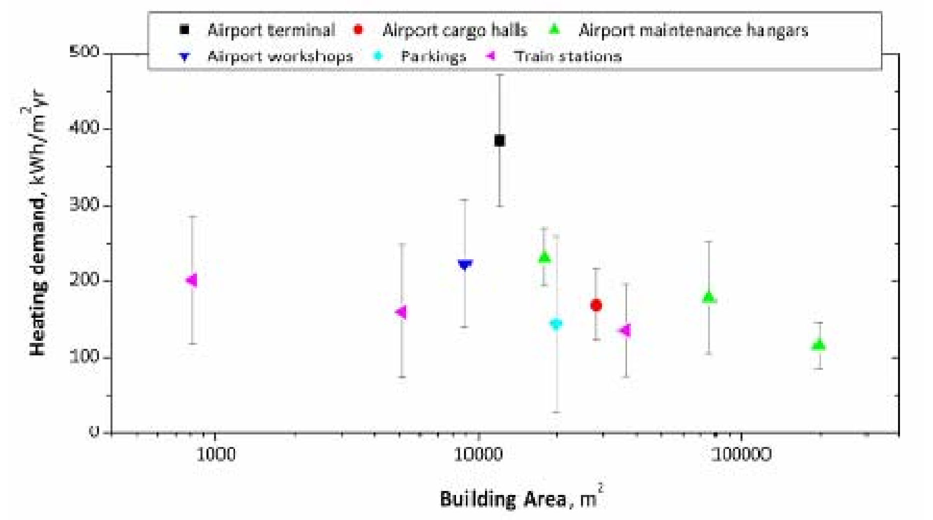
Source: Arge Benchmark, 2009

Figure 3.11: Heating demand vs. area of bars restaurants and cinemas



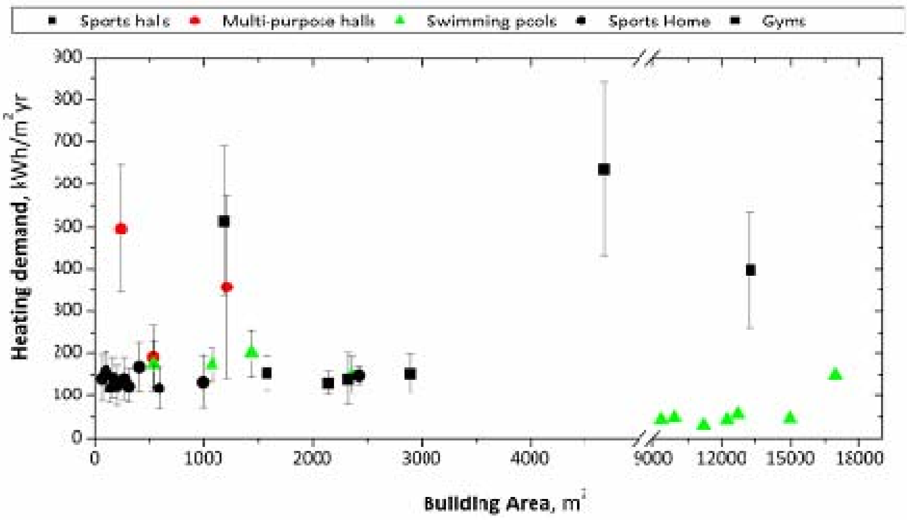
Source: Arge Benchmark, 2009

Figure 3.12: Heating demand vs. area of hospitals



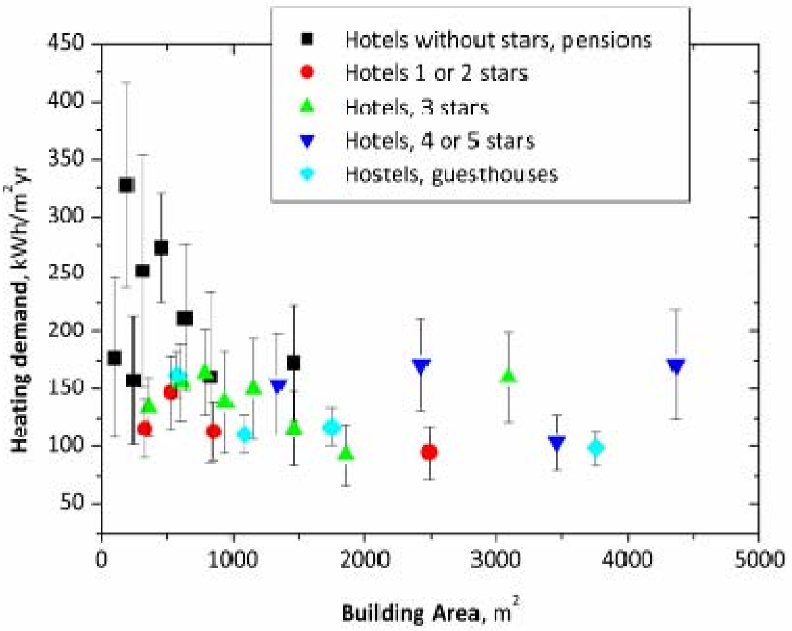
Source: Arge Benchmark, 2009

Figure 3.13: Heating demand vs. area of infrastructure buildings



Source: Arge Benchmark, 2009

Figure 3.14: Heating demand vs. area of sports buildings



Source: Arge Benchmark, 2009

Figure 3.15: Heating demand vs. area of hotels

Average **office buildings** consume from 100 to 200 kWh/m^{2}yr, although best performers have less demand to 25 – 50 kWh. Nevertheless, the differences between only heated buildings (usually smaller and older buildings) mechanically ventilated and with full climatisation installations (usually newer and bigger) are significant. The differences may be caused by occupation density, which may be lower for only heated buildings. The performance of **food** and **non-food retailers'** buildings are deeply studied in the reference document on best environmental management practice of the retail trade sector (EC, 2011a). The huge refrigeraton load of food retailers produce a significant amount of excess heat, which can be recovered. Best performers can produce excess heat due to integrative building and HVAC approaches, which is represented by negative values. A benchmark of 0 kWh/m^{2}yr is established for this building typology. As a general rule for the other commercial buildings, it can be said that the bigger the building, the lower demand, although there are many exceptions and some are due to specific characterisitics of the corresponding sectors. For instance, **hospitals** consume around 200 kWh per m^2 per yr and this value is increased for bigger hospitals, which may be caused by the varying number of beds, occupancy density or provided services. For **bars**, **restaurants, sports facilities, infrastructures,** and **hotels**, it is remarkeable that buildings over 10 000 m^2 have average heating consumptions of about 100 – 150 kWh per m^2 per yr, while the performance for smaller buildings is usually higher. A complex variety of factors may cause this difference:

- system design for bigger buildings require important installations and correct and optimised design is often taking place, while small buildings or small building units (e.g. a flat in a residential building) are usually not well optimised
- bigger facilities have a great proportion of transit zones, which may be not heated or only partially heated
- the values shown in figures assess the consumption of heat, so heat generation efficiencies differences may play a key role.

The most important factor influencing the thermal performance of buildings is the insulation and the U-value of building elements, the air exchange rate and the efficiency of heat generation. In the retail trade best practice document (EC, 2011a), a method for the comparison of the thermal performance of buildings is proposed and can be applied for every type of building. It consists of the representation of the heat demand versus the quotient heat demand / heating degree days([9]). This factor can be directly related to the U-value, as shown below.

The U-value is defined by

$$U = \frac{q}{A\Delta T}$$

where U is measured in W/m^2K, q is the heat flux (J/m^2s) over a surface of 1 m^2 of building envelope and ΔT is the temperature difference between building indoor and outdoor environments.

The U-value is a technical parameter that represents how the building element loses or gains heat. The definition depends on a variety of factors. The amount of energy to maintain a constant temperature has to be equal to the energy loss through the envelope, and is directly proportional to the temperature difference. Temperature difference and time can be integrated in the heating degree days definition and a new expression may be derived:

$$U = k\frac{Q}{A_s HDD}$$

where k is a constant conversion factor, Q is the specific heat consumption per square metre of sales area (kWh/m^2yr), A_s is the building envelope area per m^2 of sales area, and HDD is heating degree days value.

The area of building envelope per m^2 of sales area is related to the building shape, size and design and the *k* factor also depends on the air exchange rate and on the efficiency of the heat generation.

Figure 3.16 shows the plot Q vs Q/HDD for buildings belonging to the same non-food retailer and for hotels of the same chain. If a high standardisation level is achieved, the plot would only be affected by the U-value, which can be assumed to be proportional to the Q/HDD quotient. So, the figure representing heat demand vs. Q/HDD for very similar buildings can be considered

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([9]) Heating degree days (HDD) express the severity of the cold in a specific time period taking into consideration outdoor temperature and room temperature. EUROSTAT uses the following calculation method:

- T_m is the mean ((T_{min} + T_{max})/ 2) outdoor temperature over a day.
- The HDD of a year [**°C** *d/a] is the sum of the following expressions for each day:
  - **18 °C - T_m:** if T_m is lower than or equal to 15 °C (heating threshold)

0 °C: otherwise

equivalent to a figure representing how the heat demand varies with the U-value of a building with the same design. The non-food retailer and the hotels chain achieve important standardisation levels so, a linear behaviour is observed in the charts. The values for heating demand shown in Figure 3.16 are low if compared with the averages shown in previous pages, as these companies are considered best performers (see EC, 2011a and 2011b). The slope of variation changes with the climate (so, in warmer climates heating demand of a building would be higher than the same building in a northern country), but the main influence is the characteristics of the building.

Even if the similarity of U-values and Q/HDD could not be stated due to differences in shape, air change rate and efficiencies, it can be said that this factor relates to the thermal characterisitics of the building; the lower Q/HDD , the better performance of the building. Also, it identifies that the thermal envelope improvement could have important benefits for any climate. In the case of the retailer, it is observed that many buildings in warmer climates performe worse than others in central Europe or in Northern countries.

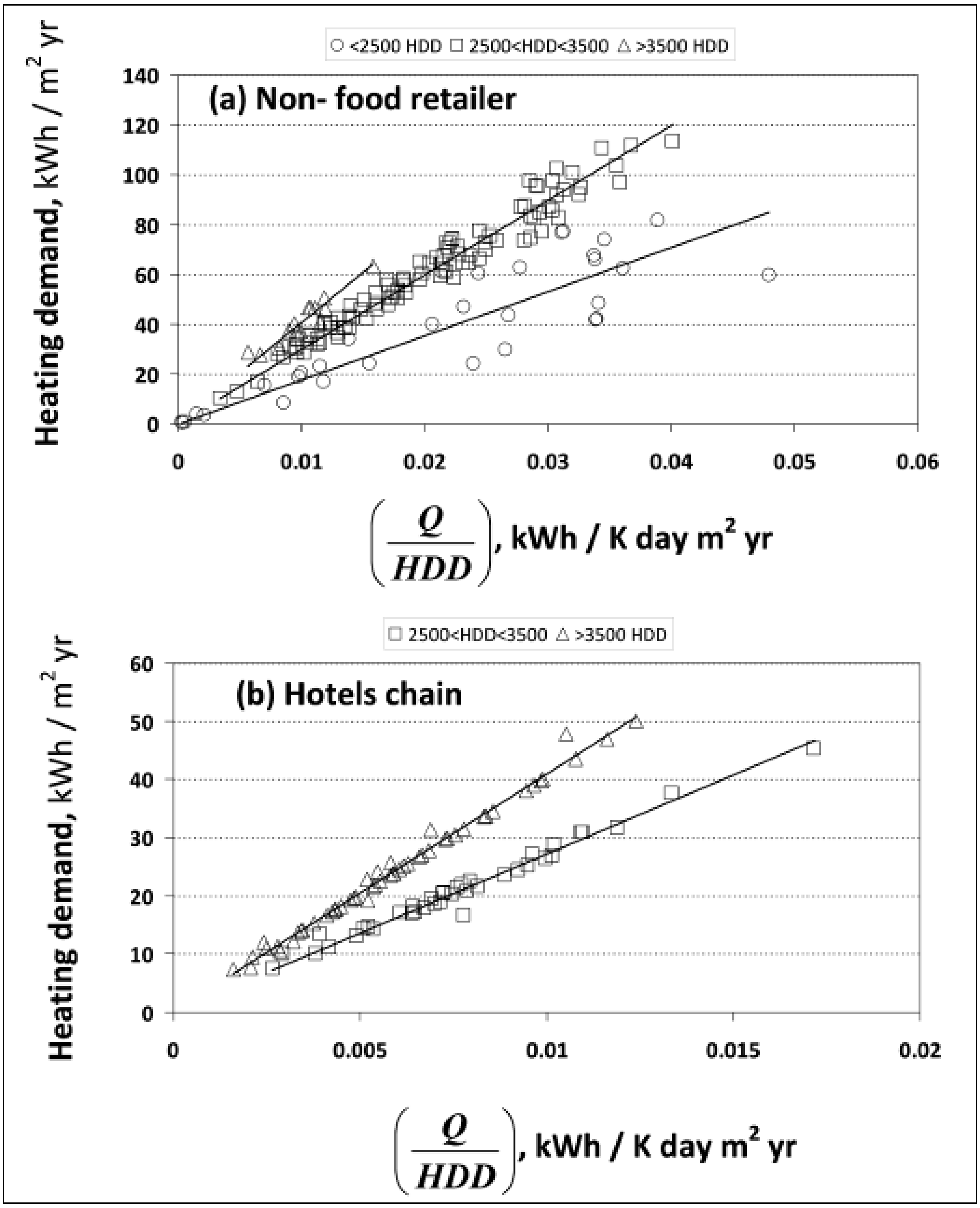


Figure 3.16: Heating demand vs. Q/HDD factor for non-food retailer buildings (a) and hotels (b)

From the life cycle perspective, less importance is given to water use and management when assessing the whole life of a building. Also, less performance information can be found per building typology. Best practices on water management should consider monitoring practices, leakage detection and removal, water reuse, rainwater harvesting and efficient systems.

Water is mainly consumed for four different uses:

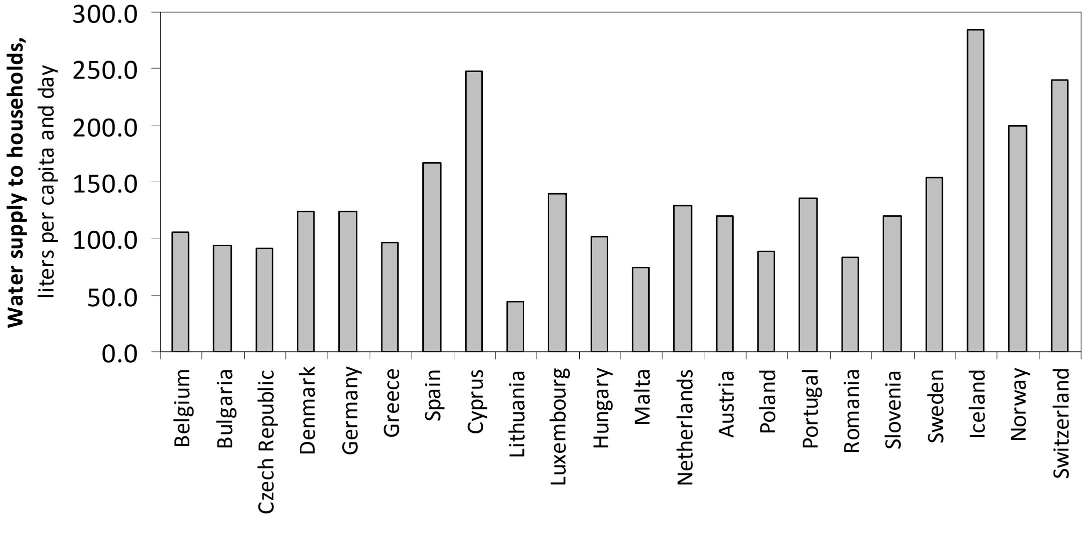
- Indoor sanitary use: water used by the building's occupants for hygiene purpose (showering, cleaning), kitchen fixtures and equipment, and drinking water
- Outdoor water use: water taken from the building for watering green areas on the premises
- Leakages within the plumbing system
- Water used in processes (cooling towers, heaters).

There is a correlation between water use and energy consumption, since water used for hygiene purposes is often heated. The consumption of water in a building raises environmental issues for its occupants in terms of quality, as well as of quantity. The quality of water depends on the plumbing devices, and can impact on users' health. Due to the scarcity of water resources, it has become necessary to adopt water efficient practices in building operation.

The quantity of water consumed strongly depends on the user's behaviour. This behaviour is driven by other factors, such as the number of users in a household. A study lead by Portsmouth Water based on the monitoring of water demand in South England has revealed that single-person households use 70 % more water per person than 4 person households.

There is also a correlation between household income and household water demand, with high income households owning more water consuming appliances (dishwashers, washing machines, swimming pools). Finally, water demand in residential buildings is also affected by the climatic conditions of the region, hot weather leading to a higher consumption of water for showers or baths, irrigation purposes or drinking.

The average European household (2.5 persons) has an average water demand of around 380 l/household/d, with a range of 247 – 511 l/household/d (EC, 2009). This corresponds to a daily water demand of 153 litres per person. This value is calculated for European countries and shown in Figure 3.17.



Source: Eurostat

Figure 3.17: Water consumption in households: average for several Euopean countries

The water performance values for water consumption, assessed with sector specific indicators, in European commercial buildings are shown in Table 3.4.

Table 3.4: Water consumption in commercial buildings

	Water consumption	Unit	Reference
Offices	25.4	L / person per day	Defra, 2006
	520	L per m^2 per year	
Hotels 1 – 3 stars 4 – 5 stars	200 – 400 400 – 1100	L/guest night	EC, 2012
Hospitals	10.75 – 14.4	m^3/m^2yr	NHS, 1993
Museum	332	L/m^2yr	DEH, 2006
Library	203	L/m^2yr	DEH, 2006
Industrial	24.6	L/ position day	BioIS, 2009

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3.3.3 Technical background

This section provides the technical information required for a deeper understanding of the best environmental management practidescription. It does not cover comprehensively all the technicalities of building designs , but provides some basics to different aspects of building design.

3.3.3.1 Orientation of the building

The position and orientation of a building is important in terms of heat loss and solar gains, as well as having an impact on micro-climate in cities. Building orientation depends on the local climate but also on e.g. shading by other buildings, trees etc. As an example, the town of Graz has published a map giving detailed advice on orientation and the form of buildings in their area (Graz, 2010). Simulation of insolation may help finding the best orientation in a given situation. In general, to maximise solar gain, roof areas and main rooms should be oriented south ±30° to minimise heating demand in temperate climates. For warm climates, the optimisation of the orientation can lead to a significant minimisation of the heat demand, which can be important for current building practices. Regarding the whole space heating and cooling demand, the optimal solution can assume a small increase in the cooling demand to have a sharp decrease of the heating demand (Schlenger, 2009).

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3.3.3.2 Building envelope

Building envelope means the integrated elements of a building which separate its interior from the outdoor environment, as defined by the Directive 2010/31/EU on the energy performance of buildings, EPBD. The building envelope encompasses exterior walls, floors, ceilings or roofs, windows, and exterior doors. In this section, many envelope elements are described and the list of techniques covered is large and comprehensive, although it may not be complete.

Exterior walls, ceiling and floor screed
Wall constructions can be differentiated into interior and exterior as well as structural and non-structural walls. In most cases, exterior walls have to absorb loads caused by building components, building use, snow, wind or earthquakes and transfer the resulting forces to the foundations. Furthermore thermal influences (thermal contraction and expansion), shrinkage and creep load exterior walls. Thus, walls have to provide adequate thickness, strength and stiffness. Exterior walls are the main elements of the building envelope and therefore influence the energy performance of the building. Moreover walls have to provide water proofing, noise protection, fire protection and have to be compatible with human health. (CRTE, 2009; Lünser, 2005; Mötzl and Zegler, 2000)

The type of building materials depends on the building construction techniques, which can be divided into solid construction and frame construction. In solid construction, masonry (incl. concrete blocks), concrete (excl. concrete blocks) and wood can be used. In frame construction wood-frames, steel-frames and concrete-frames may be employed (Neumann and Weinbrenner, 2002)

Table 3.5 provides typical examples for actual and former solid wall constructions. Today, single-layer solid wall constructions are often made of heat-insulating bricks, as the use of bricks with poor insulating characteristics requires an additional insulation layer. Double-layer solid walls consist of an interior structural wall and an exterior nonstructural layer as protection against weathering. Double-layer walls can be further differentiated into double-layer walls with air layer core insulation, as well as with air layer plus heat insulation.

Besides prerequisites concerning functionality, building physics, building chemistry, aesthetics, indoor climate and fire protection, a thorough solid wall building material comparison of environmental aspects should be performed. Table 3.6 provides a comparison of selected building materials used in solid construction in a life cycle approach. With respect to the energy efficiency of the building, the thermal conductivity is critical, whereas the energy demand for the production of the building materials should also be taken into account in any building energy balance to determine the real life cycle energy performance. The environmental performance of transport of the high-density solid wall materials requires special consideration of the local availability of the components and production plants.

Table 3.5: Typical solid wall constructions

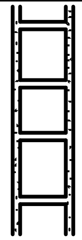
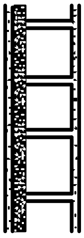
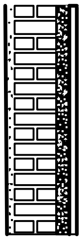
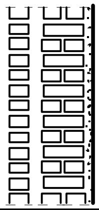
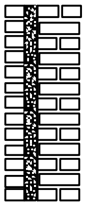
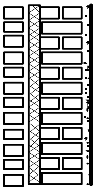
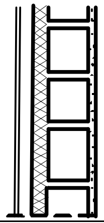
	Single-layer wall of large-sized heat-insulating bricks, plastered on both sides
	Single-layer wall of large-sized bricks with exterior heat insulation layer, plastered on both sides Construction materials: Bricks + mortar + heat insulation + 2 plaster
	Single-layer wall of small-sized bricks with interior heat insulation layer, plastered on both sides Construction materials: Bricks + mortar + heat insulation + 2 plaster
	Double-layer wall with air layer Construction materials: 2 Bricks + 2 mortar + plaster
	Double-layer wall with core insulation Construction materials: 2 Bricks + 2 mortar + heat insulation + plaster
	Double-layer wall with air layer and core insulation Construction materials: 2 Bricks + 2 mortar + heat insulation + plaster
	Masonry with core insulation and rear ventilated curtain wall Construction materials: Curtain wall + heat insulation + bricks + mortar + plaster

Table 3.6: Technical and environmental performance of selected solid wall building materials (CRTE, 2009). Scale from low (+) to high (+++++), fire classification according to DIN EN 13501-1

	Sand-lime brick	**Autoclaved aerated concrete block**	**Lightweight concrete block**		**Clay brick**	**Reinforced concrete**	**Concrete block**
			Pumice	Expanded clay			
Components	Sand, water, lime, additives	Water, sand, lime, cement, anhydrite, aluminium	Gravel, sand, portland cement, water, pumice	Gravel, sand, portland cement, water, clay	Clay, water, flue ash, sand, lime	Gravel, sand, portland cement, water, reinforcement (iron, steel)	Gravel, sand, portland cement, water
Production							
Non renewable energy demand in MJ/kg	N.A.	+++	++++	+	+++	+++++	+++++
GHG-potential in kg CO_2-equivalent/kg	N.A.	+	++++	+	++++	+++++	+++++
Acidification in kg SO_x-equivalent/kg	N.A.	++++	+++++	+	++++	+++++	+++++
Photosmog in kg ethene-equivalent/kg	N.A.	++++	+++++	+	++++	+++++	+++++
Construction							
Density in kg/m³	700 – 2000	350 – 1000	500 – 1200	500 – 1200	1000 – 2200	2430	1200 – 2400
Thermal conductivity in W/(mK)	0.5 – 1.3 (density: 1000 – 2200 kg/m³)	0.11 – 0.27 (density: 350 – 800 kg/m³)	0.15 – 0.44	0.18 – 0.46	0.3 – 0.96	2.1 (normal concrete)	2.1
Nominal compressive strength in N/mm²	4 – 28	N.A.	2 – 12	2 – 12	N.A.	N.A.	N.A.
Fire classification	A1	A1	N.A.	A1	A1	A1 (normal concrete), A1/A2 (steel)	A1
Use							
Average lifetime in yrs	120	100	100	100	90 – 120	-	70 – 120
Material-specific remarks	-	Possibly fungicides by surface treatment	Emission of eco-relevant materials by washing out and leaching, elevated radio activity (pumice)		-	-	Emission of eco-relevant materials by washing out and leaching
Indoor climate	Breathable, odor-absorbing, moisture regulating, disinfectant, mold repellent	Moderate moisture characterstics, long drying time			Breath-able, moisture regulating	Mostly diffusion resistant, waterproof, long drying time	Diffusion resistant
Deconstruction / dismantling							
Recyclability (reuse / utilisation)	Recycling in production process, construction waste	Reuse, concrete aggregate			Reuse, gravel, concrete aggregate, mostly deposited	Recycling (separation of steel and concrete)	Reuse, concrete aggregate

In general, some measures in order to reduce the environmental impact of solid wall construction (CRTE, 2009) are:

- use of material with high recycled fraction
- alleviation of dismantling processes by reduction of material variety
- avoidance of composite construction materials
- avoidance of hazardous additives as anti-freezing agents
- avoidance of cutting scrap
- delivery of bricks without packaging (shrinking foil) and on europallets

- avoidance of later openings by inclusion of openings in the construction process
- use of reusable parts for openings.
-

In frame construction, the loads are transferred in a punctual and not in a linear manner. In frame construction wood-frames, steel-frames and concrete-frames can be used. The advantages of frame construction in contrast to solid construction are the better use of solar radiation by transparent exterior and interior walls, higher flexibility with respect to indoor space utilisation and reduction of permanent loads (CRTE, 2009; Neumann and Weinbrenner, 2002).

To reduce the environmental impact of frame construction, some measures are proposed in the litreature (CRTE, 2009):

- alleviation of the reuse of timber and steel girders by adequate construction and deconstruction
- preference of constructional protection measures in contrast to chemical ones
- avoidance of later openings by inclusion of openings in the construction process
- use of reusable parts for openings
- time saving and avoidance of cutting scrap by paying attention to fitting accuracy of precasted wooden parts in the planning process
- avoidance of wood preservatives
- delivery of wood with a minimum of packaging.

Plaster is a layer placed on interior and exterior walls as well as on ceilings. It consists of adhesive agents, additives and water. Plaster can be classified according to the adhesive agents used into mineral and organic (CRTE, 2009; Starzner and Wurmer-Weiß, 2005). Table 3.7 provides a comparison of selected plasters from a life cycle perspective. Especially for heat insulation plaster, the thermal conductivity is of major importance with respect to the energy efficiency of the building, whereas the energy demand caused by the production of the building materials should also be taken into account. The environmental aspects related to the transport of the plaster should be also considered.

For plaster application, some environmentally-friendly measures should be applied (CRTE, 2009):

- Utilisation of premixed mortar in order to avoid incorrect mixing and the intake of contaminant loads at the construction site
- Utilisation of plaster which is made of secondary raw materials
- avoidance of small packagings by delivery in silos or containers
- electrical installation: utilisation of re-usable plastic covers for sockets, avoidance of filling with used paper
- filling of plastered slots with used paper or natural fibres
- avoidance of provisional façade protection systems against weathering.

Table 3.7: Technical and environmental performance of selected plasters (CRTE, 2009): Scale from low (+) to high (+++++), fire classification according to DIN EN 13501-1

	Lime plaster	**Cement plaster / cement screed**	**Synthetic resin plaster**	**Lightweight plaster**	**Heat insulation plaster with expanded polystyrene**	**Gypsum plaster**	**Loam rendering**
Production							
Non renewable energy demand in MJ/kg	+++++	+++++	+	++++	++++	+++++	+++++
GHG-potential in kg CO_2-equivalent/kg	++++	++++	+++	+	+++	+++++	+++++
Acidification in kg SO_x-equivalent/kg	+++++	++++	+	+++	++++	+++++	+++++
Photosmog in kg ethene-equivalent/kg	++++	+++++	+	++++	++++	+++++	+++++
Construction							
Density in kg/m^3	1800	2000	1100	600 – 1300	<=200	1300	1500 – 1700
Thermal conductivity in W/(mK)	0.87	1.4	0.7	0.21 – 0.36	0.06 – 0.1	0.6	0.65 – 0.7
Fire classification	A1	A1	B/C	A1	B/C	A1	B/C
Use							
Average lifetime in yrs	N.A.	30 – 80	30	N.A.	40	N.A.	30
Material-specific remarks	-	-	VOC, socyanate, epichlorhydrin, methyl metacrylate	Elevated radioactivity (not if portland cement is used)	-	-	-
Indoor climate	Breathable, odour-absorbing, moisture regulating, disinfectant, mold repellent	Diffusion resistant, long drying time	Diffusion resistant	Low diffusibility, moderate moisture characteristics, long drying time	Breathable, moisture regulating, high diffusibility	Breathable, partially moisture regulating	Breathable, odor-absorbing, moisture regulating
Deconstruction / dismantling							
Recyclability	Construction waste	Construction waste	Energetic recovery	Construction waste (if purely mineral)	-	-	Reuse after addition of water

Ceilings consist of different layers and can be built of precast components. They have to meet static requirements and should provide noise, fire and heat protection. Floor screed can be amended by a floor cover or it can serve as a topmost floor layer. It has to meet the following general requirements: wear resistance, heat protection, noise protection, as well as planeness and gradient respectively (CRTE, 2009; Neumann and Weinbrenner, 2002). There are some environmentally-friendly measures that should be regarded for ceilings and floor production phases: reuse of packagings and utilisation of silos at the construction site; return of construction waste by the supplier into the production process (Starzner and Wurmer-Weiß, 2000), delivery of basic materials in silos or containers, avoidance of small packagings, and use of of polyethylene interlayers with a thickness of 0.5 mm as moisture barrier, which can also be reused or recycled after the dismantling phase.

Roof

Roofs have to provide protection against the intrusion of water, snow and fire. Therefore a major task of a roof is the enduring preservation of the basic structure of a building. The external roof layer depends on the type of the roof. Roof claddings are typical for steep roofs, whereas roof sealings are commonly used upon flat roofs. The roof pitch influences the applicability of different materials and the required fixing.

Flat roofs have their origin often in aesthetic considerations. It should also be checked if a roof garden or a roof terrace could be installed. Steep roofs often provide longer lifetimes. Flat roofs can be constructed with or without a protective layer, e.g. gravel. The lack of a protective layer requires a waterproofing which is able to resist high loads. Additional recommendations can be given for the environmental performance of roofs: utilisation of water as solvent in black painting of bitumen, utilisation of solvent-free paints, avoidance of the use of herbicides by performing inspection walkways every 2 years, and utilisation of solvant-free coatings.

Windows

As the energy performance of a builiding is strongly influenced by the windows, their selection deserves special attention. The requirements, which have to be met include (CRTE, 2009; Neumann and Weinbrenner, 2002):

- solar gain
- heat protection
- protection against driving rain
- noise protection
- fire protection
- etc.

Windows, exterior walls and the connection joints constitute a common system with respect to heat protection requirements a common system. The weakness of one of these components produces inefficiency in the whole system. Therefore glazing, frame, jointing and connections have to provide low heat transfer coefficients and airtightness.

The performance of windows can be characterised by the following indicators reflecting heat protection, solar gain and noise protection:

- The heat transfer coefficient of the window U_w, e.g. in W/m²K, characterises the heat protection of a whole window (including the frame). The higher U_w is, the lower the heat protection of a window is.
- The heat transfer coefficient of the glazing U_g, e.g. in W/m²K, characterises the heat protection of a glazing. The higher U_g is, the lower the heat protection of a window is.
- The solar heat gain coefficient (SHGC) or G-value characterises the solar energy transmittance through windows. The G-value ranges from 0 to 1. The higher the G-value is, the higher the solar gain is.
- The sound reduction index Rw [dB] characterises the noise protection of windows. The higher Rw is, the better the noise protection is.
- The emissivity *e* of a material is the relative ability of its surface to emit energy by radiation. The higher *e* is, the lower the heat protection of a window is. Low-e glass causes radiant heat originating from indoors in winter to be reflected back inside.
- The airtightness A, e.g. in m³/hm, of a window describes the air volume flow entering the window from outside per gap length at a defined pressure difference. The higher A is, the lower the heat protection of a window is.

Table 3.8 provides selected characteristics of windows with different frame materials, i.e. PVC, aluminium, wood and combined wood-aluminium. The data corresponds to a single-leaf window with heat protection glass and a dimension of 1.23 m x 1.28 m. (Kreißig, 1998).

Table 3.8: Environmental performance of windows with different frame materials (CRTE, 2009; Kreißig et al., 1998): Scale from low (+) to high (+++++)

Frame material	PVC	Aluminium	Wood	Wood/Aluminium
Production				
Energy demand in MJ/window	+++	+	+++++	+++
GHG-potential in kg CO_2-equivalent/window	++++	+	+++++	++++
Acidification in kg SO_x-equivalent/window	+++++	+	++++	+++
Photosmog in kg ethene-equivalent/window	+++++	+++++	+	++
Use				
Average lifetime in yrs	40 – 50	60	40 – 50	60
Maintenance	Possibly yellowing (irreversible)	-	Exterior painting every 5 years	-
Remarks /contaminant loads	VOC emissions, vinyl chloride, phthalate	-	Pollutant emission by surface treatment	-
Deconstruction / dismantling				
Recyclability (reuse / utilisation)	PVC is recyclable, energetic recovery is possible (the emission of dioxins has to be regarded), in Germany a nationwide collection system exists	Aluminium is recyclable, collection systems exist	Energetic valorisation is possible, need for flue-gas purification plant depends on finishing	Aluminium is recyclable, energetic recovery of wood is possible

Exterior doors

Exterior doors are necessary for access, ventilation and illumination. They can consist of different materials (wood, aluminium, PVC, steel, insulation material) and may or may not provide glazing or not. Exterior doors have to provide heat protection, noise protection, protection against unauthorised persons, weather protection and fire protection.

The performance of an exterior door can be characterised by the following figures reflecting the heat protection of an exterior door:

- The heat transfer coefficient of a door U_D, e.g. in W/m²K, characterises the heat protection of a whole door. The higher U_D is, the lower the heat protection of a door is.
- The airtightness A, e.g. in m³/h m of a door describes the air volume flow entering the door from outside per gap length at a defined pressure difference. The higher A is, the lower the heat protection of a door is.

In Germany, exterior doors, that can be certified for the use in passive houses, provide U_D-values of about 0.68 – 0.8 W/m²K and A-values of about 1.07 – 2.25 m³/hm at a pressure difference of 100 Pa (PasivHaus, 2010; Gürlich & Wöller, 2010).

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3.3.3.3 Heating, ventilation, air conditioning

Indoor air quality requirements state humidity rates of 40 – 55 % as the optimum for living and working conditions. As CO_2 and waste air need to be transferred to the environment and fresh air into the rooms, experts have developed guidelines for air changes per hour, which vary between around 5 (for living rooms and offices) to up to 25 (for kitchens and lavatories). Optimum indoor temperature is considered to be between 19 and 25 °C, which requires heating in winter times and cooling in summer times and increasing needs for badly isolated houses.

This section firstly covers techniques for heating, as heating is the main concern in terms of energy requirements, and an is therefore an area with large improvement potential for most of Europe. Later techniques for ventilation and air conditioning are described. These three types of systems do not only influence each other, but can be produced as an all-in-one product for new houses with very low heating requirements such as for passive houses. Therefore, integrated approaches are preferred best practices, as HVAC needs are minimised and the overall environmental impact is significantly reduced.

Heating

The heating system itself consists of several separate units, which together determine the overall system efficiency. Heat generation in boilers, collectors and similar installations are usually the main concern and starting point of actions to increase energy efficiency. However, attention should also be paid to the rest of the system, i.e. good radiators, a heat loss minimising delivery and storage system and an energy efficient pumping system. In order to be as efficient and environmentally-friendly as possible, each unit has to be optimised with regard to the individual targets (boiler – maximum thermal efficiency, pump – minimum specific electricity consumption, heating cycle – minimum pressure drop and temperature loss, and radiators – best possible heat distribution to the room).

One important factor in choosing the economically and ecologically best heating system is the definition of its system boundaries. Many old dwellings and apartment houses still have separate heat generators for each room. This form of completely decentralised organisation has been replaced by more and more centralised systems, whether for single apartments, houses, apartment complexes or even local districts. Centralising the heating system allows a larger one to be used, thereby obtaining scale effects in economic (specific investment, overall efficiency, operating and maintenance costs) and environmental terms (better combustion, continuous operation, scale effects for expensive technologies). By covering a growing amount of households, the energy generation process becomes more and more similar to conventional power plant processes. Operating times increase, individual demand volatilities can be combined and counterbalancing effects create some sort of basic heat load demand. As this does not apply for single households, the heat generator is designed for peak demand and accepts low average load operation. Intermediate system sizes have to cope with hybrid solutions, since special peak-load installations require a minimum size to be economically feasible.

Completely decentralised systems remain efficient at places of very low heat demand, as otherwise installation costs for a duct system would be too high.

Heat storage tanks. The most popular intermediate solution is a buffer store or storage tank. Available in sizes beginning from 500 litres up to several thousand litres of capacity, these tanks can absorb excess supply, store the heat with small losses and provide it in times of small excess demand. This balancing function helps to generate stable operations, especially a stable combustion process at a local optimum with regard to efficiency and environmental impacts. Some new installations select storage tank cascades with inlet and withdrawal at the first tank, i.e. a sort of buffer store system in cascades. This system configuration can minimise heat losses and investment, since the amount of tank insulation, and accordingly the specific heat loss, can be defined for each cascading member individually. However, overall equipment cost are high and this technique will not be economically feasible in many cases.

The general principle for storing heat is that longer lasting excessive demand or supply will lead to a slow change in load status, beginning with filling or discharging the storage. Minimising the number of load changes, especially the number of start-ups and shut-downs, will minimise the overall amount of emitted pollutants, since soot, carbon monoxide and many other partially oxidised substances have maximum formation rates during load transition states. Overall storage volume can be selected according to expected demand volatility and consumption figures.

Non-fossil systems require the installation of buffer stores or storage tanks as well, since as for solar thermal heat, supply and demand times and volumes do not coincide. For example, solar thermal heat will be generated mainly at midday, whereas high demand usually occurs in the morning and especially in the evening.

Heating cycle. With growing centralisation, the heat fluid has to be transported long distances, from generation via storage to the individual radiator. Therefore, efficient transport mechanisms, pumping technology and minimum heat and pressure losses are the main indicators of an energy and cost-effective distribution system. Oversized pumps and high pressure losses result in additional power needs, thereby reducing the overall electrical efficiency of systems and producing unnecessary operating costs. Due to demand-driven capacity utilisation rates, indicating high volatility and the need to serve maximum peak flows, special attention should be paid to installing systems with high efficiency at medium and transition load levels. Since the task of a heating system is, for example, to hold room temperature at certain values or supply individual radiators with a manually-fixed amount of heat (centralised temperature-driven control or manual control), high short term volatility cannot be completely controlled by an intelligent control system.

In addition to general short term demand volatility, heat demand varies largely across the year. Winter times feature high demand rates, whereas during summer times nearly all heat energy is needed to provide hot water. Consequently, heating systems have to be able to operate at various heat output levels with respect to volume and temperature, and especially low volumes in the long term.

Heating control system. The scope of a heating control mechanism is to serve demand by steering heat production rates and storage tank levels. Heat production control has to decide for production load changes and tank filling with respect to the variables efficiency, emission rate and expected future demand rates. From environmental and economical points of view, times and lengths of periods with 100 % and 0 % load should be maximised, and periods of suboptimal generation and amounts of heat loss minimised.

One task of control systems is the coordination of several heat sources, several heat storage facilities and (in local heating systems) a very large number of consumers. For coordination tasks, special attention is drawn tothe integration of renewable sources such as solar thermal and geothermal heat generation, their supply characteristics (e.g. solar thermal being dependent on sunshine hours or geothermal as base load supplier), heat amount and maximum achievable output temperature. Additionally, these systems require the installation of peak and high-temperature heat production units (usually gas boilers) and their integration into the network. If multiple storage facilities with different insulations exist, supply and demand has to be allocated to the tanks according to volume and temperature.

Radiators. Optimisation of radiators performance is an essential issue of heating systems. One important aspect is to locate radiators at places, where heat can be distributed into the room and stays in the room. This is rather a planning task, although technological aspects can influence system efficiency, as efficient radiators need to be selected. New radiator products are designed for low temperature use, which means they can heat rooms with hot water temperatures as low as 65 °C and up to 90 °C. These radiators have smooth and large surfaces to maximise radiant heat and are able to provide heat at lower temperature levels due to better heat transmission.

Furthermore, technologies such as floor and wall heating can be operated with hot water temperatures of 35 – 40 °C. These temperature levels allow very high shares of renewable heat generation, as most renewable sources are limited with respect to temperature levels. From an economic point of view, floor and wall heating systems are more applicable to new buildings, as retrofitting requires high investments for installation.

Heat generation. Heat generation principles largely depend on the energy source used. A general differentiation can be made between combustion based and non-combustion based systems. Furthermore, heat can be generated centrally at single points and delivered to each consumer or produced at the place of demand (room specific or dwelling-specific).

The basic principle of hot water supply is a heat transfer of the hot surrounding onto a colder delivery medium in heat exchangers. Solar thermal systems use the energy provided by the sun to heat the medium, geothermal systems use the soil temperature and combustion based systems use the heat of combustion processes. Conventional domestic heat production is based on thermal combustion processes, whereas new trends such as solar thermal and geothermal heat production have gained market shares, and provide heat without emitting pollutants during operation (mainly air pollutants).

Environmental indicators for heating systems focus on the operating phase of the product, i.e. the time of heat production. Hence, indicators are efficiency (efficiency on net calorific value basis), in order to determine the CO_2 footprint and improvement potential, and air emissions (herein mainly CO_2, dust, CO, NO_x and organic compounds, where applicable). Mass and energy flows for construction and deconstruction phases vary in each product category, depending on size and type selected. For general LCA information regarding the mass and energy flows of heat generators can be found in the EcoDesign preparatory studies for solid fuel burning (EcoSolidFuel), hot water preparation (EcoHotWater) and boilers (EcoBoiler), which analyse LCA aspects of these installations. Other LCA-based information on primary energy used, total emissions (including the whole life cycle) and carbon footprints can be obtained from internationally accepted databases, such as 'GEMIS' and 'EcoInvent'.

Solar thermal heat generation. Covering energy needs, especially household energy needs by using solar radiation, has been a popular technique for the last decade. Systems are commercially available for electricity, as well as heat in form of hot water to meet demand. As solar energy is freely available, this type of technique only requires investment and maintenance costs.

For heat generation, solar thermal collectors are installed at sunlight exposed places, usually on southward facing roofs (in the northern hemisphere), which absorb the sunlight and pass the absorbed energy to a heat medium. This heat medium, usually a mixture of water and glycol, will feed the warm-water cycle in the heat exchanger. Hence, a solar thermal system consists of sunlight collectors, a heat exchanger, a heat medium and a heating cycle with feeding pump. Overall system efficiency depends on the medium characteristics (heat capacity, viscosity), heat cycle characteristics (efficiency of pump, system pressure drop), heat exchanger (flow characteristics, temperature difference, duct material and size), and the collector effectiveness (degree of absorption, heat for medium flow, sunlight exposure). A theoretical foundation and detailed discussion on each parameter can be found in many standard textbooks, as Bollin, 2009.

Collectors can be divided into several systems according to the way they bundle and absorb sunlight. Simple, and hence inexpensive systems, are flat plate or evacuated tube collectors, whereas systems which concentrate sunrays to increase absorption efficiency, such as evacuated tube collectors with additional reflectors or solar parabolic dishes are more expensive. A decision on which system will be the individual optimum is highly site specific, since it depends on local conditions such as sunlight exposure, expected days of utility, overall system efficiency, demand characteristics, as well as equipment cost and investment.

Generally, solar thermal systems can be divided into systems to heat water for domestic use and systems to heat water for domestic use and room heating. Since heat generation depends on sunlight exposure, total demand cannot solely be covered by solar thermal heat and needs a type of peak heat generation process, like gas-fired condensing boilers. Small rooftop systems can cover up to 60 % of total hot water needs of a typical household, whereas systems for space heating support have smaller shares, as demand is much larger, especially in times, where solar thermal heat is rarely available.

Geothermal heat generation. The basic principle of a geothermal heat generation system is to use the heat stored in the soil, to warm up the heat medium. Heat medium ducts are installed at depth, with a heat exchanger at the bottom, in which the soil passes heat onto the medium. As the amount of heat needed for household systems is comparatively small compared to the 'reservoir of heat in the soil', such type of heat generation is classified as renewable.

Air and surface temperatures change during the year, whereas the temperature in the ground varies less, as the ground heats up slowly during the summer and cools down slowly in winter times. This effect decreases with depth; below 10 metres seasonal influences are expected to have a negligible effects in central European climates. Additionally, soil temperature starts to increase from a certain depth onwards, which is why geothermal systems reaching deep under ground achieve relatively high temperatures. Equipment and installation costs generally increase with depth. Therefore, two different types of geothermal heat generation principles dominate the market for household applications: horizontal ground heat exchangers, an exchanger just below the surface with a total duct length of 100 - 200 meters, and vertical ground heat exchangers, where a number of ducts reach down far as 100 meters below the surface.

The overall system consists of the ground heat exchanger, a heat medium, usually a mixture of water and glycol, and a heat pump. This heat pump is for the medium circulation, as well as for temperature and pressure regulation. Ground heat exchangers need feeding temperatures well below the soil temperature and allow a certain maximum reachable temperature, which is usually below required demand levels. Pumps can be driven by electricity, or by gas, which is usually more efficient. As geothermal systems get a lot of energy from the soil, efficiency figures are not computed as before but rather as a 'heating seasonal performance factor' (HSPF). This factor measures the relation of energy provided by the system to the surrounding to energy consumption of the heat pump over a year. Usual figures are between 2 and 5, with 5 meaning, that this system provides five times the amount of energy to the heating system as it consumes. 'Good' systems are characterised by values above 3, very good systems with values above 3.5. Indirect CO_2 emissions can be calculated by dividing the CO_2 emission factor of electricity by the HSPF; primary energy factors can be calculated analogously.

The working principle of a heat pump is equivalent to the principle of a refrigerating machine (i.e. classical refrigerators); the only difference is that the off-heat of refrigerating machines is the heat used for heating in this application. As geothermal heat generation with a horizontal ground heat exchanger in combination with heat pumps is an efficient manner of heat generation for households, this type of installation is described in the chapter of available techniques.

Combustion based heat generation. Combustion based systems can be categorised according to the state of the fuels as solid, liquid or gaseous fuels. Fuels generate energy mainly by oxidising carbon to carbon dioxide and hydrogen to water. Other components of fuel mostly end up as bottom ash and emissions to air, which is why the cleanest fuels only contain hydrocarbons such as methane. Regarding dust and other emissions arisings due to incomplete combustion, good best fuel-air mixing can lower the emissions of partially oxidised substances. Consequently, recent developments use solid fuels in small pieces, such as wood pellets and wood chips, rather than log wood, to improve the fuel-air mixing. The three categories of combustion generators are:

- Gaseous fuel burners: The typical gaseous fuel burnt in household appliances is standard natural gas, available from municipal gas distribution systems. This type of natural gas has been specially prepared for decentralised combustion by industrial desulphurisation before insertion into the distribution system. Combustion installations for gaseous fuels range from conventional boilers to modern condensing boilers with efficiencies of up to 109.7 % (based on LHV)([10]) and very low emissions with respect to all pollutants.

- Liquid fuel burners: the most common liquid fuel for domestic heating is light fuel oil. Analogous to gas, light fuel oil is a product under legal standards with regards to composition, especially with regard to sulphur content. Market share of oil fired heating systems has decreased for many years, although recently oil fired condensing boilers, analogous to gas fired condensing boilers, have been introduced to the market. These condensing boilers achieve efficiency gains of up to 6 points due to condensation energy recovery, but still do not reach the efficiency performances of gas fired condensing boilers. Oil is delivered in trucks and stored in households; therefore a large storage space is required rather than a connection to public distribution systems.

- Solid fuel burners: Solid fuels for domestic appliances can be divided into biomass (excl. wood), wood, peat, brown and hard coal. Wood, in forms of pellets, chips and logs, is the most commonly used fuel, whereas hard coal, brown coal and peat only have minor, and decreasing shares. Biomass such as straw is rarely used in households due to reasons of availability and low heating value. As described in the introducing text, solid fuel combustion now focuses on the combustion of small pieces, since surface area is then maximised and complete combustion enhanced. The mechanical principle of fuel provisioning in the combustion chamber depends on the size of the installation. Apart from very small open installations, such as open fireplaces, the mechanical principles of closed combustion chambers are mainly understoker and grate firing. Understokers require dry and small pieces, i.e. high quality fuel, in order to minimise emissions, whereas grate firing, especially moving grate firing allows using larger and more impure fuels like wood processing residues. Grate firing has an embodied flue-gas flow, which guarantees better combustion and hence less substances of incomplete combustion arise, but is fragile to low load performance, as the mechanism only works for high loads (Bauer and Baumbach, 1984). Modern solid fuel combustion in household appliances concentrates mainly on wood burning, especially wood pellet and wood chip burning.

Local and district heating systems. All heat generation systems discussed so far can produce the heat the consumer site, i.e. the dwelling. The special feature of local and district heating systems is a centralised heat production for many consumers at a single place. The heat is delivered via a duct system to all consumers.

Heat generation itself can occur in many ways, whether it is a classical power station with heat production, large solar thermal areas, deep geothermal stations or via the release of industrial waste heat, such as in steelmaking, cement production and oil-refining. These heat sources

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([10]) As LHV (lower heating value) does not include condensation energy, which can be extracted from the flue-gas in condensing boilers, the efficiency of condensing boilers may be above 100 % in terms of NCV. With regard to the higher heating value, an efficiency of above 100 % is not possible. As a consequence of this, the appropriateness of efficiency figures in terms of NCV is widely discussed.

produce large and steady amounts of heat, which are fed into a heat distribution network connecting the suppliers and many consumers. By using waste heat, the overall system efficiency of the industrial processes can be raised while covering heat demand. The main disadvantage of most distribution networks is high investment for the network duct. These high investments lead to the development of loca lcompulsory connection rules for households, in the conection area. These rules can rainse the acceptance level, as lower overall emissions and guarantees on the economic environment for local and district heating systems, as these systems have high economies of scale.

A difference between local and district heating can be drawn at network size and capacity. Local heating networks usually cover neighbourhoods, whereas district heating systems may cover several districts and suburbs with network lengths of many kilometres, sometimes up to several hundred (e.g. Duisburg district heating network with a network length of approximately 500 km and 1,100 GWh of energy delivered, Brandstaetter, 2008). In contrast, large local heating networks have a network length of less than 10 km and less than 10,000 MWh energy delivered([11]). Many new local heating networks have a regenerative energy generation basis, such as large solar thermal or geothermal installations and gas or biomass CHP boilers with capacities of a few MW_{th} for peak energy generation. Large district heating networks have base load suppliers such as industrial plants or fossil fuel power stations, and additional separate small cogeneration plants for peak times.

The general advantages of these heating networks are scaling effects in terms of plant costs, centralised operation and reduced specific emissions due to better combustion and flue-gas cleaning techniques. A general disadvantage is high investment for the network ducts and high costs for low load operation, which is why many networks ruled by local authorities pledge neighbouring households to connection to these networks.

Common combination of heat generation techniques. Most regenerative heat generation principles are not able to cover the heat demand of households totally on its own in less favourable climates, since either economically achievable temperature levels are not high enough or times of high demand cannot be covered completely (winter times, peak times). Consequently, most new environmentally-friendly heating systems use regenerative heat sources to cover partial demand. Many reference installations cite coverage of 30 – 60 % of total demand by regenerative heat sources. This section shortly describes the most popular combination of regenerative and fossil heat generation principles. In theory, no constraints of matching the individual principles and techniques exist, but in reality these following systems have been mostly preferred due to economic aspects, availability and reliability:

- *Solar thermal heating and fossil fuel-fired boilers*: Solar thermal heating devices represent a currently very popular technique for heat generation. As they can be easily installed on rooftops and various other locations independent of their size, virtually no limits of application exist. Since solar thermal energy generation is not suited for high temperature and peak demand operations, it is moreover used as an add-on technology. In times of peak demand and low generation, heat has to be provided by a technique with secure energy supply suitable for peak operation. Most commonly, gas-fired condensing boilers are chosen, since installation costs and emissions are low.
- *Solar thermal heating and local heating system*: In places, where local or district heating systems exist, demand surplus may be served by this provider. Since connection to the local or district heating system may be compulsory, costs for installing additional other heat generation techniques would outweigh possible cost advantages in most cases.

Ventilation and Air Conditioning:

The recommended ventilation flow of air is about 20 – 30 m^3/h per person. The occupancy profile of the building is a determining factor and it has to be well estimated in advance, as the

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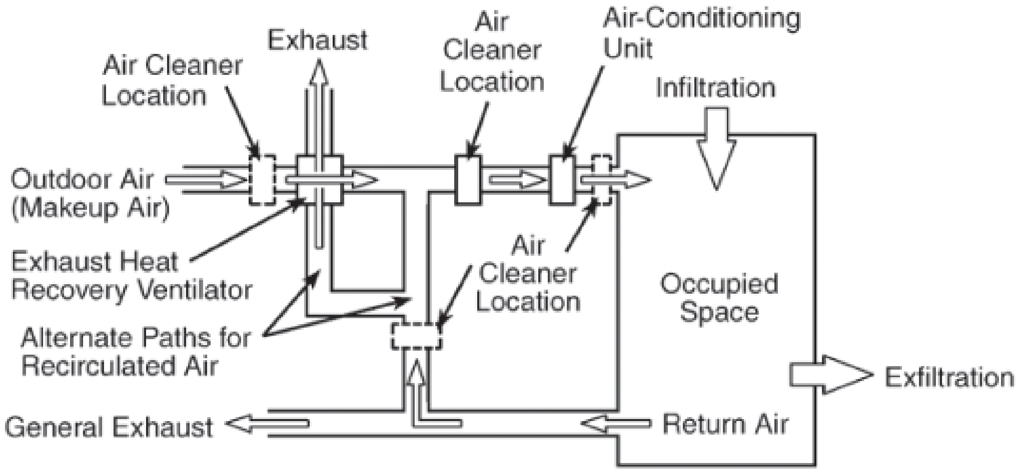
([11]) A ZSW study calculates for a village with 1,100 inhabitants (315 dwellings) a network length of 6.4 km and a yearly heating energy demand of 8,650 MWh plus losses of approximately 1,100 MWh (Bonisch, 2001) air flow also heavily influences the heating and cooling systems design. The preferred solution for minimising the energy consumption and the ventilation costs is the demand control unit, if the occupancy profile is highly variable.

Ashrae (2008) gives a general design concept for the ventilation system, as shown in Figure 3.18. The design for new buildings includes usually the possibility of recirculating air (for lower occupancy) and for heat recovery.



Source: Ashrae, 2008

Figure 3.18: Design example of a ventilation system

The task of ventilation and air conditioning systems is to guarantee an appropriate indoor air quality in terms of humidity, temperature and pollutants. Older installations divided these three tasks into ventilation systems (pollutants, i.e. provision of filtered fresh air) and air conditioning systems (humidity and temperature control). Modern systems are able to cope with both tasks, as modern construction especially requires ventilation systems due to air-tight walls and low heating requirements due to low heat losses.

Ventilation has been a concern in office buildings for many years, but also is naw for dwellings due to constructing dwellings air-tight. These systems consist of filters, a pump and a distribution and disposal duct network. A standard and efficient technique for ventilation is the waste heat recovery installation. This is an air-to-air heat exchanger, which heats the cold and fresh air by using the temperature level of discharged air. Herein, recovery rates of 80 % are easily achievable, so that further needs for air heating and energy consumption are lowered. This system helps to reduce heat losses due to ventilation to very low levels. Concepts such as low-energy house, passive house or active house with correspondingly low overall energy demands are only achievable with discharged air heat recovery installations.

Another popular system for air heating is an air heat pump, which basically works like water heat pumps but uses the air as medium. Air heat pumps cannot achieve the performance levels of water heat pumps, since air has a lower specific heat coefficient and performance levels decrease sharply for air inlet temperatures close to 0 °C. Therefore, most funding schemes do not subsidise the installation of air heat pumps, even though overall equipment costs are lower than for water heat pumps.

Waste heat recovery from exhaust air is regarded as an elementary technique for minimising energy losses and it should be regarded as common practice or an element of other techniques to be considered best practice.

In contrast, air conditioning systems are much more similar to heating systems than to ventilation systems, as they require energy to 'produce' cold air. But instead of using combustion processes and other heat sources to transfer heat into the rooms, air conditioning systems have to extract the heat of the indoor air and dispose this heat to the environment. In general, techniques can be divided into systems with thermal assistance, natural assistance and compression cooling systems.

Compression cooling systems are classical electricity-driven systems used in refrigerators and most decentralised small air-conditioners. In comparison to thermal and natural assisted systems, these systems feature higher power consumption and lower coefficients of performance. As electricity has the least favourable emission factors, these systems have the highest calculated emission rates. Natural and thermal assisted systems have the ability to use excess or geothermal heat, and therefore are more environmentally-friendly.

For thermally assisted air conditioning, two different process types exist, open and closed systems. In open systems, heat is extracted from the air, whereas in closed systems intermediate cycles with cooling media exist. These systems have an additional heat exchanger, which passes the heat of the air onto the cooling medium.

The most popular closed systems are adsorption and absorption chillers. Closed systems can be supplied either by air or by water. Water-based systems produce cold water, which has to be supplied to the rooms with the help of floor or wall radiators, analogous to heating systems. Air-based systems need to distribute the cold air into the rooms via ventilation ducts. Adsorption chillers are favourably used in large and industrial applications, as temperatures well below 0 °C are achievable and most installations have capacities above 500 kW. Absorption chillers are available starting from a capacity of 20 kW, hence are wide-spread as central cooling systems for office buildings, apartment complexes, etc. In contrast to these closed systems, desiccant evaporative cooling is the most common open system, combining ventilation, humidity control and temperature regulation, and especially suitable for smaller installations such as dwellings, apartment houses, small office buildings and hotels.

Natural systems use geothermal assistance to cool air to soil temperature level. They basically work like geothermal heat systems and earth-to-air heat exchangers, which are described in the subchapters available techniques for heating and ventilation. These systems should always be designed as ventilation and air conditioning systems, i.e. using fresh air and not indoor air as a source, as additional ventilation systems are not required any more.

Air conditioning systems are mainly characterised by the coefficient of performance, which describes the relationship of provided cooling energy in kWh by the required energy (usually electricity or heat) in kWh. As the chillers produce noise, manufacturers tryi to reduce the noise by installing dampers or splitting the cooling process and installing the noisy part on the outer building walls, also known as (mono- and multi-) splitted air conditioning systems.

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3.3.3.4 Lighting

Lighting in buildings has to fulfil practical and aesthetical effects that strongly depend on the purpose (e.g., task lighting, accent lighting, and general lighting). Lighting includes use of both artificial light sources such as lamps, and natural illumination from daylight. Artificial lighting represents a major component of building energy consumption. Poorly designed illumination not only leads to unnecessary energy consumption, but also to adverse health effects. In homes and offices a significant share of total energy consumed is due to lighting. For some buildings, 90 % of lighting energy demand is due to over-illumination. Table 3.9 shows the share of lighting in total electricity consumption in Germany.

Table 3.9: Share of lighting in electricity consumption for different sectors

	Electricity consumption for lighting in Germany [TWh/a]	Sectoral share of lighting in electricity consumption in Germany [%]
Commercial, services	38	28
Residential	14	10
Industry	19	9
Total	71	15

Source: Wuppertal, 2006

Comprehensive lighting design requires consideration of the amount of functional light required, the energy consumed, as well as the aesthetic impact supplied by the lighting system.

Table 3.10 gives an overview of illumination requirements for buildings and, as a comparison, typical daylight illuminance; the potential for daylight use in buildings is obvious from the differences in magnitude between the values.

Table 3.10: Typical illuminances of buildings and daylight

Illuminance [lx]	Typical for
10	Street illumination
50	Minimum for non-residential buildings, parking deck
100	Hallways
200	Bathroom, storage room
500	Working area in offices
3 000	Overcast winter day
20 000	Overcast summer day
60 000 – 100 000	Sunny summer day

Source: LFNUV, 2010

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3.4 Best environmental management practices in the design of buildings

Techniques and design practices to achieve best environmental performance are focused on the environmental impact produced during construction, use and end-of-life stages. According to the scope of this chapter, described best environmental management practices in this chapter are focused on:

- measures to monitor and reduce energy consumption; the renewable energy use in buildings is regarded as an element of building operation in section 3.4.5
- measures to improve water management
- reduction of construction and demolition wastes using designing out techniques.

Against the background of previous sections and according to the knowledge gained with the background document, the input of the technical working group, technical visits, meetings with experts and the review of existing litreature, the list of techniques that may constitute a best environmental management practice, BEMP, is shown in Table 3.11.

Table 3.11: Identified Best Environmental Management Practices for Construction Activities

Section	BEMP	Covered aspects	Techniques	Target audience
3.4.1.1	Increasing the performance of insulation	Energy	Options to achieve best environmental performance through reducing energy demand of the building	Designers, private developers, building users, turnkey projects companies, public administrations
3.4.1.2	Techniques to improve the performance of walls	Energy	Technology options to improve the thermal performance of walls	Designers, building users, turnkey projects companies, public administrations
3.4.1.3	Improving the environmental performance of roofs	Energy	Technology options to improve the thermal performance of roofs	Designers, building users, turnkey projects companies, public administrations
3.4.1.4	Best options for glazing	Energy	Technology options to improve the thermal performance of windows	Designers, building users, turnkey projects companies, public administrations
3.4.2	Integrated concepts	Energy	Integrative Approaches including envelope, HVAC system and other measures (e.g. passive house)	Designers, private developers, building users, turnkey projects companies, public administrations
3.4.3	Design and Retrofitting of the Heating, Ventilation and Air Conditioning (HVAC) system	Energy, Indoor Air Quality	Link between envelope and HVAC system. Ventilation, heating and cooling practices. Passive heating and cooling.	Designers, building users, turnkey projects companies, public administrations
3.4.4.1	Demand reduction through lighting concepts, strategies and integrated daylight optimisation	Energy, Indoor Air Quality	Daylighting, definition of lighting strategies, zoning, etc.	Building users, designers
3.4.4.2	Increasing the efficiency of lighting devices	Energy, Indoor Air Quality	Efficient devices: LED, T5, CFL	Building users, designers
3.4.6.1	Environmentally friendly water drainage systems	Water	Design of building drainage systems	Building users, designers
3.4.6.2	Water saving plumbing fixtures	Water	Efficient equipment for water use	Building users, designers
3.4.6.3	Non-potable water recycling systems	Water	Recycling systems for rain water and grey water.	Building users, designers
3.4.7.1	Preventing waste during the design phase	Waste	Designers role on waste prevention during construction phase	Building users, designers, construction companies, demolishing companies, private developers, public administration
3.4.7.2	Design for Deconstruction (DfD)	Waste	Designers role on waste prevention during deconstruction phase	Building users, designers, construction companies, demolishing companies, private developers, public administration

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3.4.1 Building envelope

3.4.1.1 Increasing the performance of insulation

Description

From the thermal balance point of view, insulation materials are highly important for the energy efficiency of a building. The thermal quality of the envelope is improved if thickness is increased and the thermal conductivity of the material is low. Generally, the thickness of current building stock insulation depends on the countries current practice, but e.g. in the case of walls it ranges between 15 and 30 cm of insulation and in the case of passive houses it ranges usually between 20 cm or more for external walls and 30 cm for roofs. Complex component structures require special anchor constructions that can only be provided up to a certain length. For example, in the case of roofs built with rafters, increasing the insulation thickness could require an additional insulation layer below or above the rafters (Thunshelle et al., 2005).

Insulating materials may be classified according to their composition/production into inorganic, organic and synthetic materials and according to their properties into mats/boards, rigid-foam boards, spray foams, loose-fills, blow-in insulation etc. Each of them has its application areas and its function as part of the building envelope, e.g. heat protection, moisture proofing, noise protection (impact sound insulation, airborne sound insulation) and fire protection. In selecting adequate insulating materials, environmental aspects during production and end-of-life stage as well as health impacts should also be considered (Hiete et al., 2008).

Technically, the best way to insulate a building component is on the external side as this reduces problems with thermal bridges and does not lessen the useful floor area. If it is not possible to use external insulation, e.g. because of exceeding the dimensions of the building plot or poor aesthetics (Thunshelle et al., 2005), internal insulation is used.

The most important insulating materials with respect to the business volume in Germany are (GDI, 2010):

- wood-wool insulating board
- mineral wool (glass wool and rock wool)
- expanded polystyrene
- polystyrene hard foam
- polyurethane hard foam.

Achieved environmental benefits

The reduction of heating or cooling energy demand is the main driver to assess the environmental benefit of increasing the performance of the insulation layer. Other important benefits are the enhancement of noise protection, the stabilisation of the indoor temperature, and heat protection during summertime.

The reduction in cooling energy demand by insulation measures has been investigated for a single family house (SFH) and a multi family house (MFH) of 120 m² and 1600 m² useful floor area respectively. Table 3.12 provides the results of this investigation (Boermans and Petersdorff, 2007).

Table 3.12: Cooling energy demand savings by insulation in reference houses in Seville and Marseille

	Wall		Roof		Floor	
	No insulation	Insulation	No insulation	Insulation	No insulation	Insulation
U-value [W/(m²K)]	1.7	0.6	2.25	0.5	1.0	0.5
Seville (908 cooling degree days)						
Cooling energy demand savings [kWh/(m²a)] (useful energy/useful floor area)	SFH: 4 MFH: 2		SFH: 13 MFH: 6		SFH: -4 MFH: -2	
	SFH: 14 MFH: 7					
Marseille (427 cooling degree days)						
Cooling energy demand savings [kWh/(m²a)] (useful energy/useful floor area)	SFH: 1 MFH: 0		SFH: 4 MFH: 2		SFH: -3 MFH: -1	
	SFH: 3 MFH: 1					

Source: Boermans and Petersdorff, 2007

The achievable savings in annual heating energy demand per m² component area by the improvement of the insulation of existing buildings have been investigated for existing buildings in Germany. Though, the results depend on construction details. An overview, without those details, is provided in Table 3.13. (GRE, 2002)

Table 3.13: Achievable savings in annual heating energy demand (useful energy) by insulation measures for existing buildings in Germany

Application area	U old W/m²K	U new W/m²K	Recommended (2002) insulation thickness, cm	Achievable reduction in useful energy demand kWh/m²yr (component area)
Steep roof	4.8	0.24 – 0.21	16 – 18	345 – 347
	0.8 (insulated)	0.19 – 0.17	16 – 18	46 – 47
	4	0.24 – 0.21	16 – 18	285 – 286
Topmost ceiling	3.3 (concrete)	0.19 – 0.15	20 – 25	235 – 238
	0.9 (wood)	0.20 – 0.14	16 – 25	53 – 58
Flat roof	0.75	0.30 – 0.19	8 – 16	34 – 43
	0.9	0.28 – 0.20	10 – 16	47 – 53
Exterior wall	1.3 (single layer)	0.31 – 0.21	10 – 16 (exterior insulation)	94 – 103
	0.51 (double layer, partial core insulation)	0.34 – 0.20	4 – 12 (core insulation)	16 – 29
	1.32 (single layer)	0.50 – 0.36	5 – 8 (interior insulation)	78 – 90
Ceiling of non – heated basements	1.1	0.34 – 0.29	8 – 10	36 – 38

Source: GRE, 2002

The reduction in final energy demand and the correct choice of a heat transfer coefficient is strongly influenced by the climatic conditions prevailing in the region of interest. In Europe, three climatic zones are considered, based on the outdoor temperature. The division was made according to the number of heating degree days(12) (HDD): Warm zone, up to 2000; moderate zone, from 2000 to 4000; cold zone more than 4000. Given a heat transfer coefficient of a wall or an insulation layer, the heat losses by thermal conductance are approximately proportional to the HDD.

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(12) Heating degree days (HDD) express the severity of the cold in a specific time period taking into consideration outdoor temperature and room temperature. EUROSTAT uses the following calculation method:

- T_m is the mean $((T_{min} + T_{max})/ 2)$ outdoor temperature over a day.
- The HDD of a year [**°C** *d/a] is the sum of the following expressions for each day:
  - **18 °C - T_m:** if T_m is lower than or equal to 15 °C (heating threshold)
  - **0 °C:** otherwise

Table 3.14 and Table 3.15 provide HDD (year 2005) for 25 EU Member States (Gikas and Keenan, 2006). In an analogous way cooling degree days (CDD) can be considered. A detailed map is available in (Boermans and Petersdorff, 2007)

In the EU member states different legal requirements concerning the thermal conductance of building components in new construction and refurbishment exist. Partially they reflect the different climatic conditions.

Table 3.14: Heating degree days in EU Member States, year 2005 (Part I)

State	BE	CZ	DK	DE	EE	EL	ES	FR	IE	IT	CY	LV	LT
HDD Kd/yr	2669	3564	3233	3137	4319	1625	1937	2457	2633	2051	644	4184	4014
Climatic zone	moderate	moderate	moderate	moderate	cold	warm	warm	moderate	moderate	moderate	warm	Cold	cold

Source: Gikas and Keenan, 2006

Table 3.15: Heating degree days in EU member states, year 2005 (Part II)

State	LU	HU	MT	NL	AT	PL	PT	SI	SK	FI	SE	UK
HDD Kd/a	3041	3030	662	2658	3650	3547	1360	3188	3519	5294	5098	3125
Climatic zone	Moderate	moderate	warm	moderate	moderate	moderate	warm	moderate	moderate	cold	cold	moderate

Source: Gikas and Keenan, 2006

Appropriate Environmental indicators

The heat transfer coefficient or U-value, in W/K m^2, is an appropriate parameter to control the heat loss through the building envelope. Nevertheless, its control is quite complicated and U-value does not reflect the weight of other influences (internal, solar gains; HVAC performance). Hence, it would be rather complicated to control the energy performance of a building through its U-value. The specific heating and/or cooling demand per year and per square metre is preferred. This indicator, quite useful in terms on primary and final energy demand, can indicate the overall thermal performance of the building as a whole. Nevertheless, the exact definition on how it is calculated should be provided when assessing a building: type of energy (final or primary), time of building use (an office building lifetime may not be comparable to other types of building) and area (useful area, floor area, corrected area with height, etc.). ISO 13790:2008 standard was elaborated for the calculation of the energy performance of a building (heating and cooling demand) based on its design. A simplified methodology for its calculation is shown in section 3.4.2.

Cross-media effects

Usually, the reduction in heating demand should by far exceed the required energy for the production of the insulating material. Health impacts, e.g. of carcinogen fibres, formaldehyde loads etc. should be closely examined with special attention. Furthermore the limited availability of resources and the possibility of recycling, reuse and valorisation after the use phase of the insulating material should be considered during the decision-making process.

Operational data

Besides the application area, insulating materials can be characterised by the following performance figures reflecting the above mentioned functions, i.e. heat protection, moisture proofing, noise protection and fire protection (Lünser, 2005; Mötzl and Zelger, 2000; Reyer et al, 2001)

- Thermal conductivity: The thermal conductivity, W/ K m, is a property of a material that indicates its ability to conduct heat. The higher the thermal conductivity is, the lower the heat protection of an insulating material is. In this context the dehumidification capacity is also important, as the thermal conductivity increases, if the insulating material becomes humid.

- Heat transfer coefficient: The heat transfer coefficient, W/m²K, characterises the ability of an insulating material of a given thickness to transfer heat. The higher the heat transfer coefficient is, the lower the heat protection of an insulating material is.
- Water vapour resistance factor: The water vapour resistance factor, commonly called µ-factor, is a dimensionless number describing how many times better a material or product is at resisting the passage of water vapour, compared with an equivalent thickness of air. Therefore the µ-factor characterises the moisture proofing of an insulation material.
- Specific flow resistance: The specific flow resistance, kNs/m^4 is proportional to the decrease of the sound pressure in the absorbing insulation layer. The higher the specific flow resistance, the better the airborne sound insulation is.
- Dynamic stiffness: The dynamic stiffness, MN/m³, describes the dynamic-elastic characteristics of an insulating layer as an intermediate layer in multilayer constructions. The lower the dynamic stiffness is, the better the impact sound insulation of the multilayer construction is. The determination of the dynamic stiffness of insulating materials for floating floors is described in DIN EN 29 052.
- Fire classification: A fire classification of construction products and building elements is described in the European DIN EN 13501-1, which distinguishes no contribution to fire (A1), negligible contribution to fire (A2), very minor contribution to fire (B), minor contribution to fire (C), acceptable contribution to fire (D), acceptable reaction in fire (E) and no requirements (F). Therefore the fire classification characterises the fire protection of an insulation material.
- Specific heat capacity: The specific heat capacity, kJ/kg K, is the measure of heat or thermal energy required to increase the temperature of a unit quantity of a substance by one unit. The higher the specific heat capacity is, the lower the temperature variations, e.g. in hot summer days, are. In this context the density [kg/m³] of the insulating material is also of importance, as the heat capacity (per volume) increases, if the density of the insulating material increases.

Adequate environmental aspects during production and the end-of-life stage of insulating materials should be taken into consideration (see section 4.3.1.1). With respect to the acceptance of insulating materials, national rules and standards, as well as European (e.g. European Technical Approval ETA) have to be taken into account. With respect to energy-efficiency, the Energy Performance of Buildings Directive has to be considered. This directive has to be implemented fully into the laws of all EU Member States. Table 3.16 provides in detail the application areas of selected insulating materials, as well as performance parameters – including some indicators with respect to the production processes, i.e. (non) renewable primary energy consumption, GHG-potential, acidification equivalent and photosmog equivalent. Corresponding data for a comprehensive list of insulating materials can be found in the references (Mötzl and Zelger, 2000).

Table 3.16: Application areas (ÖNORM B600), as well as performance parameters of selected insulating materials, fire classification according to DIN EN 13501-1

			Glass wool			Polyurethane hard foam		
Application area (ÖNORM B600)			**Type W**	**Type T**	**Type PT**	**Type DD**	**Type DO**	**Type BL**
Product type classification			ÖNORM B 6035			ÖNORM B 6055		
Wall	External Insulation	With rear ventilation	X	X	X	X	X	X
		Under thin plaster			X		X	
		Under thick plaster			X		X	
		Perimeter insulation						
	Core Insulation	In double-layer walls	X		X		X	X
		In light elements	X		X		X	X
		As cavity insulation	X	X	X		X	X
	Internal Insulation	Under plaster		X	X		X	
		Under dressing	X		X	X	X	X
Roof	External Insulation	Warm roof			X	X	X	X
		Inverted roof						
		Cold roof, loft conversion	X	X	X	X	X	X
		Insulation (walkable), top floor ceiling		X	X	X	X	X
		Ceiling over external air, open, sound absorption	X	X	X			
		Ceiling over external air, plastered			X		X	X
	Internal Insulation	Internal insulation under screed, without impact sound requirements		X	X	X	X	X
		Under screed at high compressive load			X	X	X	X
		Impact sound insulation under screed		X				
		Layer below ceilings	X	X	X			
Suspended ceiling		Outside	X	X	X	X	X	X
		Inside	X	X	X	X	X	X
Performance parameters								
Thermal conductivity [W/(K*m)]			0.039	0.035	0.036	0.025 – 0.03		
Water vapour resistance factor [-]			1 – 1.2			60-diffusion resistant		
Specific flow resistance [kNs/m^4]			>=5		-	-		
Dynamic stiffness [MN/m³]			-	9	-	-		
Fire classification			A1/A2			D/E		
Density [kg/m³]			19.5	67	153	>=30		
Production		Renewable primary energy demand in MJ/kg	1.39			8.22		
		Non renewable primary energy demand in MJ/kg	34.6			126.19		
		GHG-potential in kg CO_2-equivalent/kg	1.70			4.928		
		Acidification in kg SO_2-equivalent/kg	9.57			35.80		
		Photosmog in kg ethene-equivalent/kg	0.54			16.656		

Source: Mötzl and Zelger, 2000

Table 3.17 and Table 3.18 provide data for selected insulating materials in Germany. In order to achieve better comparability, costs, primary energy demand for production, and thickness refer to a heat transfer coefficient of U=0.4 W/(m²K). The compressive strength is only important if the insulation layer will be loaded, e.g. as in the case of parking levels. A higher density of the insulating material causes an increase in the thermal mass and thus a reduction of temperature variations. On the other hand it causes an increase in the insulation layers' weight and thus has different requirements for its installation. The dehumidification capacity is highly important, as the heat transfer coefficient increases, if the insulating material becomes humid. Hence a good dehumidification capacity enables a fast return to the original heat transfer coefficient. The water vapour resistance factor influences the moisture proofing of an insulating material, as well as the indoor climate of the insulated room. Health impacts, e.g. of carcinogen fibres, formaldehyde loads etc. should be closely examined. Furthermore the limited availability of resources and the possibility of recycling, reuse and energetic valorisation after the use phase of the insulating material should be already considered during the decision process.

Table 3.17: U=0.4 W/(m²K); Cost and operational data of selected insulating materials in Germany, fire classification according to DIN EN 13501-1

Material	Costs for U [€/m²]	Density [kg/m³]	Com-pressive strength [N/mm²]	Primary energy demand for U [kWh/m²]	Thick-ness for U [cm]	Specific heat capacity [kJ/(kg*K)]	Fire classification	Water vapour resis-tance factor [-]
Glass wool	6 – 20	20 – 140	0.004 – 0.08	36	10	0.84	A1/A2/B/E	1
Rock Wool	6 – 21	25 – 200	0.005 – 0.05	18	10	0.84	A1/A2/B/E	1 – 2
Coconut fibre	26	80 – 120	N. A.	115	11	1.3	D/E	1
Flax	13 – 17	18	N. A.	16 – 19	10	1.3	D/E	1
Hemp	12	25	N. A.	27 – 29	10	1.8	D/E	1 – 2
Sheep wool	15	20	N. A.	7 – 10	10	1.3	D/E	1 – 2
Perlite boards	26 – 45	150 – 200	0.25	31	14 – 15	1	A2/B/C/D/E	5
Foam glass	29 – 57	105 – 165	0.4 – 1.0	176	10 – 15	0.83	A1/A2/B/C/D/E	
Calcium silicate boards	90	200 – 260	1.0 – 2.1	468	13	1	A2	6
Mineral foam board	31	115	3.6	28	11	1	A2	5
Polyurethane hard foam	18	15 – 80	0.1 – 0.2	45	7 – 9	1.48	B/C/D/E	30 – 100
Expanded polystyrene (EPS)	7	15 – 30	0.06 – 0.25	81	9 – 10	1.48	B/C/D/E	20 – 100
Extruded polystyrene (XPS)	19	20 – 60	0.2 – 0 – 7	73	8 – 10	1.48	B/C	80 – 250
Cork boards	30	80 – 100	0.01	21	11	1.8	D/E	5 – 30
Reed boards	25	190 – 220	N. A.	36	14	1.3	B/C/D/E	2
Woodfibre boards	21	160	0.07	99	10 – 11	2.1	D/E	5 – 10
Cellulose boards	13	60 – 80	N. A.	39	10	1.94	D/E	1
Perlite loose – fills	13	60 – 165	N. A.	53	13	1	D/E	2 – 3
Expanded mica schist	18	75 – 80	N. A.	22	18	1	A1	3 – 4
Cork shred	20	80 – 140	N. A.	7	13	1.6	D/E	1
Chipped wood, wood fibres	7	50 – 100	N. A.	9	10	1.9	D/E	1 – 2
Granulated grain	14	110	0.07	27	13	1.6	D/E	1
Cellulose flocs	3 – 6	40 – 60	N. A.	9	10	1.9	B/C/D/E	1 – 2

Source: König, 2008.

Table 3.18: Application areas and additional data of selected insulating materials; type: mineral (M), synthetic (S), herbal (H), animal (A); group: mats (M), felts (F), boards (B), loose-fills (L); main application area: wall (W), roof (R), ceiling (C), floor (F)

Material	Type	Group	Main application area	Dehumidification capacity	Notes	Resources	Recycling
Glass wool	M/S	M/F/B/L	steep R, W, F	bad, not capillary conductible	cancerogenity possible	partially limited	reuse possible
Rock wool			R, W, C, F, facade				
Coconut fibre	H	M/F	darning wool, screed insulation	very good, capillary conductible	-	renewable	reuse as insulating material, energetic valorisation
Flax			R, C, F	very good	problematic additives	renewable	
Hemp				very good	-	-	-
Sheep wool	A		R, C, int. W	very good	problematic additives	renewable	reuse as insulating material, energetic valorisation
Perlite boards	M	B	flat R, parking level, melted asphalt screed	medium, not capillary	-	-	reuse as insulating material or to loosen up soil
Foam glass			basement W, flat R, F panel	no	-	-	recycling of production offcut, reuse as gravel in road construction
Calcium silicate boards			int. insulation, fire protection	very good	-	-	-
Mineral foam board			ext. insulation, fire protection	water-repellent	-	-	-
Polyurethane hard foam	S		flat R, basement W	bad, not capillary, closed-cell	-	very limited	-
Expanded polystyrene (EPS)			W, R, screed	bad, not capillary	-	very limited	reuse as insulating material, energetic valorisation (decomposition products problematic on landfills)
Extruded polystyrene (XPS)			basement W, F panel, inverted R	bad, closed-cell	-	very limited	-
Cork boards	H		on the R, ext. W, refrigeration room	good	-	renewable	-
Reed boards			R, W, F	very good			-
Woodfibre boards			R, ext./int. W, C	very good	noise protection		reuse as insulating material, energetic valorisation
Cellulose boards			R, W, C, F, facade	good	-	recycling product	-
Perlite loose-fills	M	L	cavity filling, leveling material (screed)	medium, not capillary	formation of dust	-	reuse as insulating material or to loosen up soil
Expanded mica schist			C, chimney	good	-	-	-
Cork shred	H		F, C, R	good	-	renewable	recycling possible, use of residue as fill, energetic valorisation
Chipped wood, wood fibres			R, C, F, W	good	-		reuse as insulating material, energetic valorisation
Granulated grain			R, ext./int. W, C	very good	noise protection		-
Cellulose flocs			R, C, W, F	good	-	recycling product	reuse as insulating material, energetic valorisation

Source: CRTE, 2009, König, 2008

Applicability

The techniques described are applicable to all existing buildings. Technically, the best way to insulate a building component is on the outdoor face. Internal insulation is used if it is not possible to use external insulation, e.g. because of exceeding the dimensions of the building plot or poor aesthetics. In all cases, a higher thickness of the insulation material results in better insulation. Usually, a higher insulation thickness or an insulation material with a lower thermal conductivity can be provided for almost all kinds of insulations, e.g. for insulations of walls, roofs, and floors. (Thunshelle et al., 2005)

Some recommendations are given by CRTE, 2009:

- utilisation of recycled and recyclable insulating materials as the elevated requirements of heat protection raise the amount of insulating material needed
- adequate installation
- use of environmentally friendly adhesives
- avoidance of large-area adhesion, in order to maintain recyclability
- avoidance of thermal bridges
- avoidance of cutting scrap, e.g. by utilisation of bulk insulation material (perlite, expanded mica) or loose filler as blow in cellulose; furthermore, these materials are re-usable after dismantling
- avoidance of small packaging.

Economics

The economics of insulation is determined by a trade-off of investments in and operational cost savings of energy-saving measures. Therefore, the whole life cycle of energy-saving measures has to be considered. Annuities for different cities in the EU have been compared. Assumptions concerning energy prices, interest rates (4 – 6 %), service lifetime (30 yrs), fuel mix, regional differences in investment related costs, efficiencies of heating systems etc. had to be made. Table 3.19 provides heat transfer coefficient recommendations from an economic point of view for walls, roofs and floors in new constructions and retrofits of buildings in different cities. These recommendations correspond to the situation that the construction element is being insulated and only the insulation thickness has to be determined. Wether this optimum provides an economic benefit depends in the case of retrofits on the heat transfer coefficient of the existing building and on the combination of insulation measures with refurbishment activities that are performed anyway. E.g., the replacement of the exterior plaster of walls requires scaffolds anyway, so that combined insulation measures become more economic. (Boermans and Peterdorff, 2007).

Table 3.19: Heat transfer coefficient recommendations for walls, roofs and floors in selected cities of the EU

City	Heat transfer coefficient recommendation, W/m²K		
	Wall	Roof	Floor
Palermo	0.48	0.34	1.44
Barcelona	0.44	0.27	0.84
Rome	0.32	0.25	0.58
Marseille	0.29	0.23	0.52
Zagreb	0.26	0.21	0.36
Belgrade	0.25	0.20	0.34
Nantes	0.24	0.20	0.34
Dublin	0.23	0.19	0.30
Prague	0.22	0.18	0.28
Manchester	0.21	0.17	0.26
Stockholm	0.20	0.16	0.25
Munich	0.19	0.16	0.24
Helsinki	0.18	0.14	0.23
Umea	0.17	0.13	0.20
Kiruna	0.15	0.12	0.18

Source: Boermans and Petersdorff, 2007

Investment data for the insulation of walls, roofs and floors in existing residential buildings, built before 1975 is provided in Table 3.20. The investments include labour and material and are provided in EUR per m² component area. The table contains for each of the above mentioned climatic zones, the investments for three insulation qualitites Ref1, Ref2 and Ref3. They correspond to the current building code standards from 2003 until 2006 (Ref1), a scenario with more advanced standards (Ref2) and a standard corresponding to low energy houses (Ref3).

Table 3.20: Investments for the insulation of walls, roofs and floors in existing buildings

Cold climate zone									
	Walls			Roofs			Floors		
	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3
U-value before, W/Km²: U1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.5
U-value after, W/Km²: U2	0.18	0.17	0.15	0.15	0.13	0.11	0.18	0.17	0.15
Labour, Eur/m²	66.0	66.0	66.0	37.8	39.1	44.9	21.8	21.8	21.8
Material, Eur/m²	88.9	92.9	99.0	18.9	19.6	22.3	29.3	30.7	32.7
Total investment, Eur/m²: T	154.9	158.9	165.0	56.7	58.7	67.3	51.1	52.2	54.5
T/(U1-U2)	484.1	481.5	471.4	162.0	158.6	172.6	159.7	158.2	155.7
Moderate climate zone									
	Walls			Roofs			Floors		
	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3
U-value before, W/Km²: U1	1.50	1.50	1.50	1.50	1.50	1.50	1.20	1.20	1.20
U-value after, W/Km²: U2	0.41	0.38	0.20	0.25	0.23	0.20	0.44	0.41	0.28
Labour, Eur/m²	50.6	50.6	50.6	20.6	22.3	24.4	13.8	13.8	13.8
Material, Eur/m²	36.9	38.3	49.4	10.3	10.6	21.1	15.3	16.1	19.2
Total investment, Eur/m²: T	87.5	88.9	100.0	30.8	31.9	36.6	29.1	29.9	33.0
T/(U1-U2)	80.3	79.4	76.9	24.6	25.1	28.2	38.3	37.8	35.9
Warm climate zone									
	Walls			Roofs			Floors		
	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3
U-value before, W/Km²: U1	1.97	1.97	1.97	2.46	2.46	2.46	2.46	2.46	2.46
U-value after, W/Km²: U2	0.59	0.48	0.25	0.50	0.43	0.30	0.50	0.43	0.30
Labour, Eur/m²	30.4	30.4	30.4	13.2	13.6	15.6	10.0	10.0	10.0
Material, Eur/m²	31.9	35.3	45.6	6.6	6.8	7.8	6.6	6.8	7.8
Total investment, Eur/m²: T	62.3	65.7	76.0	19.3	20.4	23.4	20.6	21.7	25.1
T/(U1-U2)	45.1	44.1	44.2	9.8	10.0	10.8	10.5	10.7	11.6

Source: Eichhammer et al., 2009

In the case of unheated and unused top floors with steep roofs, insulation of the topmost ceiling is, from an economic point of view, generally the most reasonable insulation measure. (GRE, 2002).

Further cost data is provided in Table 3.17.

Driving force for implementation

The improvement of building insulation for new and existing buildings always pays back and saves energy and reduces the carbon footprint. Also, building standards and codes are evolving to be more restrictive, so fulfilling legal requirements will also be a significant driving force.

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European Insulation Manufacturers Association, EURIMA

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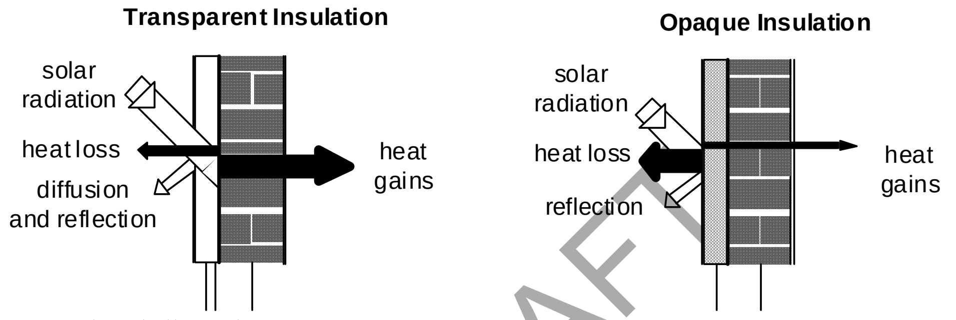
3.4.1.2 Techniques to improve the performance of walls

Description

In this section, several outstanding techniques that may be used to improve the performance of walls, apart from those referring to insulation (see 3.4.1.1), are described as transparent insulation, vacuum insulation and other techniques.

Transparent insulation reduces heat losses and increases solar gains in comparison with opaque insulation (see Figure 3.19). With this system, the solar radiation passes the transparent insulation layer and is converted to heat at the dark coloured exterior surface of the inner shell of the wall. Therefore, the insulation reduces the heat losses, especially of solar heat gains, and a large part of the gained heat is transfered to the inside of the building. (Thunshelle et al., 2005)



Source: Thunshelle et al., 2005

Figure 3.19: Functional principle of transparent insulation in comparison with opaque insulation

The application of vacuum insulated panels reduces the thermal conductivity of conventional insulation materials (down to 0.004 W/mK) (Mainka et al., 2005). This facilitates the use of thinner insulation layers in comparison to conventional constructions. The evacuated (1 mbar) core material of the panel is covered by a high-performance aluminium foil. The elements are integrated into a polystyrene cover in order to make the units applicable to construction conditions and protect them from sharp edges during transportation and mounting. The main drawbacks of these systems is that gas leakage causes an increase of the thermal conductivity of 0.0015 W/mK in 20 – 30 years. The construction boards are manufactured in certain sizes and neither nailing nor cutting is possible. Furthermore, potential damages during transport and installation have to be controlled and information has to be provided about the protection during use.

The integration of glass bubbles into plaster layers, e.g. on bricks, causes the absorption of solar radiation and that the convective heat transfer to the outside air do not occur on the same layer. Thus, the useful gains from direct and diffuse radiation increase, whereas the convective heat losses decrease. In comparison to conventional plaster systems, energy losses decrease by 15 to 25 % (Thunshelle et al., 2005). This can be combined with IR-coatings and highly absorbtive colours, further reducing heat losses and raising solar gains. The protection against weathering by similar surfaces keeps the thermal conductivity at lower levels. Furthermore, the radiant heat transfer is diminished by the presence of IR-active pigments in the paint, whereas the use of highly absorptive colours onto the south surface increases the solar gains.

Achieved environmental benefit

Techniques to improve the performance of walls reduce the heat demand and may increase the thermal comfort, through warmer inner surfaces of walls.

The useful energy saving potential of transparent thermal insulation materials compared to conventional insulation materials of the same thickness ranges from 13 to 71 kWh per m² component area (envelope) and up to 21 kWh per m² useful building floor area (Reiss et al., 2005; Thunshelle et al., 2005).

Vacuum insulated panels, compared to conventional insulation materials of the same thickness, save about 26 kWh per m² component area and about 7.3 kWh per m² useful building floor area. High performance plaster system can save from 3 to 10 kWh per m² component area and from 0.9 to 2.8 kWh per m² useful building floor area.

Appropiate environmental indicators

The described measures have an impact on the U-value, heat transfer coefficient, which can be controlled alongside the energy demand for heating, measured by the specific energy demand (energy consumed per square metre and year). This indicator, quite useful in terms of primary and final energy demand, would indicate the overall thermal performance of the building, as it is designed. Nevertheless, the exact definition on how it is calculated should be provided when assessing a building: including type of energy (final or primary), time of building use (an office building lifetime may not be comparable to other types of building) and area (useful area, floor area, corrected area with height, etc.).

This indicator is also proposed for other techniques, as it could be the main indicator gathering information on the main benefits from applying best environmental management practice. A full description on the calculation for heating and cooling (i.e. the thermal performance of the building) can be found in ISO 13790:2008. Also, a short, simplified description can be found in section 3.4.2.

Cross-media effects

Techniques increasing the capacity to gain solar radiation would have an adverse effect in summer and may increase the energy consumption for space cooling. An overall balance is recommended and best practices application should depend on it, and include that the application intensity of several measures should be assessed for every climate.

Operational data

Technical characteristics of the insulation materials described can be found in the website of suppliers. Several case studies are analysed by Thunshelle et al., 2005. For example, some cases studies revealed that transparent insulation can lead to overheating problems in summer. This can be easily solved by combining this technique with efficient shading systems. Also, there is a time shift between the solar gains and the emission of the heat to the room, so transparent insulation should be applied in rooms with higher occupancy during the evening. Vacuum installation panels should be regarded as a way of dividing compartments inside a building, saving space and increasing thermal and noise protection. Normally, the border area has to be insulated with polystyrene, as no cutting can be made in vacuum panels.

Applicability

There are no restrictions on the applicability of this practice. Climatic zones can influence the mode of implementation and the final characterisitics of the wall, but not the suitability of the technique.

Economics

In Germany, additional gross investments for transparent thermal insulation materials compared to conventional insulation materials of the same thickness range from 13 to 71 € per m² component area and from 1 to 21 € per m² useful building floor area. For vacuum insulated panels, costs are about 105 € per m² component area and about 29 € per m² useful building floor area. For high performance plasters, the cost would be from 60 to 80 € per m² component area and from 18 to 23 € per m² useful building floor area (Reiss et al., 2005; Thunshelle et al., 2005).

Driving force for implementation

The main driving force for the implementation of these techniques is the better energy performance of the building, especially for heating, where great savings can be also obtained. Also, legal requirements on the energy efficiency of buildings may influence the implementation. Also, some spatial restraints requiring special applications can be an element to consider by designers.

Reference organisations

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- Sto AG
- Va-Q-tec AG
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3.4.1.3 Improving the environmental performance of roofs

Description

The thermal behaviour of roofs can be improved by increasing the thickness of insulation materials (see 3.4.1.1). Nevertheless, some outstanding techniques are designed to enhance the environmental performance. In this section, cool, brown and green roofs are described.

A **cool roof** is a roofing system able to reject solar heat and keep roof surfaces cooler under the sun, in the same way as white houses often found in Mediterranean countries do. This ability to stay rather cool in direct sunlight is due to the properties of the materials, which reflect the solar radiation (solar reflectance or albedo) and release the heat they have absorbed (infrared emissivity). This can prevent the urban heat island effect. The main cause for this effect is the built environment, which absorbs more heat, especially streets and roofs as they are often made of dark materials (see 2.2.4).

A cool roof reflects and emits the sun's energy back to the sky instead of allowing it to enter the building below as heat. In many climate zones, a cool roof can substantially reduce the cooling load of the building. Cool roofs also cool the world independently of avoided carbon emissions, simply by reflecting the sun's incoming radiation back into the atmosphere, thereby mitigating global warming. A study found that world-wide reflective roofing will produce a global cooling effect equivalent to offsetting 24 gigatons of CO_2 over the lifetime of the roofs (Akbari et al., 2009)

The overriding aim in designing a **brown roof** is to encourage biodiversity, e.g. by compensating the loss of habitat or by providing protected habitats on the roof. Soil and rubble caused by the construction of a new building on a brownfield site can be used as brown roof substrate and provide a rooftop habitat for the flora and fauna of the former brownfield site. Rooftop habitats are protected from interferences on the ground and introduce areas of vegetation to otherwise barren places. The brown roof can be tailored specifically to the type of species the roof should provide a habitat for. Due to the flexible concept of brown roofs, it should also use a high percentage of recycled products. Dependent on the target species, the rooftop could contain plants indigenous to the area, water pools, wetland areas for the establishment of mosses and lichens, logs to provide a habitat for insects invertebrates, boulders and stones, land forms created to provide different landscape levels, seeding of indigenous plants etc.(BrownRoof, 2010).

Figure 3.20 shows a typical example for the layer build-up of brown roofs. The brown-roof comprises the following four layers:

- The substrate layer consists of a varied range of growing mediums (local soil and spoil, aggregates etc.), usually selected to maximise biodiversity.
- The filter layer consists of a geotextile filter sheet and prevents fine particles from the substrate collecting in the drainage layer.
- The drainage layer often consists of plastic sheets embossed with a pattern of water-retaining cups and therefore controls the water-retention properties of the brown roof in combination with the substrate layer. Excess water is able to percolate through.
- The waterproofing layer can be of any type suitable for flat roof applications. Ideally, the waterproofing layer will also act as a root barrier. If it does not, a separate root barrier layer will be needed.

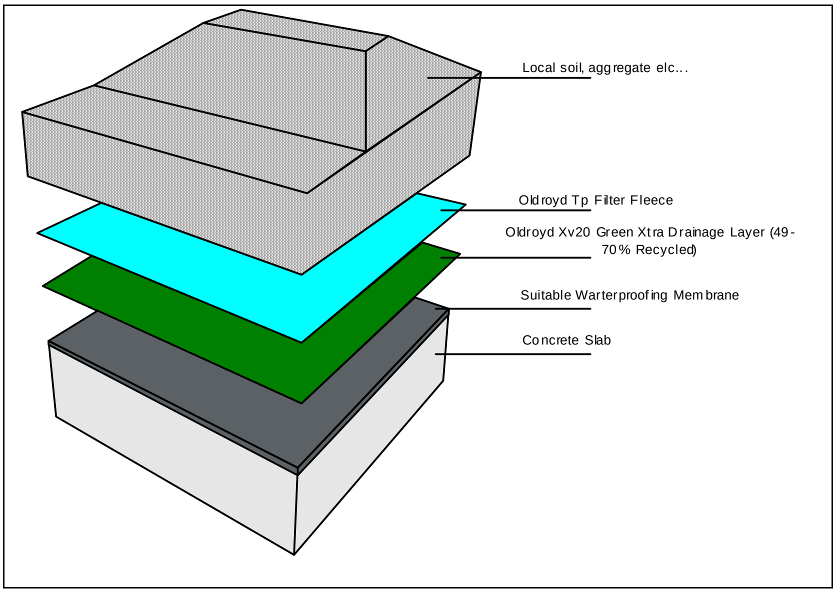
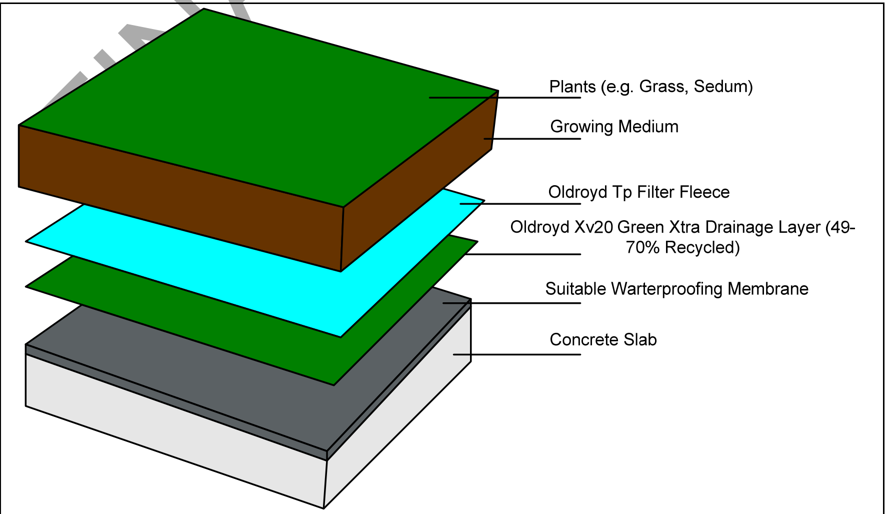


Figure 3.20: Typical layer build-up of brown roofs

Green roofs act as insulation layer: they stabilise temperatures during the summer and the winter and provide urban heat island mitigation benefits (see 2.2.4). Furthermore, storm water run-off is reduced by the absorption of water. One distinguishes into pitched green roofs and flat green roofs. The latter ones differ between extensive roofs, which have a thin layer of growing material, and intensive roofs, which have a greater soil depth. Because of the high loads intensive ones usually have to be installed over concrete slabs. Figure 3.21 provides a typical layer build-up of an extensive or semi-intensive green roof. A waterproofing layer is laid onto the underlying roof structure. Then a perforated drainage layer with reservoir capability is used in addition. Then, a filter layer soil loading and plantings are added (see operational data for more information).



Source: SafeGuard Europe, 2011b

Figure 3.21: Typical layer build-up of flat green roofs

Achieved environmental benefits

The benefit of cool roofs is to reduce space cooling demand and to reflect solar radiation, reducing directly global warming potential and avoiding environment damages caused by the urban heat island effect. By immediately reflecting solar radiation back into the atmosphere and re-emitting some portion of it as infrared light, cool roofs result in cooler air temperatures for the surrounding urban environment during hot summer months. Cool roofs, through mitigation of the urban heat island effect and reduction of ambient air temperatures, in turn improve air quality. Smog is created by photochemical reactions of air pollutants and these reactions increase at higher temperatures. Therefore, by reducing the air temperature, cool roofs decrease the rate of smog formation. Lower ambient air temperatures and the subsequent improved air quality also result in a reduction in heat-related and smog-related health issues, including heat stroke and asthma.

Because cool roofs reduce air-conditioning use during the day's hottest periods, the associated energy savings occur when the demand for electricity is at its peak. Therefore, use of cool roofs reduces the stress on the energy grid during hot summer months and helps avoid shortages that can cause blackouts or brownouts.

The cool roof concept can provide several direct benefits to the building owner and occupants:
- reduced air conditioning use, resulting in energy savings typically of 10 – 30 %
- decreased roof maintenance due to longer roof life
- increased occupant comfort, especially during hot summer months.

Based on US experiences and models, Akbari et al., 2005 calculated the following performance parameters:
- Radiative Forcing (RF) is 1.27 W/m² per 0.01 increase of albedo of treated surfaces.
- Atmospheric CO_2-equivalence of increasing solar reflectance of a surface by 0.01 is 1.4 kg/m².
- Emitted CO_2-equivalence of increasing solar reflectance of a surface by 0.01 is -2.5 kg CO_2 per m^2.
- With a typical reduction in albedo for residential and non-residential buildings after cool roof installation of 0.25, the emitted CO_2 offset for cool roofs is -63 kg CO_2/m^2; this means, that each square metre of roof converted into a cool roof can compensate the global warming of 63 kg (38 kg for cool pavements) CO_2 in the atmosphere.

Green and brown roofs are identified as good practices to conserve biodiversity, by providing new habitats in areas of deficiency and creating new links and conections to improve the mobility of wild life.They are also identified as an optimal component of drainage systems in order to control the rainfall run-off. Also, green roofs are able to uptake water, use it in their biochemical processes and release it in the evapotranspiration process. Kellagher and Lauchlan, 2005 reported that green roofs are very effective for both attenuation and volume reduction in run-off for small events. Also, green and brown roofs act as filters for pollution (especially dust and suspended materials).

From the thermal balance point of view, the additional layer of green and brown roofs adds insulation to the building, helping to reduce temperature fluctuations, not only because of insulation but also due to the evapotranspiration processes. Also, the contribution of green roofs to albedo is relevant and they can act also as a cool roof.

All of these processes (insulation, evapotranspiration and reflection of sun light) contribute to reducing the urban heat island effect in cities when applied extensively in a city. This technique is, thus, linked to several policy strategies options, as explained in section 2.2.4.

Appropriate environmental indicators

The described measures have an impact on the overall performance of heat transfer, which can be controlled alongside the energy demand for heating, measured by the specific energy consumption (energy consumed per square metre and year). This indicator, quite useful in terms of primary and final energy demand, would indicate the overall thermal performance of the building as a whole. Nevertheless, the exact definition on how it is calculated should be provided when assessing a building: including type of energy (final or primary), time of building use (an office building lifetime may not be comparable to other types of building) and area (useful area, floor area, corrected area with height, etc.). As explained in other sections, this indicator is also proposed for other techniques, as it could be the main indicator gathering information on the main benefits from applying best environmental management practices. A full description on the calculation for heating and cooling (i.e. the thermal performance of the building) can be found in ISO 13790:2008. Also, a short, simplified description can be found in section 3.4.2.

In particular, for the technique described in this section, the performance of building products for cool roofs can be measured in solar reflectance and thermal emissivity:

- Solar reflectance (or albedo) is a measure of a material's ability to reflect sunlight (including the visible, infrared, and ultraviolet wavelengths) on a scale of 0 to 1. An albedo value of 0.0 indicates that the surface absorbs all solar radiation, and a 1.0 albedo value represents total reflectivity. The ENERGY STAR Reflective Roof Products criteria specify an albedo of 0.65 or higher for low-slope roof applications and 0.25 for sloped roofs (EPA, 2010).
- The emissivity of a material is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature.

Biodiversity indicators may be used for assessing the performance of green and brown roofs, e.g., the number of species living in the roof or, qualitatively, if a certain measure is creating a net biodiversity gain. Also, the impact on water can be measured by the amount of water collected during short or large events of rainfall.

Cross-media effects

Reduced maintenance and extended roof life is claimed, thus reducing solid waste. The increased heating in colder periods reduces energy savings, depending on climate (see Applicability).

Operational data

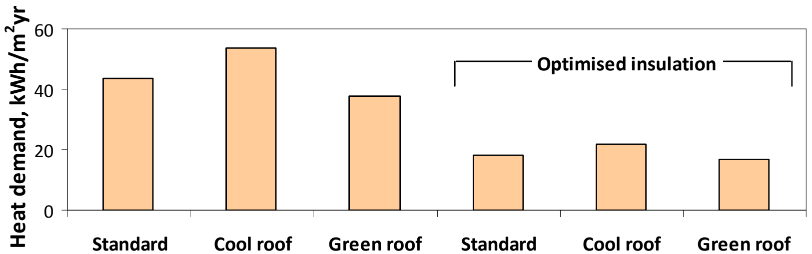
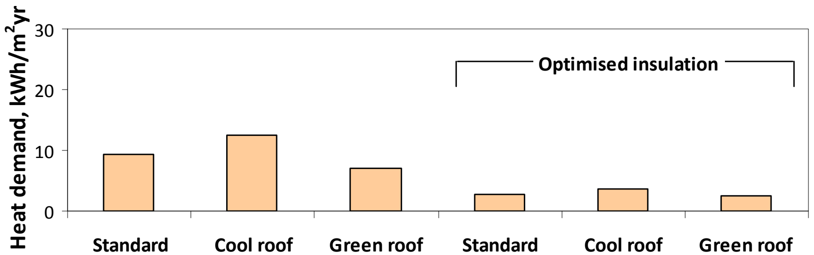
To produce the cool roof effect, many ‘cool colour’ products exist. These use darker-coloured pigments that are highly reflective in the near infrared (non-visible) portion of the solar spectrum. With ‘cool colour’ technologies, there are roofs that come in a wide variety of colours and still maintain a high solar reflectance. The two basic characteristics that determine the ‘coolness’ of a roof are solar reflectance and thermal emissivity. Both properties are rated on a scale from 0 to 1, where 1 is the most reflective or emissive.

The project COOLROOFS developed a database of cool materials and can be consulted at the project webpage (Cool Roofs, 2010). In addition, five case studies are decribed in the ‘Report on the five case studies and analysis of the results’ Final Version, WP3: Technical Aspects of Cool Roofs, Task 3.2: Pilot Actions and Analysis of the Results’ available at the webpage of the project. These demonstration projects encompass the following buildings:

- cooled 800 m^2 office building in a school campus in Trapani, Italy
- cooled 50 m^2 laboratory in Chania, Greece
- two not cooled elementary school buildings in Kessariani, Greece
- not cooled laboratory in London, England
- not cooled 100 m^2 residential unit in La Rochelle, France.

The final results showed that indoor temperature decreased substantially in these buildings after the application of cool materials. According to the results obtained, some models were made and simulations in insulated and non-insulated buildings were developed. In Table 3.21, charts show the results of the comparison of green roofs and cool roofs for a Mediterranean city (Barcelona) in a row house and office buildings.

Table 3.21: Heat, cooling and total energy demand of a row house and an office building with different types of roofs

<table>
<tr><th>Building type</th><th>Row house</th><th>Office building</th></tr>
<tr><td>Heat demand</td><td>
</td><td>
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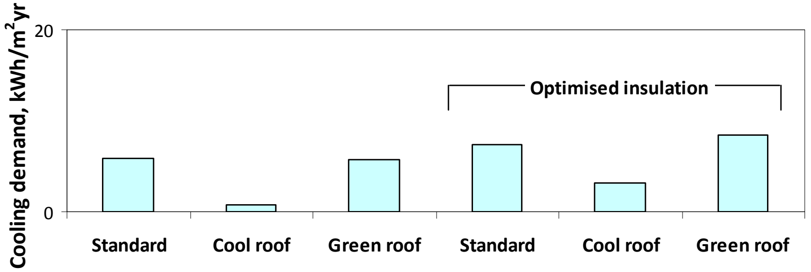
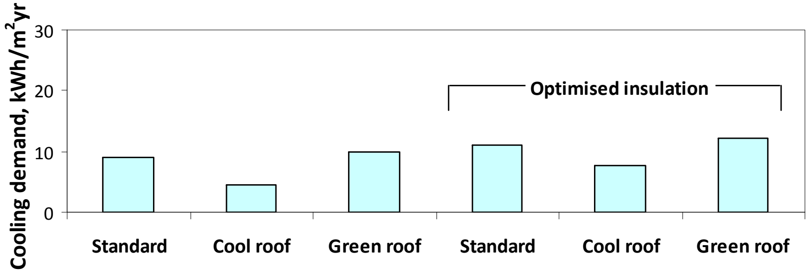
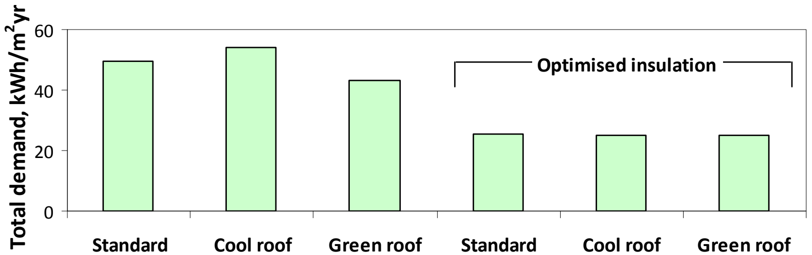
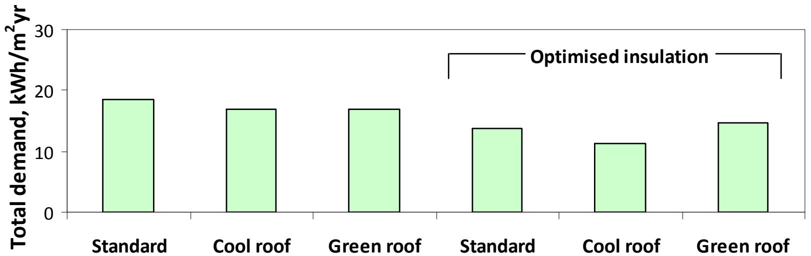
<tr><td>Cooling demand</td><td>
</td><td>
</td></tr>
<tr><td>Total heating + cooling</td><td>
</td><td>
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</table>

N.B. Adapted from Cool Roofs, 2010

According to the results of Table 3.21, cool roofs are able to reduce the energy demand for cooling but with a counter effect on the energy demand for heating, as solar gains are reduced. Green roofs have an insulation capacity, so the effect may not be good for cooling, but they reduce heating demand. Then, total energy demand does not vary much from the 'standard practice' building compared to cool and green roofs, for row houses and for office buildings. Nevertheless, when applying an optimal insulation level, the overall energy demand is reduced significantly, even though energy demand is increased because of the higher influence of internal gains. Integrative approaches are definetly needed when applying cool or green roofs. For well insulated and optimised buildings (e.g. passive house standards), the influence of cool roofs may be negligible for the thermal performance of the building. Nevertheless, the use of reflective materials will always have a positive impact on the mitigation of urban heat islands. For green roofs, the benefits go beyond the thermal balance: biodiversity, urban heat island benefits, reduction of water run-off, etc. are several environmental benefits derived from their application.

There are two main types of green roofs:

- extensive green roofs
  - require less maintenances (one or two inspections per year, without water or nutrients supply)
  - adapted plant communities (low demanding and self-regenerating)
  - load of 150 kg per m^2 (layers up to 12 cm)
  - low installation costs
- intensive green roofs
  - designed with a purpose, i.e. Roof Garden
  - higher water storage
  - different loads, depending on different plant communities
  - may require more maintenance and water irrigation.

There are other intermediate options, such as semi-intensive or semi-extensive green roofs depending on the use and purpose of the roof. Characteristics of the substrates for several examples of green roof are shown in Table 3.22.

Table 3.22: Commercial green substrate for several types of green roofs

Characteristics	**Extensive (Sedum)**	**Extensive (Rocky type plant)**	**Semi-extensive**	**Intensive**
Granules < 0.063mm	< 7 %	< 15 %	< 15 %	< 20 %
Maximum water capacity	25 %	36 %	42 %	46 %
Air content at maximum water capacity	38 %	27 %	22 %	18 %
Water permeability	> 1 mm/s	> 0.97 mm/s	> 0.64 mm/s	> 0.34 mm/s

N.B. Adapted from Nagase et al., 2011

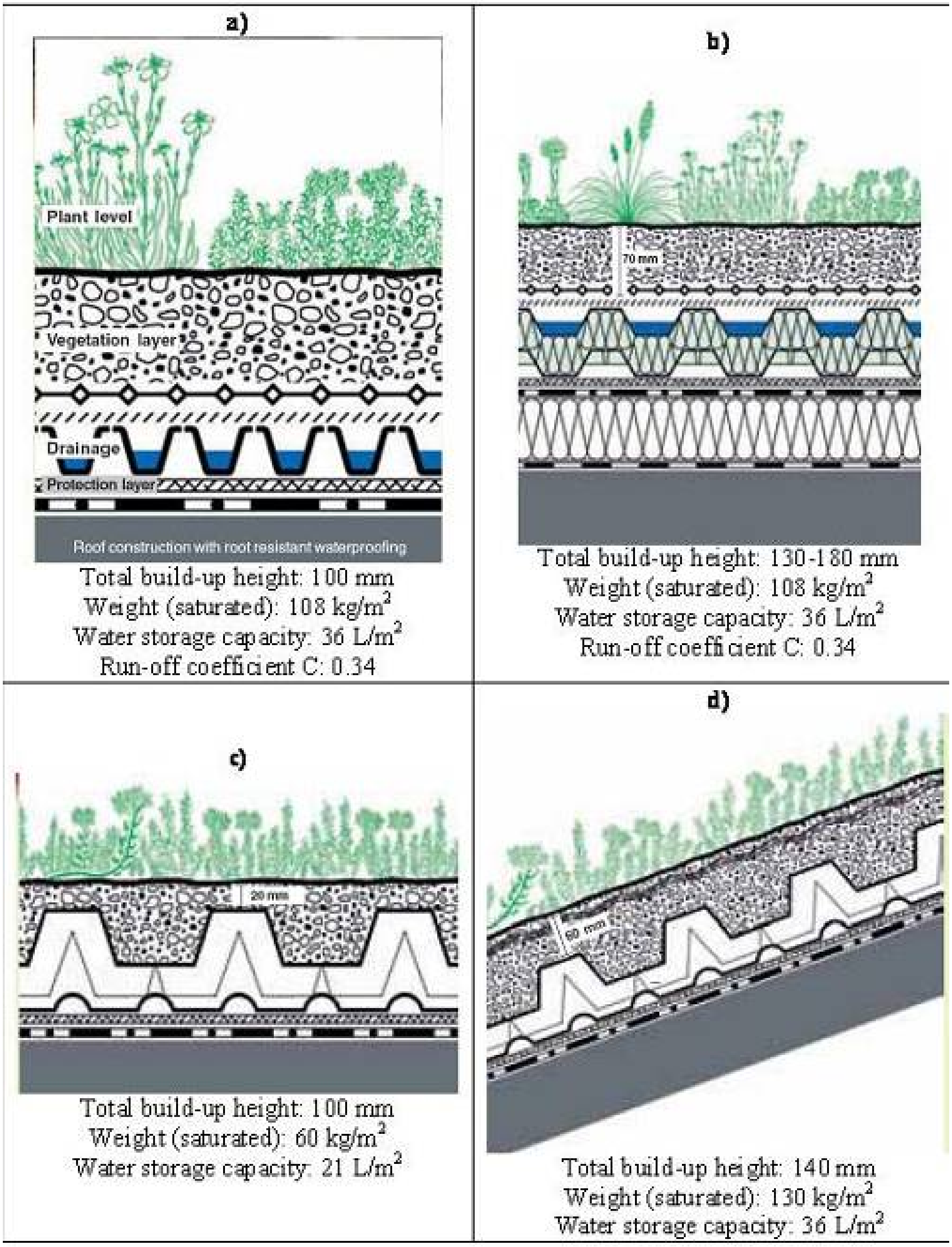
According to Zinco, a green roof supplier, rockery type plants are those plants which provide a long blooming period and allow for different appearences through-out the vegetation period. Sedum species and other pernnials are used as ground cover. They are low growing species. The main blooming time is in early summer, with yellow or red and white flowers. A list of plants used in extensive roofs is shown in Table 3.23.

Table 3.23: Examples of plants to be used in extensive green roofs

Botanical name	Common name	Height (cm)	Blossom colour
'Rockery type plants'			
Dianthus carthusianorum	Clusterhead pink	40	red
Festuca Cinerea-Hybride	Blue Fescue	25 – 30	brown
Gypsophila repens e.g. 'Rosa Schönheit'	Baby's Breath	10 – 15	rose
Helianthemum nummularium	Sun Rose	5 – 10	yellow
Koeleria glauca	Large blue Hair Grass	45 – 50	bluish
Petrorhagia saxifraga	Tunic Flower	10 – 20	rose – white
Saponaria ocymoides	Rock Soapwort	15 – 20	rose
Satureja montana ssp. *illyrica*	Winter Savory	10 – 15	violet
Saxifraga paniculata	Livelong Saxifrage	20 – 25	white
Sempervivum	Houseleek hybrids	10 – 20	red/rose
' Sedum Carpet'			
Sedum album varieties	white stonecrop varieties	5 – 10	white
'Coral Carpet'		5 – 10	white
'Murale'	Nettle – leaved goosefoot	5 – 10	Pale-rose
Sedum cauticolum	Stonecrop	10 – 15	rose
Sedum floriferum 'Weihensteph. Gold'	Gold Sedum	10 – 15	golden
Sedum hybridum 'Immergrünchen'	Hybrid Stonecrop	10 – 15	yellow
Sedum reflexum	Crooked Yellow Stonecrop	20 – 25	yellow
Sedum sexangulare	Tasteless Yellow Stonecrop	5 – 10	yellow
Sedum spurium in varieties	Dragons Blood		
eg. 'Album Superbum'	Stonecrop	10 – 15	white
'Fuldaglut'		10 – 15	red
'Roseum Superbum'		10 – 15	rose
'Splendens'		10 – 15	rose
' Variegatum'		10 – 15	rose

N.B.: Adapted from Zinco, 2011

Some example structures of green roofs can be found in Figure 3.22. The important issues in the design are the weight load on the roof and the resistance to roots of the existing waterproofing layer. As shown, the design is adaptable to any insulation requirement of the roof and to its slope.



Source: Zinco, 2011

Figure 3.22: Green roof designs for: a) normal extensive, rock type plants, b) combined with thermal insulation, c) low weight option and d) pitched roof

The run-off coefficient, C, of Figure 3.22, is a dimensionless ratio intended to indicate the amount of run-off generated given an average intensity of precipitation for a storm. It is implied by the rational method to determine discharge flow of water and it states that the intensity of run-off is proportional to the intensity of rainfall. The coefficient represents the fraction of rainfall converted to run-off. Standard values for several built environments are given in Table 3.24.

Table 3.24: Standard run-off coefficients

Description	Run-off Coefficient
Downtown areas	0.70 – 0.95
Neighborhood areas	0.50 – 0.70
Single family	0.30 – 0.50
Multi-family detached	0.40 – 0.60
Multi-family attached	0.60 – 0.75
Residential suburban	0.25 – 0.40
Apartments	0.50 – 0.70
Asphalt street	0.70 – 0.95
Concrete street	0.80 – 0.95
Brick	0.70 – 0.85
Lawns, sandy soils, flat	0.05 – 0.10
Lawns, sandy soils, slope 2 % – 7 %	0.10 – 0.15
Lawns, sandy soils, slope >7 %	0.15 – 0.20
Lawns, heavy soils, flat	0.13 – 0.17
Lawns, heavy soils, slope 2 % – 7 %	0.18 – 0.22
Lawns, heavy soils, slope >7 %	0.25 – 0.35

The values of the run-off coefficients shown in Table 3.24 are comparable to those shown in Figure 3.22 for several options of green roofs. Green roofs have higher run-off than lawns or natural soils, but generally better performance than built environments. This would also have a benefit on reducing soil sealing.

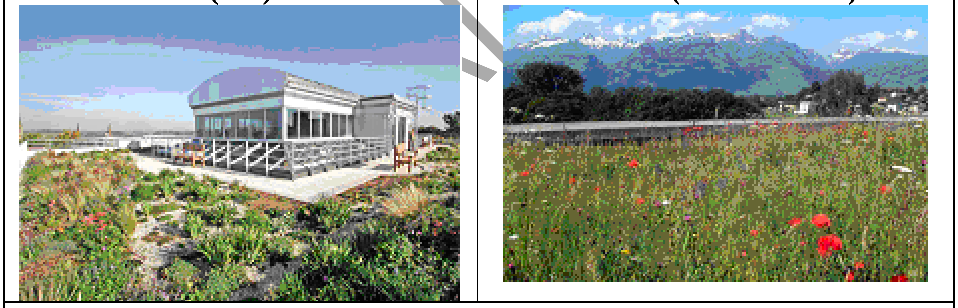
For brown and green roofs, many informative guides and examples can be found in the references. In Barking, East London, a brown roof with a size of 776 m², a loadbearing of 60 kg/m² and an average roof build up of 95 – 100 mm has been installed in 2007. It is made over a metal standing seam for a load of 60 kg/m^2. Sedum blankets were used to create a margin around all perimeters. The depth of the substrate was variable, depending of the different flora. An Oldroyd Xv20 Green Xtra 20mm drainage system (> 49 % recycled) was installed with 40mm of mineral wool substrate plates for drainage and water retention.

Another example is located in Hackney (East London). A roof of 330 m^2 was retrofitted (Figure 3.23). Some techniques applied on this roof are rain water pools, sand mounds, pebbled crushed brick piles, split logs with small decaying tree branches, etc. Areas were seeded with local species to recreate local habitats (Brown Roofs, 2011). Drainage and water reservoir mat were made from off cuts textile industry. Seeds are supplied from UK based native British wild flower seed supplier.

Source: BrownRoofs, 2011

Figure 3.23: Picture of an example brown roof

One of the most important suppliers, Zinco, published the results of some projects for the installation of green roofs. A simple-extensive green roof was installed in the Moorgate Crofts Business Centre in Roherham (Figure 3.24a). In this case, the main objective of this green roof is to increase biodiversity, to provide some flowering from spring to autumn, and to increase the durability of the roof. Sedum carpet species were employed. In Eschen, a multipurpose building was insulated with the objective to reduce energy consumption (Figure 3.24b), with a combination of insulation layer and rockery type plants. A pitched roof was retrofitted to green roof (shown in Figure 3.24c) in a major renovation of a 19th century building.



a) Moorgate Crofts, Rotherham (UK)

b) Multi purpose building in Eschen (Liechtenstein)

c) Pakhuis Australië, Amsterdam (Netherlands)

Figure 3.24: Some examples of green roofs

Applicability

Cool roofs can be applied to most types of roofs, including those of homes, apartment blocks, industrial structures, commercial buildings and offices.

However, the benefit of the reduced solar heating of buildings is limited to hot climate zones. At high latitudes in winter, the increase in roof albedo is less effective at reducing the heat island due to low incoming solar radiation, and even a need for increased heating that compensates for reduced solar heating. In a research paper (Oleson et al., 2010), global space heating increased more than air conditioning decreased. Researchers noted that the benefits of white roofs will grow as the use of air-conditioning around the world grows.

The concept of green roofs is applicable on flat roofs and on steep roofs with low pitch. Steep roofs need special consideration for the selection of plants. Resistance is a key factor, as water is less available in this type of roof. Also, mechanical aspects when designing a green roof should be taken into account. Loads of more than 100 kg per square metre are normal.

Economics

Specific data is not available. However, additional costs when building or refurbishing roofs should be limited and have to be compared to the expected reduced cooling and roof maintenance costs.

Some economic benefits can be derived from the application of green roofs:

- Cost of drainage system can be reduced, as water retention from green roofs is between 50 and 90 %.
- Increase the lifetime of the waterproofing layer, as it is better protected from UV radiation and oscillations in temperature.
- Energy costs are reduced if proper integration with insulation is achieved (see section 3.4.1.1)
- Additional spaces, as gardens, with commercial purposes can produce economical advantages.

Driving force for implementation

For warm climates with a huge potential for energy savings, cool techniques may be required or, even, subsidised. In some regions (California), all new buildings have to be equipped with cool roofs as part of the government's climate strategy. Neverhteless, costs savings due to achievable energy savings of cool roofs is the most outstanding point for applying cool techniques to roofs.

Green and brown roofs have enhanced thermal performances, due to some insulation properties. Nevertheless, the main driving forces for the installation are biodiversity protection and encouragement by:

- maximising the number of species (biodiversity) living on the rooftop
- providing a habitat for a specific species (e.g. a threatened species living on a brownfield site that a building is being constructed on).

Also, water drainage is improved and rainfall water management for short events can be controlled with green or brown roofs.

Also, cool, green and brown roofs can be part of urban heat island mitigation strategies and can be part of incentives from local governements or even a mandatory part of urban codes (see 2.2.4.

Reference organisations

- Abolin: cool paints supplier.
- Oldroyd AS: drainage membranes for brown and green roofs
- Safeguard Europe Ltd.: water solutions and green and brown roofs provider
- Wild Flower Turf. Turf supplier for green roofs.
- Cool roof project. (Intelligent Energy Europe)
- Zinco (green roof designer and supplier)

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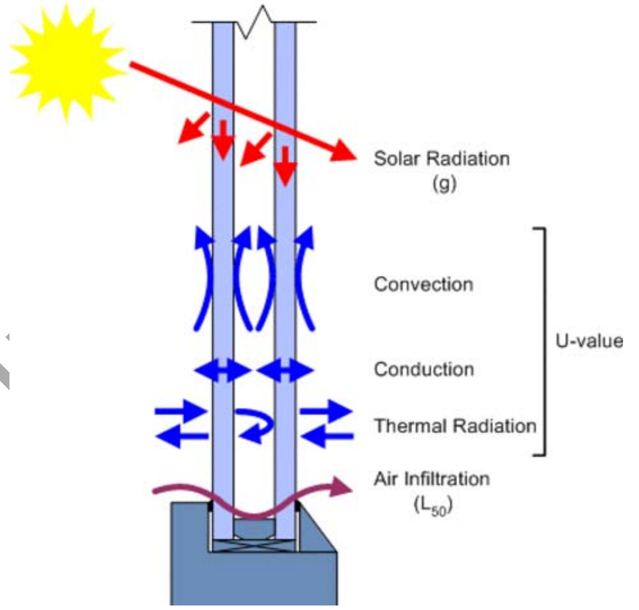
3.4.1.4 Best options for glazing

Description

Windows are responsible for heat loss in cold climates during winter and a source of heat gain in warm climates during summer. They provide natural light, ventilation and increase the comfort of occupants by providing a view of the outdoors.

From a thermal point of view, glazings are highly important for the energy efficiency of a building. Best options for glazing should take into account the performance of the window in an overall thermal balance. Schlenger, 2009, made an assessment for best design options for glazing and window quality for office buildings. Optimised buildings in all locations require the best insulation properties of glazing in all locations. Also, the proportion of glazing in façades does not affect much the total primary energy demand of buildings, as heating and cooling would be the predominant processes. Nevertheless, the best results indicate that the minimum energy demand would take place at 65 % of glazing of facades at almost all orientations. For Northern countries, less would be necessary, 30-50 %, for walls oriented to the North.

Windows with the best insulating properties provide the best thermal balance among all the windows elements and these are, usually, triple glazing with low emissivity and filled with gas (argon or krypton). Figure 3.25 shows the main components of the thermal balance of a window.



Source: MTP, 2007

Figure 3.25: Energy flow through a window

The total energy flow for a window consists of three major components (see Figure 1):

- Solar heat gain from solar radiation. This is measured by the solar factor (g), which measures energy gains from solar radiation. The value of g is given as a number between 0 and 1 and a higher g means more solar heat gain.
- Heat losses and gains from conduction, convection and radiation arising from all the components of the window. This is measured by the U-value and a window with a lower U-value loses less energy through heat losses.

- Heat losses from air infiltration through the window. This is measured by the L_{50} value, which measures uncontrolled air leakage through a window. Air leakage through the windows is considered to be part of the performance of the frame.

Usually, the heat transfer coefficient, the U-value, can be considered as the best way to assess the thermal performance of a window. From the thermal balance point of view, best performing windows are those with high insulation properties at any climate (Schlenger, 2009). An example of best performing window is the high g-value, low-e glass and krypton filling triple glazed window, with U values less than 0.7 W/m^{2}K. The amount of light and the solar gain term of thermal balances are not highly relevant compared to heat losses through convection or conduction through the window. The quality of windows strongly influences living comfort and indoor climate. During the winter in cold climate zones, the cold surface of windows with insufficient heat insulation causes water condensation, as well as ‘cold radiation’, and lacking airtightness causes infiltration. The corresponding lacks in comfort are often reduced by additional heating, whereas triple-glazed windows with heat protection glass prevent these lacks without intensified heating. They provide airtightness, the surface temperature of the room sided pane does not fall by more than 2 – 3 °C below room temperature and furthermore, building owners and architects are able to arrange windows and heating devices in a more flexible manner as the elevated surface temperature, prevents water condensation (Hensler et al., 2009)

The best configuration of buildings may include using shading systems with different seasonal uses. During summertime, the solar radiation entering the windows causes additional cooling requirements. Therefore, shading of windows reduces the cooling energy demand and influences the lighthing of a building. Some of the most common external devices are shutters and blinds. Examples of internal devices are blinds and curtains. Furthermore, shutters can reduce the heating demand by acting as a thermal barrier (Stack et al., 2010; Standaert, 2006).

Achieved environmental and health benefits

Triple-glazed windows with high g-value, low-e glass and krypton filling help to improve the energy efficiency of buildings. By the enhancement of the thermal insulation of the building envelope, a high solar gain and airtightness, the heating or cooling demand of buildings can be substantially reduced. Thus the environmental impacts caused by heating or cooling can be reduced. The window should incorporate an insulated window-frame, three gaskets and has to be installed in an airtight way. Thus, also noise protection can be enhanced remarkably (Hensler et al., 2009).

Triple-glazed windows with high g-value, low-e glass and krypton filling have the following performance data (Schneider, 2008)

- U_g = 0.5-0.7 W/(m^{2}K) (glazing)
- U_W = 0.7-0.8 W/(m^{2}K) (whole window)
- g = 0.47-0.55.

The achievable reduction in annual transmission losses per square metre window surface ranges from 42 % in comparison to double-glazing, to up to 88 % in comparison to single-glazing (Hensler et al., 2009). Based on annual transmission losses (useful energy) of 460 kWh/(yr 1.69 m² component surface) for single glazing, this corresponds to heating energy demand savings up to 272 kWh useful energy per m² component area, assuming 3500 heating degree days, without consideration of solar gains and improved airtightness (Brandt, 2007).

In general, shading systems reduce cooling and heating demand, indoor air is stabilised, glare is avoided and they act as an additional barrier to excessive heat gain in summer. The reduction in cooling energy demand by external shading has been investigated for a single family house (SFH) and a multi family house (MFH) of 120 m² and 1600 m² useful floor area, respectively. In Seville (908 cooling degree days), the external shading of windows (75 %) facilitates a yearly reduction of cooling energy demand in SFH of 10-13 kWh useful energy per m² of useful floor area, and in MFH of 8-9 kWh useful energy per m² of useful floor area. In Marseille (427 cooling degree days), the external shading of windows (75 %) facilitates a reduction of energy cooling demand in SFH of 6-7 kWh useful energy per m^2 of useful floor area, and in MFH of 4-5 kWh useful energy per m^2 of useful floor area (Boermans et al., 2007).

Furthermore, the reductions in heating and cooling energy demand have been simulated for a room of 25 m^2 useful area in a MFH and a SFH. Table 3.25 provides the selected results. (Standaert, 2006)

Table 3.25: Simulation results for the reduction in useful energy demand in SFH and MFH caused by shading

City	Building type	Reduction in heating energy demand kWh/m^2yr			Reduction in cooling energy demand kWh/m^2yr			
		Blind	**Shutter**		**Blind**		**Shutter**	
		External	Internal	External	Internal	External	Internal	External
Brussels	SFH	N.A.	6-11	11	N.A.		10-11	15-16
	MFH	0-1	N.A.	3-6	8-9		N.A.	2-9
Budapest	SFH	N.A.	10	10	N.A.		24	41
Rome	SFH	N.A.	6	5	N.A.		24	41
	MFH	N.A.	N.A.	4	N.A.		N.A.	23
Stockholm	SFH	N.A.	14	13	N.A.		15	25

Appropiate environmental indicators

The described measures have an impact on the overall performance of heat transfer, which can be controlled alongside the energy demand for heating, measured by the specific energy consumption (energy consumed per square metre and year). This indicator, quite useful in terms of primary and final energy demand, would indicate the overall thermal performance of the building as a whole. Nevertheless, the exact definition on how it is calculated should be provided when assessing a building: including type of energy (final or primary), time of building use (an office building lifetime may not be comparable to other types of building) and area (useful area, floor area, corrected area with height, etc.)

For windows, there are technical parameters that are easy to handle when assessing the performance of windows: the U-value (for glazing, U_g and for the window U_W, W/(m^2K)), the g-value (dimensionless, from 0 to 1 to assess the heat gain from solar radiation) and the emissivity, as they influence the heating or cooling demand of a building.

Cross-media effects

Adverse effects can take place if the overall performance is not taken into account in order to refurbish an existing building. For instance, the replacement of windows in existing buildings could contribute to mould built-up, if the ventilation does not perform correctly. Changes in the ventilation procedures are necessary if airtight windows are installed, as the improvement in airtightness raises the humidity in the inside air if no additional intermittent ventilation or adequate mechanical ventilation is installed. Furthermore, the insulation of walls, roller shutter casings etc. should be done in parallel to the replacement of windows, as high surface temperatures avoid the condensation of water (Zink, J., 2009).

Operational data

Some information about the performance of several typologies of windows are shown in Table 3.26. In this table, SHGC is the Solar Heat Gain Coefficient (similar to the g-value) and it is the ratio of solar heat passing through the glass to solar heat falling on the glass at a 90° angle. VT is the visible transmittance, which measures how much visible light is admitted by the window glass.

Table 3.26: Energy parameters of windows glazing options (adapted from Krigger et al., 2004)

Assembly	U-value	SHGC	VT
Single glass	1.1	0.87	0.9
Standard double glazed	0.5	0.76	0.81
Double glazed High g, low-e insulated glass	0.3	0.74	0.76
Double glazed Low SHGC, low-e insulated doble glass	0.29	0.41	0.65
Triple glazed, 2 low-e insulated coatings	0.12	0.5	0.65

Schlenger, 2009, also studied the window proportion that would be optimal for the optimal thermal behaviour in European office buildings. The results concluded that the best insulation level is always required, while windows proportion in the total façade is not a high influencing factor. The options analysed always required the highest achievable insulation.

Table 3.27: Optimisation results of office buildings window insulation level and window proportion (adapted from Schlenger, 2009)

Group of latitude	Location	Optimal window proportion	Optimal window insulation level	Total Primary energy demand, kWh/m^2yr
60 °N	Oslo	47.5 %	High	118
55 °N	London	65 %	High	109
50 °N	Prague	65 %	High	111
45 °N	Milano	65 %	High	109
40 °N	Palma de Mallorca	65 %	High	100

Besides triple-glazing with high g-value, low-e glass and krypton filling, the window should incorporate an insulated window-frame, three gaskets and it has to be installed in an airtight way. As airtightness may cause the occurrence of water condensation and mould in exterior walls, a simultaneous insulation of them should also be performed. By integration of the window-frame in the exterior wall insulation, thermal bridges at the window-frame and the corresponding water condensation can be avoided. Roller shutter casings should also be airtight and insulated in order to provide a further enhancement of heat and noise protection. Airtightness causes higher humidity, so intensified venting could be necessary. This could be performed by an automatic ventilation device with integrated heat recovery (Hensler, 2009).

For shading devices, no representative operational data is available. Nevertheless, the type of shading should be chosen also according to the final energy savings that may be produced. For instance, internal or external shadings with low permeability usually have greater impact, as they partly avoid convection mechanism taking place. Installing shading devices in existing buildings can save from 20 to 40 kWh/m^2yr (ESSO, 2006).

Applicability

The areas of high performing windows application encompass:

- highly-insulating glazings for new buildings (ideal for low-energy buildings concepts)

- energy-efficient building renovation, where a huge potential for saving energy is identified.

There is no climate differentiation in the application of efficient windows. The identified benefit of highly insulated windows is usually higher in warm climates. Shading devices are applicable for almost every type of window. The seasonal character of the measure should be taken into account, by automatic shading devices or natural shading, such as deciduous trees, to avoid unwanted gains in summer but desired affects during winter.

Economics

The extra charge of triple-glazing in comparison to double-glazing is about 15-70 €/(m² of glass). In the new construction of typical German single family houses with oil-fired heating and a constant fuel oil price of 0.85 €/L, this additional investment has a payback period of about 5 years. Under the same assumptions, the replacement of single-glazing windows in existing buildings by triple-glazing windows with insulated frame has a payback period of about 6 years. The replacement of uncoated insulating-glazing including frame has a payback period of about 15 years. With raising energy prices, the investments will have shorter payback periods. Furthermore, the investment will raise market value and the attractivity of the building (Hensler, 2009)

The benefit of the reduced heating or cooling of buildings depends on the climate zones. Table 3.28 contains reference prices of 1.3m x 1.3m triple-glazing windows in Germany (2009) for different frame materials.

Table 3.28: Reference prices of 1.3m x 1.3m triple-glazing windows in Germany (2009) (From Hensler, 2009)

Frame	Net price, EUR	Installation, EUR	Value added tax, EUR	Total, EUR
Plastic	300	120	79.80	499.80
Timber	350	120	89.30	559.30
Timber-aluminium	450	120	108.30	678.30
Aluminium	540	120	125.40	785.40

Driving force for implementation

Important costs savings in the operation of buildings can arise from this technique. Less energy and less equivalent CO_2 emissions will be produced due to a reduction of heating or cooling energy demand. Better noise protection and enhancement of indoor climate and living comfort and fulfilment of legal requirements concerning the energy efficiency of buildings and safety and health aspects are also key drivers to implement measures to improve the performance of windows.

Reference organisations

- Federal German Association of Flat Glass: http://www.bundesverband-flachglas.de/
- German Quality and Control Association for Windows and Doors: http://www.window.de/
- European Solar Shading Association: www.es-so.com

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3.4.2 Integrated concepts for buildings and the example of the Passive House approach

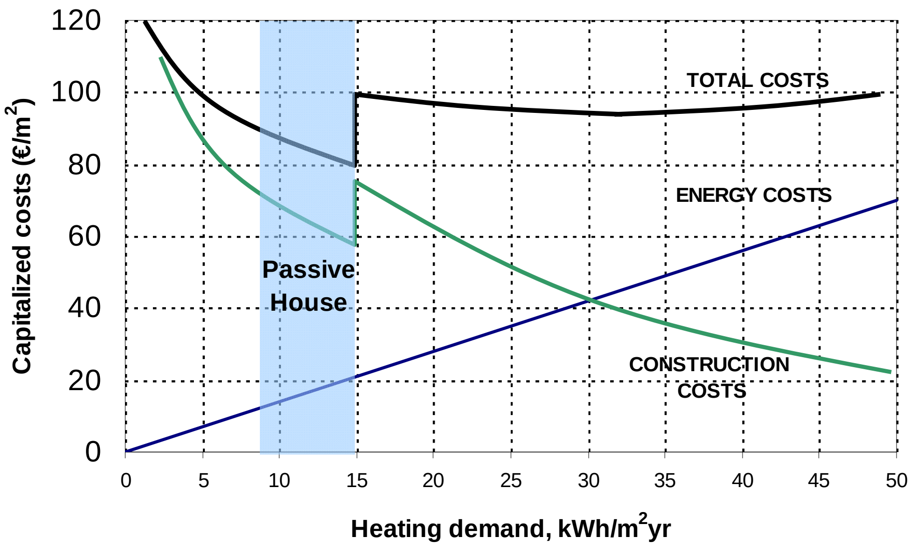
Description

Integrated concepts or standards minimise the environmental impact of the building life cycle through a cost-optimal integration of building elements. Energy consumption during the use phase is the main source of environmental impact in the life cycle of a building, and this section describes the integration of energy efficiency measures in buildings for minimal life cycle costs, while also achieving good thermal and comfort conditions for the occupants.

Generally speaking, integrative concepts of buildings use the term ‘low energy building’, which usually indicates a building with better energy efficiency than the standard energy efficiency requirements of the corresponding building code. The EPBD defines nearly zero-energy building as a building with a goodenergy performance, where the energy demand should be covered to a very significant extent by energy from renewable sources (also produced on-site) (EP, 2011). Nevertheless, the Directive does not extend this definition and relies on Member States to draw a detailed application in practice of the definition of nearly zero-energy buildings, reflecting their national, regional or local conditions. An EU-wide definition does not exist. The reduction of heating and cooling energy demand is typically achieved by the utilisation of energy efficient windows, high insulation levels, heat recovery ventilation and air tightness. Furthermore, active solar technologies, passive solar design techniques and water heat recycling technologies may be used. The expressions high-performance house, low energy house, passive house, zero energy house, zero carbon house, energy savings house, 3-litre house, energy positive house, etc. are synonyms for a low energy building, used across Europe. Definitions for zero energy buildings, plus energy buildings and life cycle zero energy buildings are developed in section 3.3.1.3 Concepts labelled as green building or eco-building do not just focus on the energy demand as low energy buildings, and take into account therefore more environmental performance parameters. Furthermore, the energy use, which is taken into account in all concepts, may be not consistent. Whereas often only space heating is considered, ideally water heating, air conditioning and the consumption of electricity should be included as well (EC, 2009).

Up to 2009, a definition of a low energy building was introduced in eight EU Member States (Austria, Belgium (Flanders), Czech Republic, Germany, Denmark, United Kingdom, Finland and France). Generally, these definitions target new buildings, but in Austria, Czech Republic, Germany, and Denmark they also include existing buildings. In almost all cases they cover non-residential and residential buildings. The required reduction in energy demand with respect to the standard technology defined for new buildings ranges usually from 30 to 50 %. The labelling of low-energy buildings has been introduced in some countries, e.g. Swiss Minergie (Swiss Energy, 2007).

One of the best examples of the approach considered as best environmental management practice is the implementation of the Passive House concept. For this standard, the maximum value of energy consumption for space heating or cooling is 15 kWh/m^{2}yr. So, the heating system is very simple and the approach saves costs if the building life cycle costs are analysed. Figure 3.26 shows the construction costs (initial investment), the energy costs during the lifetime and the total costs. In the chart of Figure 3.26, a drop at 15 kWh/m^{2}yr is observed: this point represents the minimum energy cost. Below this value, the construction costs would increase due to significant insulation and tightness. If heating demand is higher than 15 kWh/m^{2}yr, the life cycle costs would increase sharply due to the need of higher power for the heating system (PassivHaus Institute, 2007). While the total installed heating power is less than 10 W/m^2, the heating system can be kept simple enough to reduce its costs. If the power is higher than 10 W/m^2 (usually when the demand is higher than 15 kWh/yr m^2), the needed heating system and its maintenance costs increase, provoking the sharp rise in of Figure 3.26.



Source: Laustsen, 2008

Figure 3.26: Total costs, energy costs and construction costs vs. building heat demand.

The aim of the Passive House approach is to provide an improved indoor environment (air quality and thermal comfort) with the minimum energy demand and cost. The basic idea of a Passive House is to improve the envelope to a point in which the heating demand becomes very low (Feist et al., 2005). This would lead to the minimum cost reflected in Figure 3.26. Table 3.29 gives an overview of what other requirements define the Passive House concept and how they can be achieved (Laustsen, 2008).

Table 3.29: Passive House requirements and measures to achieve them

Requirement	Measure to achieve it
The building heating + cooling demand must be lower than **15 kWh/m^{2}yr** The specific heat load should be less than **10 W/m^2** The building must not leak more air **than 0.6 times** the house volume at the 50 Pa test (n_{50} value) Total primary energy demand cannot be more than **120 kWh/m^{2}yr**	Improved insulation. Recommended U-values less than **0.15 W/m^{2}K** Design without **thermal bridges** Windows U-values lower than **0.85 W/m^{2}K** Air tight. **Mechanical ventilation** with heating recovery from exhaust air **Innovative heating technology** (renewable sources would account for 0 kWh/m^{2}yr of consumption)

The Passive House concept and other integrative approaches can be employed in the design of any new building for any building, taking into account the specific needs of each type of building. Then, the use of integrated concepts, as the Passive House, to reduce energy demand of buildings should be regarded as best practice for building design and, when appropriate, for the retrofitting of existing buildings.

Achieved environmental benefits

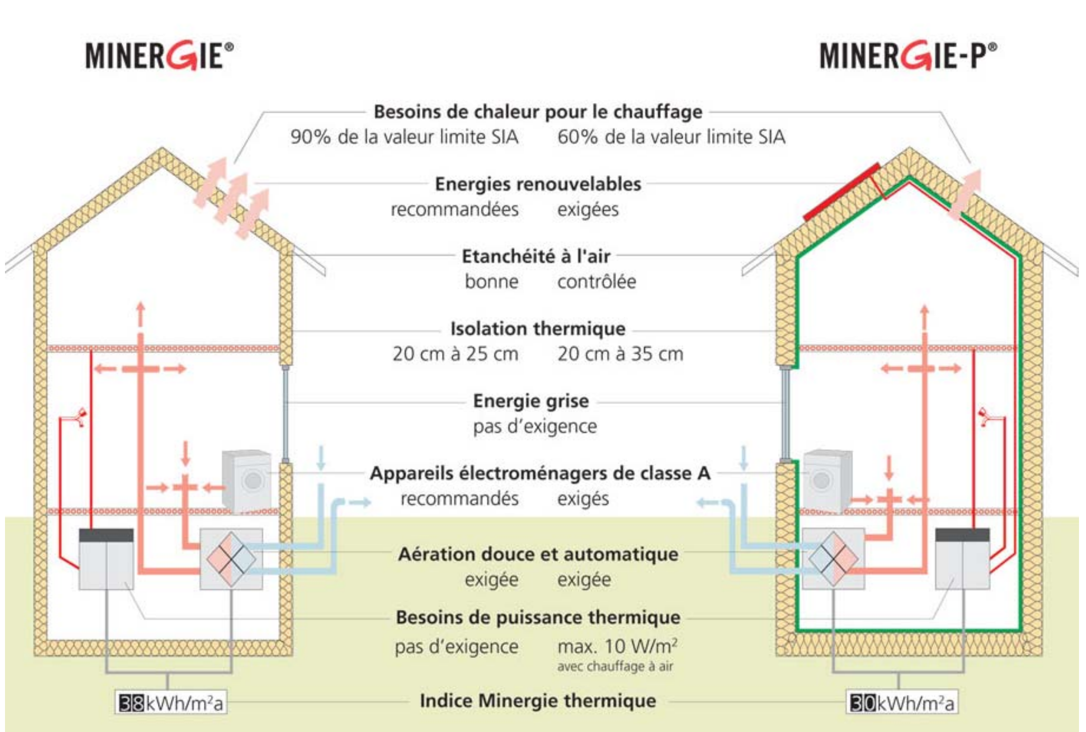
The main benefit is the reduction of the primary/useful/final energy demand, e.g. for space heating/cooling, water heating, air conditioning as well as a reduction in the consumption of electricity. Nevertheless, integrated approaches are also intended to avoid cross-sectoral effects that may appear if individual techniques are considered.

Table 3.30 provides some definitions and specific energy demands for low energy buildings in selected EU member states.

Table 3.30: Examples of definitions for low energy building standards (Engelund Thomsen et al., 2008; EC, 2009)

Country	Official Definition
Austria	• Low energy building = annual heating energy demand below 60 – 40 KWh/m² gross area (30 % better than standard performance) • Passive building = passive house standard: 15 kWh/m^2yr per useful area and per heated area
Belgium (Flanders)	• Low Energy Class 1 for houses: 40 % lower than standard levels, 30 % lower for office and school buildings • Very low energy class: 60 % reduction for houses, 45 % for schools and office buildings
Czech Republic	• Low energy class: 51-97 kWh/m^2yr • Very low energy class: below 51 kWh/ m^2yr, also passive house standard of 15 kWh/ m^2yr is used
Denmark	• Low Energy Class 1 = calculated energy performance is 50 % better than the minimum requirement for new buildings • Low Energy Class 2 = calculated energy performance is 25 % better than the minimum requirement for new buildings (i.e. for residential buildings = 70 + 2200/A m^2yr where A is the heated gross floor area, and for other buildings = 95 + 2200/A m^2yr (includes electricity for lighting)
Finland	• Low energy standard: 40 % better than standard buildings
France	• New dwellings: average annual requirement for hot water, heating, ventilation, cooling, and lighting have to be to be lower than 50 kWh/m² (in primary energy). This ranges from 40 – 65 kWh/m² depending on the climatic area and altitude. • Other new buildings: average annual requirement for hot water, heating, ventilation, cooling, and lighting has to be 50 % lower than current Building Regulation requirements • Renovation: 80 kWh/m² as of 2009
Germany	• Residential low energy building requirements = KfW60 (60 kWh/ m^2yr) or KfW40 (40 kWh/ m^2yr) maximum primary energy demand • Passive house = KfW40 buildings with an annual useful energy demand for space heating lower than 15 kWh/ m^2yr and total primary energy demand lower than 120 kWh/ m^2yr
England & Wales	Graduated minimum requirements over time: • 2010 level 3 (25 % better than current regulations), • 2013 level 4 (44 % better than current regulations and almost similar to passive house) • 2016 level 5 (zero carbon for heating and lighting), • 2016 level 6 (zero carbon for all uses and appliances)

In Switzerland, a set of exemplary standards were developed for buildings, called Minergie. The Minergie standard has been quite successful in its application, even outside Switzerland. Minergie-P standard uses a similar approach to the Passive House. In the operational data section, more data on the requirements for the Minergie-P are described. Figure 3.27 shows a comparison of the requirements and differences between Minergie and Minergie-P. One of the outstanding characteristics of Minergie is the development of a concept seeking comfort and energy efficiency, with a main feasibility approach stating that the actual costs should not be more than 10 % of the costs of the construction of an average building fulfilling legal requirements. Minergie develops the requirements for the primary energy consumption of the heating system, taking into account the efficiency of the heating system, hot water demand and the electricity used for ventilation. This should be taken into account when comparing with the Passive house standard, which benchmarks only the demand.

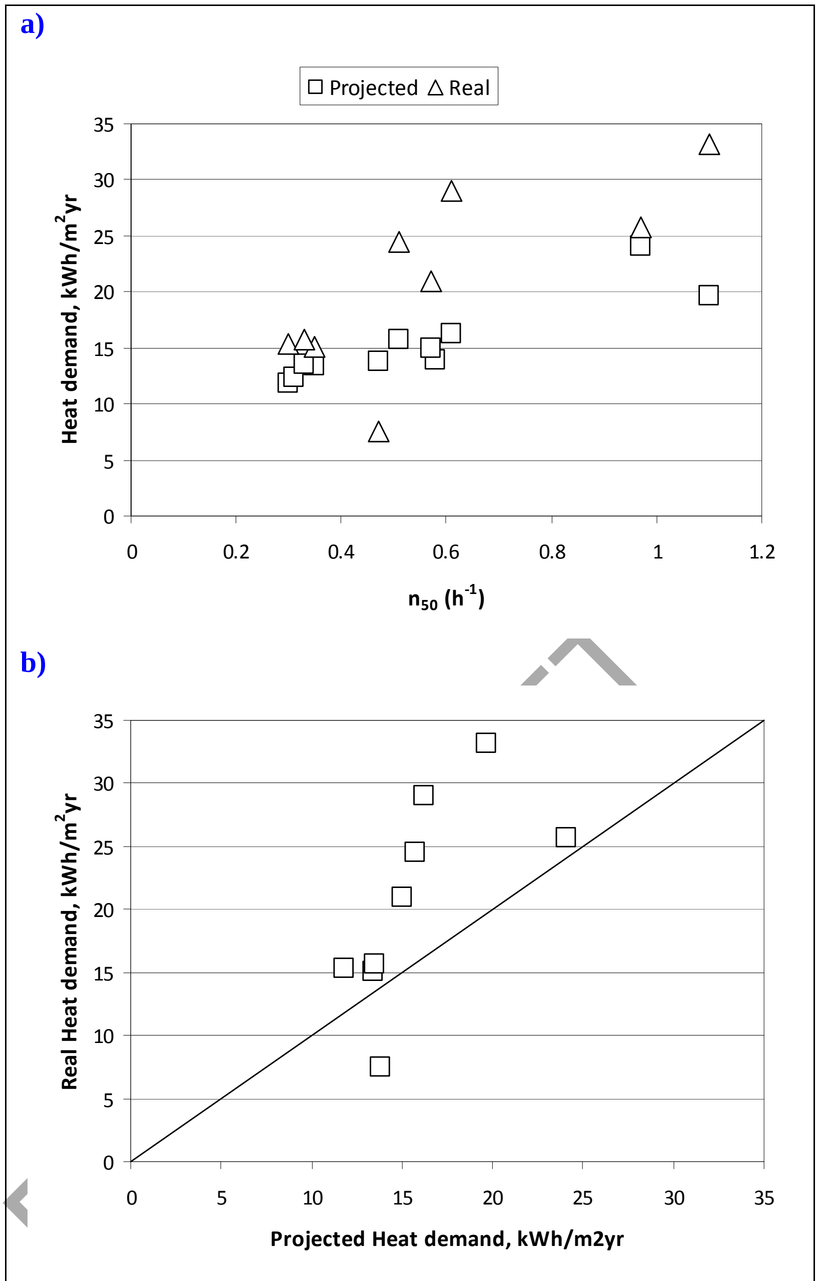


Source: Minergie, 2010

Figure 3.27: Summary of requirements for Minergie and Minergie-P

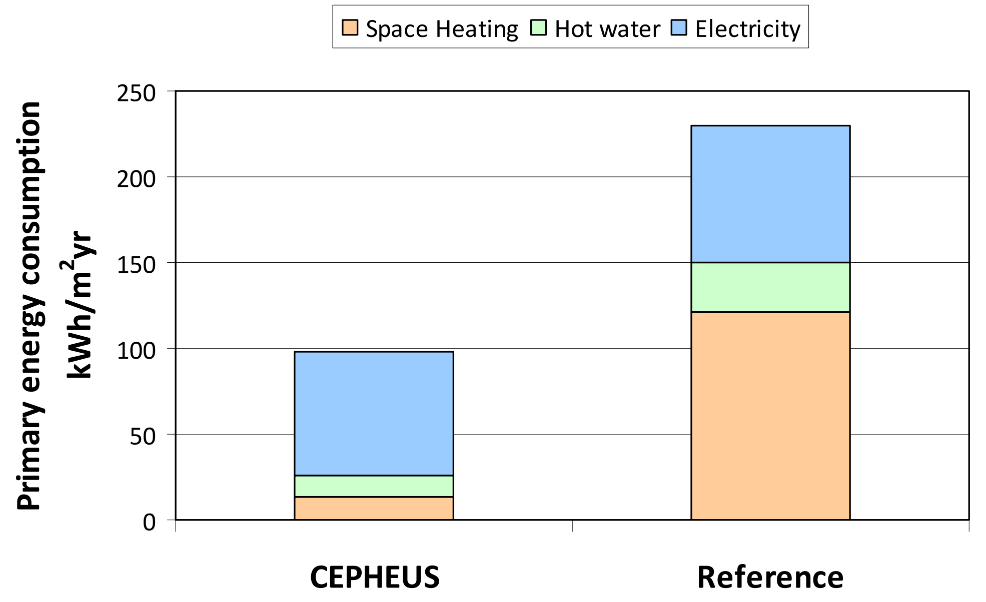
Regarding the passive house integrated approach, the CEPHEUS project studied the technical feasibility of a low extra cost for a variety of buildings. In total, 14 new buildings were built (comprising 221 different residential building units). An overall summary of the project, the Passive House standard and the final results can be found at Feist et al., 2005.

Figure 3.28 shows the heat demand results of the 14 passive house buildings. There are differences between the achieved heat demand and the projected one (i.e. the passive house standard), due to climatic differences over the initial design, although the difference is not higher than 5 kWh/m^{2}yr. Nevertheless, the influence of the air leakage (n_{50}) on the total demand is evident. According to Feist et al., a clear definition on the calculation of the treated floor area was needed fully compare these results. Nevertheless, there is a significant environmental benefit. Figure 3.29 shows the differences in the primary energy consumption between CEPHEUS buildings and the reference buildings according to standards and codes. The economical results are shown below, in the 'economics' section and the influence of the embodied energy is further explained in the 'cross-media effects' section.



Source: Adapted from Feist et al., 2005.

Figure 3.28: Heat demand vs. air leakage (a) and measured heat demand vs. projected heat demand



Source: Adapted from Feist et al., 2005.

Figure 3.29: Comparison of primary energy consumption of all CEPHEUS projects with new buildings from 2005 according to building codes

The good results achieved by the Passive House approach make it a good example of what is desirable for a benchmark of excellence. Similar characteristics are observed for the Minergie-P standard (Swiss Energie, 2007), so this approach is also suitable as a benchmark. In general, it can be stated that, for the energy consumption of buildings, outstanding standards constitute benchmarks of excellence if the approach:

- benchmarks processes, such as heating;
- uses comparable indicators, such as kWh/m^{2}yr, not ratios or ratings (e.g. A-B-C) based on ratios;
- defines and uses an appropriate methodology to calculate the indicator and its calculation is simply enough to convert it to different approaches in order to allow comparability;
- does not offset energy consumption (or indirect CO_2 equivalents) with renewable energy in the calculation, so the demand is actually benchmarked; and
- is as ambitious as Minergie or the Passive House.

The best example of a benchmark of excellence is the Passive House standard and the equivalent Minergie-P values. For existing buildings, the Passive House and Minergie values are also regarded as outstanding examples. Reference values are given in Table 3.31. Any other equivalent building approach, using the approach stated and as ambitious as those proposed here, should be considered also as a benchmark of excellence.

Table 3.31: Different exemplary approaches and the associated benchmarks

Approach	Residential	Non-Residential
Passive House (New)	Heating: 15 kWh/m^{2}yr (cooling 15 kWh/m^{2}yr or heating + cooling = 15 kWh/m^{2}yr, see Passive-On, 2007)	Heating: 15 kWh/m^{2}yr (cooling 15 kWh/m^{2}yr or heating + cooling = 15 kWh/m^{2}yr, see Passive-On, 2007)
Passive House (Existing Buildings)	Heating: 25 kWh/m^{2}yr	Heating: 25 kWh/m^{2}yr
Minergie-P (New- Buildings)	HVAC and DHW primary energy consumption: Residential, 30 kWh/m^{2}yr	HVAC primary energy consumption: Public administration, schools, commercial 25 kWh/m^{2}yr Restaurants, 40 kWh/m^{2}yr Hospitals, 45 kWh/m^{2}yr Industry, 15 kWh/m^{2}yr Warehouse, 15 kWh/m^{2}yr Sports, 20 kWh/m^{2}yr
Minergie (Existing Buildings)	HVAC and DHW primary energy consumption: 60 kWh/m^{2}yr	HVAC primary energy consumption: Public administration, schools, commercial 55 kWh/m^{2}yr Restaurants, 65 kWh/m^{2}yr Hospitals, 85 kWh/m^{2}yr Industry, 40 kWh/m^{2}yr Warehouses, 35 kWh/m^{2}yr Sports, 40 kWh/m^{2}yr

N.B. HVAC: Heating, Ventilation and Air Conditioning; DHW: Domestic Hot Water

The total energy consumption, measured in primary energy terms, is also a recommendable term for benchmarks. There are very few examples of benchmarks of excellence of the total primary energy consumption. For instance, the Passive House standard proposes 120 kWh per m^2 for every new building and up to 132 for existing buildings, which are really ambitious. Although very ambitious, it is likely that buildings achieving very low heating demands will have much lower primary energy consumption than e.g. 120 kWh/m^{2}yr, as is the case for many of the Passive Houses visited during the development of this document. Also, lack of data per building type may be also a main barrier for the application of this benchmark. Where possible, it is recommended to develop benchmarks per process (heating, lighting, others): this is the case for refrigeration processes in retailers' supermarkets, lighting in office buildings and other user oriented approaches.

Appropriate Environmental Indicator

As already explained for other management practices, the specific energy consumption per square metre and year (e.g., kWh/m^{2}yr) seems to be the most important indicator to control the energy performance. Thus, the easiest way to control the environmental impact of the HVAC system performance is to disclose the energy consumption for space heating and/or cooling, defined per unit of sales area and year. This indicator would include all the techniques involving building envelope and the HVAC aspects. In order to compare different buildings, correction factors with a scientific basis can be used to calculate the sales area (e.g. height, use factors for corridors, stairs, etc.). The time of use of the building can differ for different regions across Europe, but it is not recommended to correct it unless comparisons between systems are being performed. Two alternatives can be used: the specific primary energy consumption, with factors from primary to final defined at national or regional level; or to calculate the energy demand of the building through the use of comprehensive estimation models.

Technically, the thermal behaviour of the envelope (see 3.4.1.1 and 3.4.1.2) is controlled by the air tightness, the heat transfer coefficient (U-value) and the ventilation air flow or air change rate, among others.

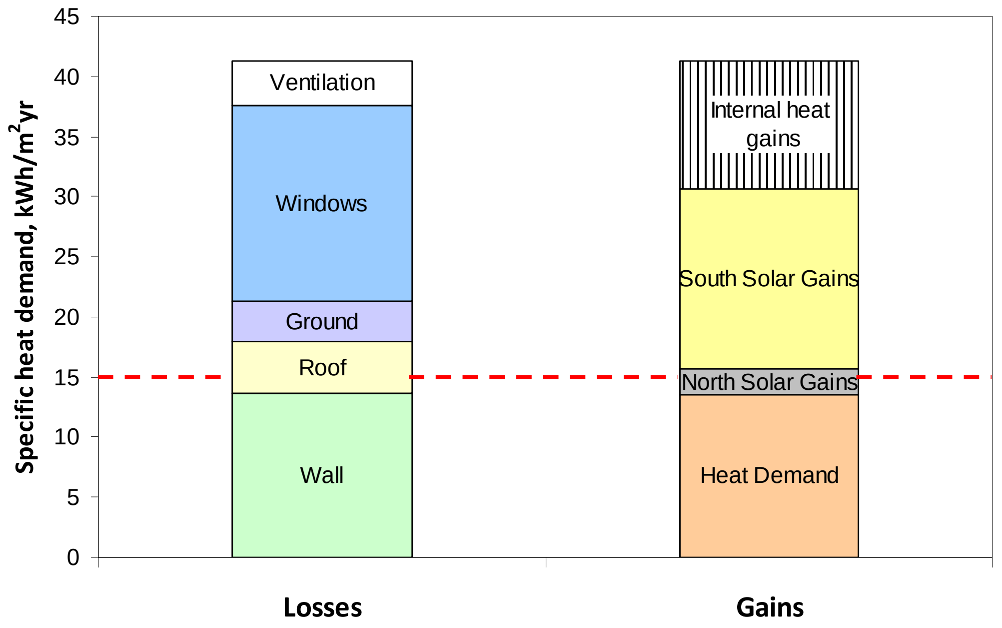
Notes on the methodology on the calculation of the energy performance and specific heat demand for the Passive House Standard.

This section describes the Passive House as a best environmental management practice example for the design of buildings using integrative concepts. The Passive House standard is oriented to the energy performance of buildings and it proposes a methodology to calculate the energy demand of buildings through an optimised simplified, stationary method.

The Passive House Planning Package, PHPP, (Passivhaus, 2010), developed by the Passive House Institute, is a workbook where the calculation of all the elements of the energy demand are gathered and the amount of entry data is minimised. The specific annual heat demand is calculated according to ISO 13790, taking into account the following terms:

- Transmission heat losses, Q_T
- Ventilation heat losses, Q_V
- Available solar heat gains, Q_S
- Internal heat gains, Q_I

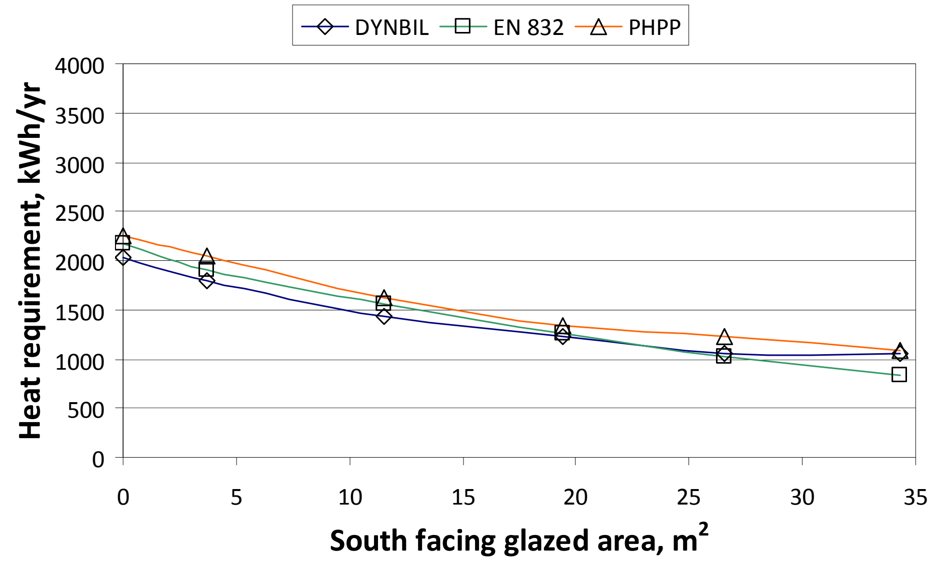
By balancing these terms, the total heat demand can be calculated. An example can be seen in Figure 3.30. There are two methods to calculate the specific heat demand: the monthly and the annual method. Both consist of calculating the heat balance (losses and gains) to calculate the specific heat demand on an annual basis (annual method), or the sum of calculations per month (monthly method). The PHPP calculates all the energy balances, including the U-value for each building element, plans the windows, designs the comfort ventilation system, determines the heating load (10 W/m^2 is the maximum for the Passive House standard), estimates the summer comfort, the cooling demand and load, the hot water supply and proposes a standardised methodology to determine the total primary energy consumption, including appliances, auxiliary services, etc., without taking into account the energy generated on site (Passivhaus, 2010).



Source: *Passivhaus, 2010*

Figure 3.30: Annual heating balance for a passive house using the PHPP

Precise models, based on fundamental physics equations, can be very accurate but they need a significant amount of data. According to the Passive House institute, independent data entries can require more than 2000 entries, without the climate dataset. On top of that, high accuracy for data entries is needed for precise models. In order to avoid using excessive calculation to verify energy performance for the Passive House standard, the simplified method of the Passive House institute seems accurate when compared to other methodologies. In Figure 3.31, a comparison of PHPP with other simulations is done. As observed, the level of agreement is acceptable. The reason for this accuracy is the adjustment of the utilisation function of the PHPP to match the results of other dynamic simulations. At the same time, different assumptions and boundary conditions are taken (Passivhaus, 2010)



Source: Adapted from Passivhaus, 2010

Figure 3.31: Comparison between simulation (DYNBIL) and the Passive House Planning Package (Monthly and Annual Methods)

Short description of the methodology for the calculation of the heat demand of a building in the Passive House Planning Package (PHPP)

1. The **specific annual heat demand** is the difference between heat losses and heat gains:

$$\text{Annual Heat Demand} = Q_L - Q_G \quad \text{(kWh/yr or kWh/m}^2\text{yr if divided by } A_{TFA}\text{)}$$

where

- Q_L is the amount of heat losses through the envelope and in the ventilation system (through the exhaust air or through the leaked air)
- Q_G is the heat gained from solar or internal gains.
- A_{TFA} is the treated floor area and is defined as the living or useful area within the thermal envelope

2. **Heat losses** are defined as:

$$Q_L = (Q_T + Q_V) \times (\text{reduction factor as night or weekend savings})$$

where

- Q_T is the transmission heat loss and corresponds to the heat transferred by the building to the surroundings through the envelope. It can be calculated as

$$Q_T = \sum_i A_i U_i f_{t,i} G_t$$

where

- A_i is the area of the building element
- U_i is the U-value of the element (calculated in the PHPP)
- $f_{t,i}$ is the ground reduction factor of the heat loss (calculated in the PHPP).
- G_t is the value of the heating degree hours (calculated from climate data in the PHPP)

As an example, Table 3.32 shows the values calculated for one example, available in the demo version of the PHPP for a terraced house.

Table 3.32: Transmission heat loss calculated for an example

Building Element	Area, A_i m^2	U-value, W/(m²K)	Ground reduction factor, $f_{t,i}$	G_t, kKh/yr	Heat loss kWh/yr	Heat loss per m^2 of treated floor area, kWh/m^2
Exterior Wall	184.3	0.138	1.00	84.0	2129	13.7
Roof/Ceiling	83.4	0.095	1.00	84.0	665	4.3
Floor Slab	80.9	0.131	0.59	84.0	520	3.3
Windows	43.5	0.777	1.00	84.0	2838	18.2
Total					6152	39.4

Source: Adapted from Passivhaus, 2010

- Q_V is the value of the ventilation heat losses, produced by air leakages. It can be calculated through the following expression:
-

$$Q_V = V_V n_V c_{air} G_t$$

The calculation of Q_V through this equation requires several parameters. The description and the calculation method are shown in Table 3.33.

Table 3.33: Parameters for the calculation of the ventilation heat losses

Parameter	**Description**	**Calculation**
V_V	Total effective air volume within the thermal envelope, m^3	$V_V = A_{TFA} \times (\text{Room height})$
n_V	Air change rate (1/h)	$n_V = n_{V,system}(1-\Phi_{HR})n_{V,\text{Res}}$
$n_{V,\ system}$	Design air change rate	Usually calculated for the occupancy rate with 30 m^3/h p and/or taking into account hygienic needs of the building. A standard value for residential house is 0.3 h^{-1}
Φ_{HR}	Heat recovery parameter	$\Phi_{HR} = 1-(1-\eta_{eff})(1-\eta_{SHX})$
η_{eff}	Effective heat recovery efficiency of the ventilation system with heat recovery	Depends on the systems. See PHPP for more details
η_{SHX}	Efficiency of subsoil heat exchanger	$\eta_{SHX} = \eta^*_{SHX} \dfrac{T_{ground} - T_{\textbf{ambient air}}}{T_{room} - T_{\textbf{ambient air}}}$ For more details, see PHPP: Passivhaus, 2010
$n_{V,\ Res}$	Infiltration air exchange rate	$n_{V,\text{Res}} = \dfrac{V_{n50}}{A_{TFA}} n_{50} \dfrac{e}{1+\dfrac{f}{e}\left(\dfrac{\text{excess of extracted air}}{n_{50}}\right)}$
V_{n50}	Net air volume for leakage test	Measured
n_{50}	Air change rate at pressure test	Measured
e	Wind protection coefficient	Table in PHPP, depending on different levels of screening
f	Wind protection coefficient	Table in PHPP
-	Excess of extracted air	0 for balanced ventilation system with heat recovery, n_{50} for discharge air systems
c_{air}	Specific heat of air	0.33 Wh/m^2K
G_t	Heating degree hours	Depends on the climate. Calculated from HDD.

3. **Heat gains** can be calculated as

$$Q_G = \eta_G Q_F ,$$

where

- Q_G is the value of heat gains
- η_G is the utilisation factor for heat gains
- Q_F is the value of free heat, defined as $Q_S + Q_I$, the sum of solar heat gains, Q_S, and other internal heat gains, Q_I

The utilisation factor, η_G, can be calculated from the ration of free heat to heat losses, Q_F/Q_L, through the following expression:

$$\eta_G = \frac{1-\left(Q_F/Q_L\right)^n}{1-\left(Q_F/Q_L\right)^{n+1}}$$

where n is the time constant of the building. In the PHPP example case study, n = 5.

The free heat, Q_F, is calculated through the sum of the following parameters:

- Available solar heat gains,

$$Q_S = f \cdot g \cdot A_w \cdot (\text{Received radiation})$$

where

- *g* is the heat gain factor and represents the amount of received radiation passing through the window
- A_w is the area of windows
- *Received radiation* is the amount of energy available for each orientation of the building. It is calculated from climate data.
- *f* is a reduction factor calculated as a multiplication of the shading factor, the dirtiness factor, non-perpendicular incident radiation and the glazing fraction of the windows.

An example of the calculation of the solar heat gains is explained in Table 3.34 (for the calculation of the reduction factor) and in Table 3.35 for the calculation of the total solar gain.

Table 3.34: Example of reduction factor for solar radiation calculation

Window Area Orientation	**Shading** s	**Dirtiness** d	**Non-Perpendicular Incident Radiation** npr	**Window Area, m^2** A_w	**Glazing Area, m^2** A_g	**Glazing Fraction,** $f_g=A_g/A_w$	**Reduction Factor for Solar Radiation** $f= s\cdot d\cdot npr\cdot f_g$
North	0.89	0.95	0.85	11.04	7.1	0.644	**0.46**
East	0.75	0.95	0.85	0.00	0.0	0.000	**0.00**
South	0.84	0.95	0.85	30.42	19.9	0.655	**0.44**
West	0.82	0.95	0.85	2.00	1.2	0.604	**0.40**
Horizontal	0.75	0.95	0.85	0.00	0.0	0.000	**0.00**

Table 3.35: Example of avalaible solar gain calculation

Window Area Orientation	Reduction Factor for Solar Radiation	g-value	Dirtiness d	Window Area, m^2 A_w	Received radiation, kWh/m^2yr	Solar gain, kWh/m^2a
North	0.46	0.89	0.95	11.04	140	2.28
East	0.00	0.75	0.95	0.00	220	0.00
South	0.44	0.84	0.95	30.42	370	15.96
West	0.40	0.82	0.95	2.00	230	0.59
Horizontal	0.00	0.75	0.95	0.00	360	0.00
					Total	**18.8**

N.B. Source: Passivhaus, 2010. Received radiation is calculated per square metre of window area and the solar gain is calculated per square metre of treated floor area.

- Available internal heat gains,

There are two options to calculate internal heat gains. The simplest one is to assume a value of the power gained per square metre. Standard methods use 4-5 W/m^2 for households, while the PHPP assumes less, 2.1 W/m^2 in order to be more realistic (Passivhaus, 2010). So, internal heat gains can be easily calculated multiplying this value, 2.1 W/m^2 by the length of the heating period.

Dynamic models tend to simplify the calculation of internal heat gains. The PHPP proposes a more detailed calculation of the internal heat gains from the heat 'generators' inside the building. Table 3.36 shows the example for a residential house.

Table 3.36: Example of internal heat gains calculation of the PHPP

Application	Norm consumption	Frequency	Useful Energy (kWh/a)	Availa-bility	Used During Time Period (kh/a)	Internal Heat Source (W)
Dishwashing	1.1 kWh/Use	65 (P yr)$^{-1}$	319	0.30	8.76	11
Clothes Washing	1.0 kWh/Use	57 (P yr)$^{-1}$	241	0.30	8.76	8
Refrigerating	0.3 kWh/d	365 d/yr	102	1.00	8.76	12
Freezing	0.6 kWh/d	365 d/yr	181	1.00	8.76	0
Cooking	0.3 kWh/Use	500 (P yr)$^{-1}$	557	0.50	8.76	32
Lighting	20.8 W	2.9 kh/(P yr)	269	1.00	8.76	31
Consumer Electronics	80.0 W	0.55 kh/(P yr)	196	1.00	8.76	22
Others	50.0 kWh	1.0 (P yr)$^{-1}$	223	1.00	8.76	25
Persons (x 4)	80.0 W/P	8.76 kh/yr	2803	0.55	8.76	176
Cold Water	-5.0 W/P	8.76 kh/yr				-20
Evaporation	-25.0 W/P	8.76 kh/yr	-876	1.00	8.76	-100
					Total	202
					Specific Demand, W/m^2	**1.30**
					Heat Available From Internal Sources, kWh/(m^2yr)	**7.0**

Short description of the methodology for the calculation of the primary energy demand of a building in the Passive House Planning Package (PHPP)

The PHPP uses a workbook where the main assumptions and data on electric appliances, auxiliary demand, heating system characteristics, etc., are inserted. After the determination of the specific final energy demand of every process (taking into account process efficiency), primary energy can be easily calculated with the primary energy factors, mainly sourced from DIN 4701-10 for Germany (see Table 3.37). In Table 3.38, an example for the calculation of the primary energy demand for a residential passive house is shown. According to Feist, 2005, one of the most important characteristics of the methodology of the PHPP is the exclusion of renewable energy generated on-site in the calculation of primary energy demand. This means that electricity demand is always multiplied by the primary energy factor of the public grid, irrespective of the local renewable contribution. This is derived from a political perspective, aiming at the reduction of the demand. From the consumer perspective, the amount of electricity locally produced has to be taken into account. PHPP also calculates this contribution, but does not consider it when verifying compliance with the Passive House standard.

Table 3.37: Primary energy factors used in the PHPP (2007 version)

Energy Type	Energy Carrier	PE (non-regenerative) kWh_{Prim}/kWh_{Final}
Fuel Source	Oil	1.1
	Natural Gas	1.1
	LPG	1.1
	Hard Coal	1.1
	Wood	0.2
Electricity	Electricity-Mix	2.7
	Electricity from Photovoltaics	0.7

Table 3.38: Example of primary energy demand calculation of a Passive House

Origin of demand	Final Energy Demand kWh/m^2yr	Primary Energy Demand kWh/m^2yr
Electricity Demand (without Heat Pump)	11.6	31.3
Heat Pump	0.0	0.0
Compact Heat Pump Unit	0.0	0.0
Boiler	26.7	29.4
District Heat	0.0	0.0
Other (e.g. non-electric cooking)	3.6	3.9
Cooling with Electric Heat Pump	0.0	0.0
Total	**41.9**	**64.6**

Cross-media effects

When looking at cross-media effects, the use of integrative concepts to reduce the overall life cycle impact of a building is usually regarded as increasing the embodied energy of the building. This is usually the case for low energy buildings, as passive house or other typologies of integrative concepts. Nevertheless, operating energy represents the most important source of environmental impact.

A passive house can reduce by a factor of three or four the energy consumption of an equivalent conventional building and increase by 20 % the embodied energy from materials (Sartori and Hestnes, 2007).

Other approaches achieve higher values of embodied energy (e.g. multiplying by two the embodied energy in the case of solar houses) but, still, the building operating energy demand is much higher. It is not possible to reduce the energy consumption of the building sector only by reducing the energy demand of the life cycle of construction materials. Reuse, recycling and greening the supply chain should be the main concern when choosing materials, not only their embodied energy.

Also, air-tightness is usually very high, so special attention should be paid to the correct design of the indoor air quality management system.

Notes on the energy performance value, EPV, according to Minergie Standards

According to Minergie, 2010, the Energy Performance Value, EPV, is the sum of three main elements:

$$EPV = A + B + C$$

All parameters are measured in units of energy per surface unit and year, e.g. kWh/m^{2}yr

A is the primary energy demand for heating. It is calculated according to:

$$A = \frac{D \cdot F}{E}$$

where D is the demand calculated according to a Swiss standard based on ISO 13790. E is the equipment efficiency (see Table 3.39) and F is the primary energy factor (see Table 3.40).

B is the primary energy demand for domestic hot water preparation. It can be calculated according to the following expression:

$$B = \frac{H \cdot F}{E}$$

where H is the actual energy demand, E is the equipment efficiency and F is the primary energy factor.

C is the primary energy demand for ventilation, which is defined as:

$$B = V \cdot F$$

where V is the electricity use for ventilation and F is the primary energy factor.

Below, the values for heating efficiency (Table 3.39) and primary energy factors (Table 3.40) are shown.

Table 3.39: Efficiency of heating and hot water generation technologies according to MINERGIE

Technology	Energy efficiency for heating	Energy efficiency for hot water
Oil or gas furnace	0.85	0.85
Oil, condensing furnaces	0.91	0.88
Gas, condensing furnaces	0.95	0.92
Wood-fired furnaces	0.75	0.75
Wood pellet furnaces	0.85	0.85
District heating	1	1
Heat pump, outside air monovalent	2.3	2.3
Heat pump, ground source	3.1	2.7
Heat pump, ground water, direct	3.2	2.9

Table 3.40: Primary energy factor for different energy sources for Minergie standards

Energy source	Primary energy factor
Solar and ambient heat	0
Biomass (wood, biogas)	0.7
Waste heat	0.6
Fossil fuels	1.0
Electricity	2.0

An example for the calculation of the energy performance of a single-family house is shown below, in Table 3.41.

Table 3.41: Example of the calculation of energy performance value for Minergie standards

(Value in kWh/m^{2}yr)	Demand	Efficiency	End use energy	Primary energy factor	Primary energy demand
Heating demand	50	-	-	-	-
Savings from heat recovery	-15	-	-	-	-
Effective heating energy	35	3.2	10.9	2	21.8
Hot water	14	2.9	4.8	2	9.6
Electricity for ventilation	-	-	3	2	6
Energy performance value, kWh/m^{2}yr					**37.4**

Operational data

Some operational and technical performance data of the Passive House standard are provided here. The three key components of the Passive House standard are the heat consumption (< 15 kWh/m^{2}yr), the total primary energy consumption (< 120 kWh/m^{2}yr) and the air leakage at 50 Pa (<0.6 h^{-1}). For the design, some recommendations are given by the standard to fulfil the requirements. In Table 3.42, recommended and best practice examples from existing buildings are provided (Feist et al., 2005).

Table 3.42: Recommendations and best practices of elements for the Passive House standard

Component	Recommended	Best practice
Insulation (envelope), U-value W/m^{2}K	< 0.15	0.05
Thermal bridges	No thermal bridges	No thermal bridges
Glazing, U-value, W/m^{2}K	< 0.8	0.5
Window framework without thermal bridge, U-value, W/m^{2}K	< 0.8	0.75
Exhaust air heat recovery, efficiency, %	> 75	92
Air leakage, %	< 3	<1
Electricity demand for ventilation, W/(m^3/h)	< 0.45	0.3

Source: Feist et al., 2005

When primary energy is evaluated, a factor of almost 3 is given to the electricity supplied from the grid. The Passive House standard is aimed at reducing the demand, so the supply of renewable electricity is considered as grid electricity when calculating the primary energy demand. The use of renewable energy is always a good option, but the application of passive house concepts intends primarily to reduce demand.

Regarding the implementation of Passive House concepts, the policy approach of the city of Frankfurt can be regarded as an exemplar. By 2010, the city had already built 800 new dwellings, two schools and two kindergartens in accordance to the Passive House standard, adding up to 100 000 m^2. According to Neumann, 2010, the implementation of the Passive House approach in Frankfurt is a combination of 'proven, economic techniques' as well as the motivation and commitment of architects, construction companies and the local government. Regarding to the last point, public administration involvement has been essential: the local government made a resolution to ensure that the passive house standard is used when purchasing municipally owned land, for all new city government buildings and for all buildings to be renovated in the future, city facilities and establishments. The use of less demanding standards is possible but has to be well justified with a minimum requirement of minus 30 % of the current EnEv, the energy efficiency act in Germany (Neumann, 2010; Stadt Frankfurt, 2007).

During the development of this work, the Riedberg elementary school in Frankfurt (see pictures in Table 3.43) was visited. This is a very relevant example on the applicability of the Passive House standard to non-residential buildings. The specific elements for school Passive Houses are also described in the information provided by the Passive House Institute.

The Riedberg elementary school was opened in 2004. Its gross area is 8785 m^2, although its useful area (treated floor area, according to the PHPP) is 7670 m^2. The building cost about EUR 16.7 million (Bretzke, 2010), with an extra investment of 5.3 % above the EnEV minus 30 % (implemented for all public buildings at the moment of building the Riedberg school). More economic details of the Riedberg school are given in the economics section.

Table 3.43: Pictures and descriptions from the Riedberg Elementary School

Picture	Description
	General overview of the Riedberg School. Photovoltaic panels are installed on the roof.
	Insulation thickness of walls is about 30 cm, leading to U-values of around 0.1 W/m^{2}yr
	Ventilation openings – in summer they are automatically opened and closed at times of the lowest ambient air temperature (e.g. 4 – 6 a.m.)
	Heat exchangers with filters for fresh and exhaust air. There are 6 heat exchangers (cross plate heat exchangers), two on the roof and 4 in the basement

Table 3.43: Pictures and descriptions from the Riedberg Elementary School

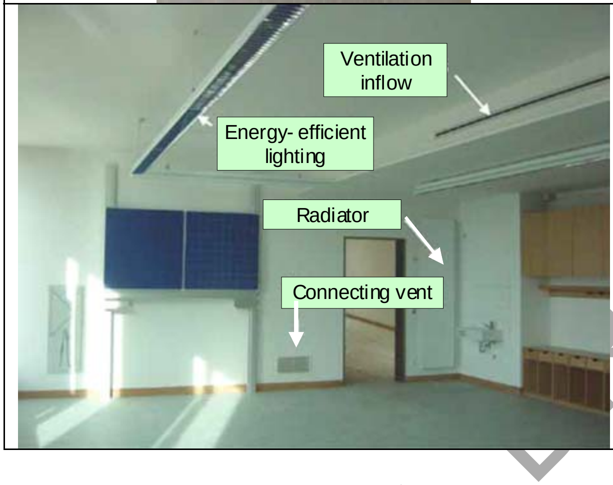
Picture	Description
	Fresh air is fed to classrooms, then moves to auxiliary rooms (e.g. computer rooms), then to the corridor and is finally flows out tthrough the toilets (therefore there is a big opening at the lower part of the toilet doors).
	Room arrangement. Radiators are not placed under the window, as natural convection does not take place with the same intensity as for other buildings because of the high insulation level.

Table 3.44 shows the main technical characteristics to assess the thermal envelope of the school. A technical and very comprehensive report of the performance of the school is given by Peper et al., 2007. Other characteristics are shown in Table 3.45.

Table 3.44: Technical characteristics of the thermal envelope of the Riedberg school in Frankfurt

Element	**Description**
Façade	Modular, wood-aluminium substructure, U = 0.16 W/m^{2}K
Roof	0.11 W/m^{2}K
Floor	Frost barrier (20 cm of insulation extends 2m below the floor slab) U = 0.34 W/m^{2}K (with a reduction factor of 0.22)
Windows	Triple glazed, U-value of 0.74 W/m^{2}K
Internal Loads	25 students per room, where the internal gain is up to 2 kW per room. This reduces the need for insulation.
External blinds	Automatic control with a temporary manual switch
Ventilation	Central ventilation. 6 systems (3 of them are passive house systems and the other three are for the kitchen, cafeteria and sportshall) with a total capacity of 21700 m^3/h (estimate of 20 m^3/h per person). Heat recovery with an efficiency of 84 %. Consumption of 0.45 Wh/m^3 (meeting DIN 13779 and Passive House standards)
Air change rate	At fully occupancy is 2/h; n_{50} value is 0.46/h

Table 3.45: Other energy-related technical characteristics of the Riedberg schoolin Frankfurt

Element	Description
Heating system	10.5 W/m^2; 2 automatic wooden pellet boilers of 60 kW each Heat demand coverage is made by radiators (stealing in the sportshall), individual rooms thermostat
Primary energy demand	59 kWh/m^{2}yr
Lighting system	< 6 W/m^2 (requirement of less than 2 W / 100 lux /m^2)
Others	Users: 400 primary school students in 16 classes plus 100 – 125 kindergarten children and 50 adults. Volumetric flow regulator including CO_2 and/or mixed gas sensors

The environmental benefit of a building like the Riedberg school is clear. According to the assessment made by Peper et al., 2007, standard schools in Frankfurt were consuming more than 191 kWh/m^{2}yr on average (from 30 similar schools) for warm water preparation and space heating. A sample of similar schools all over Germany revealed an average even higher, 230 kWh/m^{2}yr. The consumption of the Riedberg School is much lower: 22.6 kWh/m^{2}yr for space heating and warm water preparation.

Figure 3.32 shows the seasonal consumption of the school in 2009 for every internal process (a), and the monthly variation from 2007 to 2009 of the space heating demand (b), and of the heating degree days (c). In the charts, air heating refers to the energy consumed to heat the air entering to different parts through the six air intake systems and heating is the energy consumed to heat all the radiators, except for those in the sportshall, as they are differentiated. As shown, the heating energy consumption is almost constant for every month (except for August) and the variation between the energy consumption for heating and the heating degree days is proportional, though with some exceptions, such as February 2007.

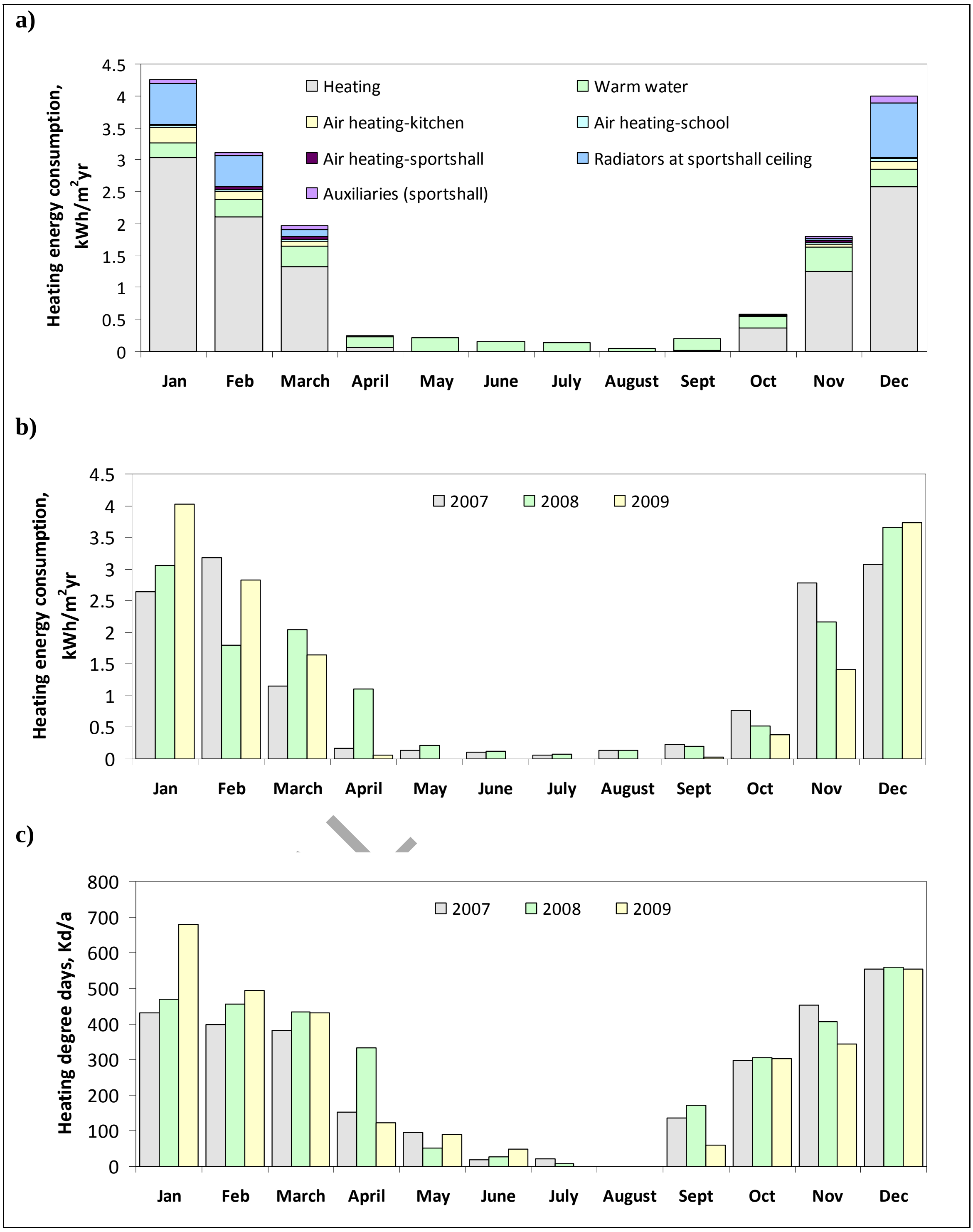


Figure 3.32: a) Monthly heating energy consumption at Riedberg school during 2009 for several internal processes. b) Monthly heating energy consumption (excl. hot water preparation) in 2997, 2008 and 2009. c) Monthly value of heating degree days in Frankfurt in 2007, 2008 and 2009.

Applicability

Every construction technique should adapt to the environment, climate and surroundings of the building location. The challenge for designers is to be able to build nearly self-sufficient buildings in any part of the world. The example of the Passive House concept can be seen as one exemplar way to achieve that objective. The Passive House approach is regarded as a simple solution for a low energy building and its applicability to warmer or colder climates is not a complicated task. The Passive house concept relies on, more or less, simple: insulation, heat recovery, mechanical ventilation and air tightness. This solution achieves a peak heat load of less than 10 W per square metre, easily achievable in warm climates and achievable in colder climates with careful planning.

The climatic applicability

According to the Passive-On project (Passive-On, 2007), no generalisation on the applicability of the Passive House approach is possible, as each new building should be studied separately. The maximum environmental benefit and energy performance improvement could be different for each location, local circumstances, climate, solar radiation, etc. Usually, the techniques to be applied can differ to obtain a similar energy performance (heating and cooling demand) at a reasonable economic performance.

The degree days concept is useful to determine the heating or cooling demands, but these are also influenced by the received solar radiation, just as many passive measures to save energy depend on the availability of solar gains. A proposed method to compare climates is the Climatic Severity Index, which is calculated for winter (Winter Climatic Severity, WCS) and for summer (Summer Climatic Severity). Two different locations can have the same index if the heating demand is the same (even under different climatic conditions). Some calculations made by the Passive-On project of this index are shown in Table 3.46, where the heat demand for different locations has been calculated and then divided by the results for Madrid (Passive-On, 2007).

Table 3.46: Climatic severity indexes in several European locations

Location	Winter Climatic Severity, WCS	Summer Climatic Severity, SCS
Germany, Freiburg	2.14	0.10
UK, London	2.22	0.01
France, Agen	1.44	0.19
Italy, Rome	0.83	1.19
Portugal, Lisbon	0.37	1.05
Spain, Seville	0.32	2.56

N.B. Taken from Passive-on, 2007.

The Passive House Institute gives some recommendations for the application of Passive House in different climates. It should be taken that, in principle, the limit of peak heating load is 10 W/m^2 and the same applies for cooling. This low load meets the requirement of simplification of the heating or cooling systems to a level where air, from the ventilation system, can be used to distribute the heat (or remove it). The practical hints for achieving this (see www.passipedia.org) are:

- First, it is essential to keep a high comfort level.
- Passive House solutions should be simpler than conventional building practice in order to achieve good economic performance.
- The solution is not usually the zero energy building.
- Insulation is always required for any climate.
- Heat recovery is needed for every climate.
- Fans in ventilation systems should use efficient technologies. At the same time, moving air requires less energy than heating or cooling it.
- Use the ground as a heat or cold buffer.

Performance data for warm climates

The applicability of techniques should be studied and, if possible, tested for every location. As an example, some calculations were made to determine the average savings of improving the roof by reducing the U-value from the standard code by 0.1 W/m^{2}K (see Figure 3.33). In this figure, it can be seen where the application of the measure produces most energy savings. It should be taken into account that exactly the same building was evaluated in every location for comparability. The results indicate the energy savings in the south, where less heating energy is needed, can produce larger benefits during winter, due to less heat losses.

Source: Passive-On, 2007

Figure 3.33: Average savings in Europe, in kWh per m^2 yr, for the improvement of the roof insulation by 0.1 W/m^{2}K of the same building

The application of the passive elements to buildings in several warm locations has different consequences on the application of the Passive House concept. Table 3.47 shows the main proposed changes for the design of a Passive House for warmer climates. This information was taken from the Passive-On project for Spain, Italy and Portugal.

One of the more important common points for the approaches shown in Table 3.47 is the increased value of the air change rate, n_{50}, to around 1 h^{-1} or more in order to allow the heat release during summer, as the internal gains are difficult to reduce. The use of active cooling seems to be only needed when the summer severity index is high (e.g. in Seville) and when the insulation level of the building is not as high as for countries like Germany or Austria. These measures may increase heating consumption in winter, but reduce considerably the cooling needs in summer. As a conclusion, the use of the Passive House concept needs a tailor-made approach to be applied for every location and even for every new building. So, unique solutions are not plausible.

Table 3.47: Design features of the Passive House approach in warm climates (deviations from current practice in central Europe)

Location	Main changes from the Passive House approach applied in central Europe	Energy consumption
Spain, Seville	No mechanical ventilation, so air tightness of the building was low High inertia with low density ceramic block Active system for cooling	24.5 kWh/m^{2}yr for cooling and 2.8 kWh/m^{2}yr for heating (In total, 57 % savings compared to building code requirements)
Spain, Granada	No mechanical ventilation, so air tightness of the building was low	7.9 kWh/m^{2}yr for cooling and 8.7 kWh/m^{2}yr for heating (76 % of energy savings compared to the building code requirements)
Italy, Milano	Air infiltration rate of 1h^{-1} in the pressure test Natural and active ventilation at night	10.4 kWh/m^{2}yr for cooling and 3.2 kWh/m^{2}yr for heating
Italy, Rome	Air infiltration rate of 1h^{-1} in the pressure test Natural and active ventilation at night	6.2 kWh/m^{2}yr for cooling and 6.6 kWh/m^{2}yr for heating
Portugal, Lisbon	Air infiltration rate of 0.8h^{-1} in the pressure test Lower insulation values (0.23 W/m^{2}K for roof, and 0.32 for walls) Only 1 m of the perimeter of the floor slab is insulated in order to allow the house to release heat to the soil during the summer High thermal inertia (concrete slab and internal partitions) Night ventilation strategy except for the bedroom.	3.7 kWh/m^{2}yr for cooling and 5.9 kWh/m^{2}yr for heating (91 % of energy savings compared to the building code requirements)

Source: Passive-On, 2007.

Performance in Northern Countries

As was the case with the high severity index for summer, a high severity climatic index can also limit the application of the requirements of the Passive House. A good example is presented by the Passive House Institute for Sweden, where a new kindergarten has been built meeting the standard but with a very low tightness (n_{50} of 0.15 h^{-1}) with a heat demand of 14.6 kWh/m^{2}yr.

Economics

In all cases, the additional costs for low energy buildings depend on specific conditions, but the extra upfront investments are about 10 % or less, with a clearly declining trend. Energy prices, labour cost, available experience, expertise and the way in which each construction project is executed differ significantly from one country to another, so that the transfer of cost estimations should be treated with caution. Especially, the transfer of price estimations from countries with an advanced diffusion of low energy buildings, such as Germany, to countries just beginning diffusion can be misleading. However, in general, the additional investment will be in the range of 100 EUR/m² or less (Lenormand et al., 2006) (more if expensive solutions are used), with payback returns of less than 20 years. Laustsen, 2008, also gives some important economic data (see Figure 3.26.)

Some data were published in 2007 for the economic performance of the construction of Passive Houses in Europe (Passive-On, 2007). Data are shown in Table 3.48.

Table 3.48: Economic performance estimation of Passive House standards application in Europe

Item	France	Germany	Italy	Spain (Granada)	Spain (Seville)	UK
Extra capital cost (EUR/m^2)	103	94	60	24	20.5	73
Extra capital cost (%)	9 %	6.7 %	5 %	3.3 %	2.8 %	5.54 %
Energy savings, kWh/m^{2}yr	55	75	86	65.5	38	40
LCC 20 years, standard construction, EUR	160300	204900	221000	118000	109000	118000
LCC 20 years, passive construction, EUR	160500	200600	198460	104000	102300	117000
Discounted payback time, yr	19.5	19	8	4	5	19

There are two main characteristics of Passive House economics for new buildings: construction costs are relatively similar and only a 5 to 10 % increase is observed. Energy savings are significant, but payback time periods can be really long for countries with better building practice traditions or standards. For Italy and Spain, current building practice would really benefit from the standard, with short payback periods.

According to the results, a variation from 8 to 17 % extra costs were observed in 2001. In the CEPHEUS project, cost prices per kWh of energy saved where less than EUR 0.06 (uniform real interest rate of 4 % and service life of 25 years, taking into account the maintenance of equipment, the cost of electricity for ventilation and additional operating cost savings).

The main conclusion from the application of the Passive House standard is that it will always pay back investment costs, when compared to current building practices.

For the Riedberg school in Frankfurt (example shown in the pictures of Table 3.43), the total project cost was EUR 16.7 millions, where the construction costs were EUR 11.1 millions, 5.3 % higher than the construction according to existing codes. The extra cost breakdown is shown in Figure 3.34. As observed, the extra insulation counts for more than 49 % of the total extra cost, while the extra ventilation systems counts for 23 % of the total extra costs.

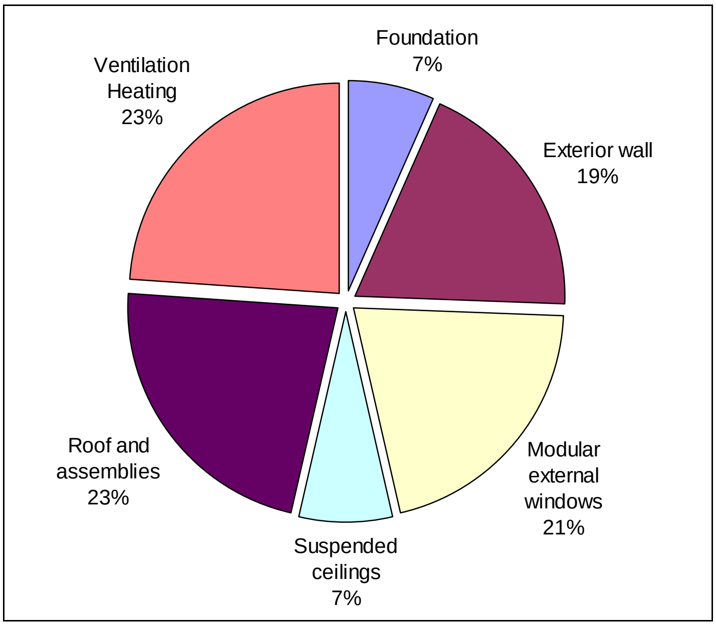


Figure 3.34: Extra cost breakdown for the Riedberg school construction in Frankfurt.

Driving force for implementation

The main driving forces for the implementation of integrative approaches, apart from the evident environmental benefits, are those associated to energy savings, cost savings, reduction of CO_2 emissions, enhanced thermal comfort and indoor air quality and, in the case of the major renovation of buildings, the fulfilling of legal requirements. The Energy Performance for Buildings Directive states that by 2020, all new buildings should be nearly zero energy buildings. Although the definition of this kind of building is still pending and depends on every Member State, it is foreseen that integrative approaches like the Passive House standard will meet this requirement.

Reference organisations

There are many organisations applying, developing and researching integrated concepts for buildings. To mention a few:

In Germany, the **Passive House Institute** (PHI) is an independent Research Institute under the scientific direction of Univ. Prof. Dr. Wolfgang Feist. The PHI is engaged in the research, development and promulgation of building concepts, building components, planning tools and validation for particularly energy efficient buildings. They developed in the early 90's the Passive House approach. More info in: www.passiv.de

Passive house examples are provided in references: Wagner et al., 2010; IPHA, 2010, Cepheus, 2010 and Passive-On, 2007.

In Switzerland, the **Minergie Standard** is widely accepted by builders, planners, architects or engineers as it can be met with a high degree of freedom in the design of building structures and the choice of materials. Economics are also considered within the standard: the budget for a certified new building (or for the renovation) should not exceed more than the 10 % of the typical cost of a similar uncertified building. It is a well-known and recognised standards family among central European architects and its variant **Minergie-P** is considered as the equivalent to the Passive House standard.

The **BBC-Effienergie label** (developed by the Effienergie association) is a French standard, similar to the Passive House, which benchmarks the primary energy consumption should not be higher than 50 kWh per square metre per year (which may vary depending on the region). In this value, it is considered the energy uses that can be actively influenced from the design of a building:

- Heating
- Hot water
- Auxiliary appliances for ventilation and heating
- Lighting (via natural lighting)
- Air-conditioning.

It does not include other utilisations of electricity (particularly household appliances, audiovisual equipment, etc.) that are equivalent to more than 50 kWh/m^2 year of additional consumption. More information on this standard can be found in www.efienergie.org.

As a successful application of the Passive House standard, the **City of Frankfurt** can be regarded as a reference organisation, as in the city it is mandatory to apply the Passive House approach to any new public building, big refurbishment or building constructed in purchased land to the authorities (http://www.energiemanagement.stadt-frankfurt.de/)

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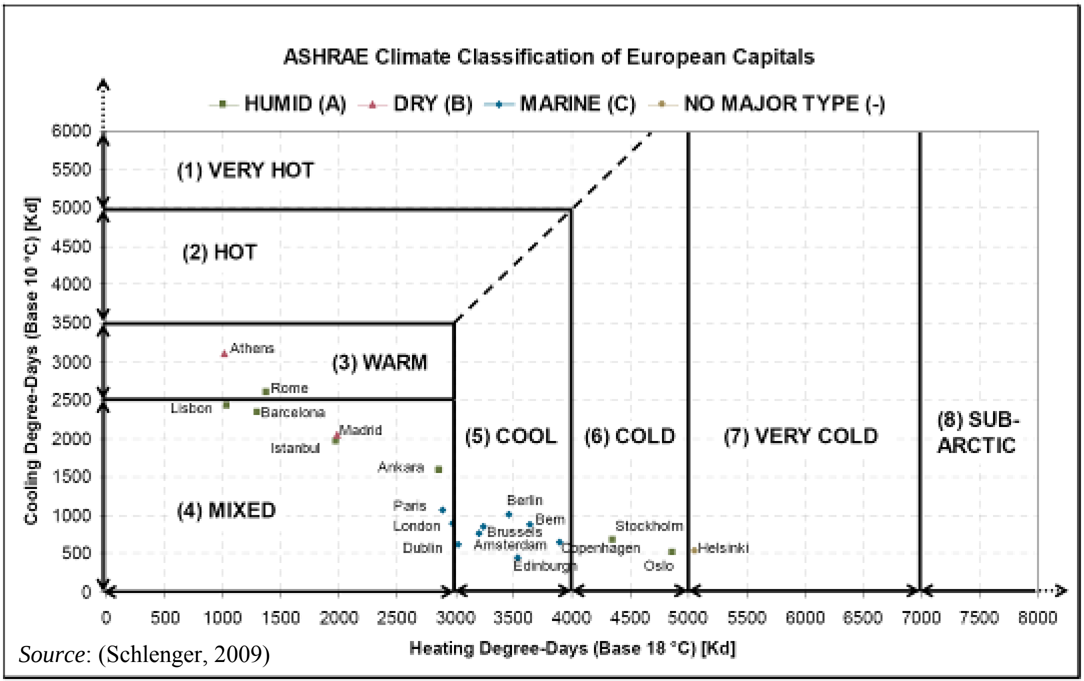
3.4.3 Design and Retrofitting of the Heating, Ventilation and Air Conditioning (HVAC) system

Description

The purpose of the HVAC system of a building is to achieve comfortable conditions for the occupants, avoiding any source of nuisance. For a deeper description and technical background, see Section 3.3.3.3. The design substantially changes across Europe, as e.g. the heating load is low in the south of Europe, or the cooling demand can be neglected in Nordic countries. Figure 3.35 illustrates the segregation of climates in Europe, where some cities are differentiated by the cooling degree days (13) and the heating degree days (14) (Schlenger, 2009; Boermans et al., 2006).



Source: (Schlenger, 2009)

Figure 3.35: Climate classification of European capitals

Under the term HVAC, a huge variety of technologies are available and, therefore, the definition of best environmental management practice becomes complex. In general terms, best practices for HVAC should take into account its integration with the building envelope as a whole. No singular technology should be considered best practice as such without a full perspective on the integration within the building. Nevertheless, a prioritisation scale is proposed for this description (represented by the yellow callouts of Figure 3.36):

1. Integrated design of the HVAC system in a fully optimised thermal system of the building. This means that, first, a effective reduction of demand should be achieved in order to avoid oversizing of systems.
2. Smart metering and control. Monitoring and control have a very important influence on the HVAC energy consumption, which is mainly dependant on user's behaviour.
3. Best practice for heating
4. Best practice for cooling
5. Best practice for ventilation

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(13)Cooling Degree Days (CDD): number of days when the outdoor temperature is 1 °C higher than 10 °C (for the 10 °C basis). If the difference is, for example, 2 °C during one day, the value of CDD would be 2 for that day. So, the general expression for its calculation is $CDD = (10 - T) \times \Delta t$, where Δt is the time in days.

(14) Heating Degree Days (HDD): number of days when the outdoor temperature is 1 °C lower than 18 °C (for the 18 °C basis). If the difference is 2 °C during one day, the value of HDD would be 2 for that day. So, the general expression for its calculation is $HDD = (18 - T) \times \Delta t$, where Δt is the time in days.

6. Maintenance.
7. Retrofitting.

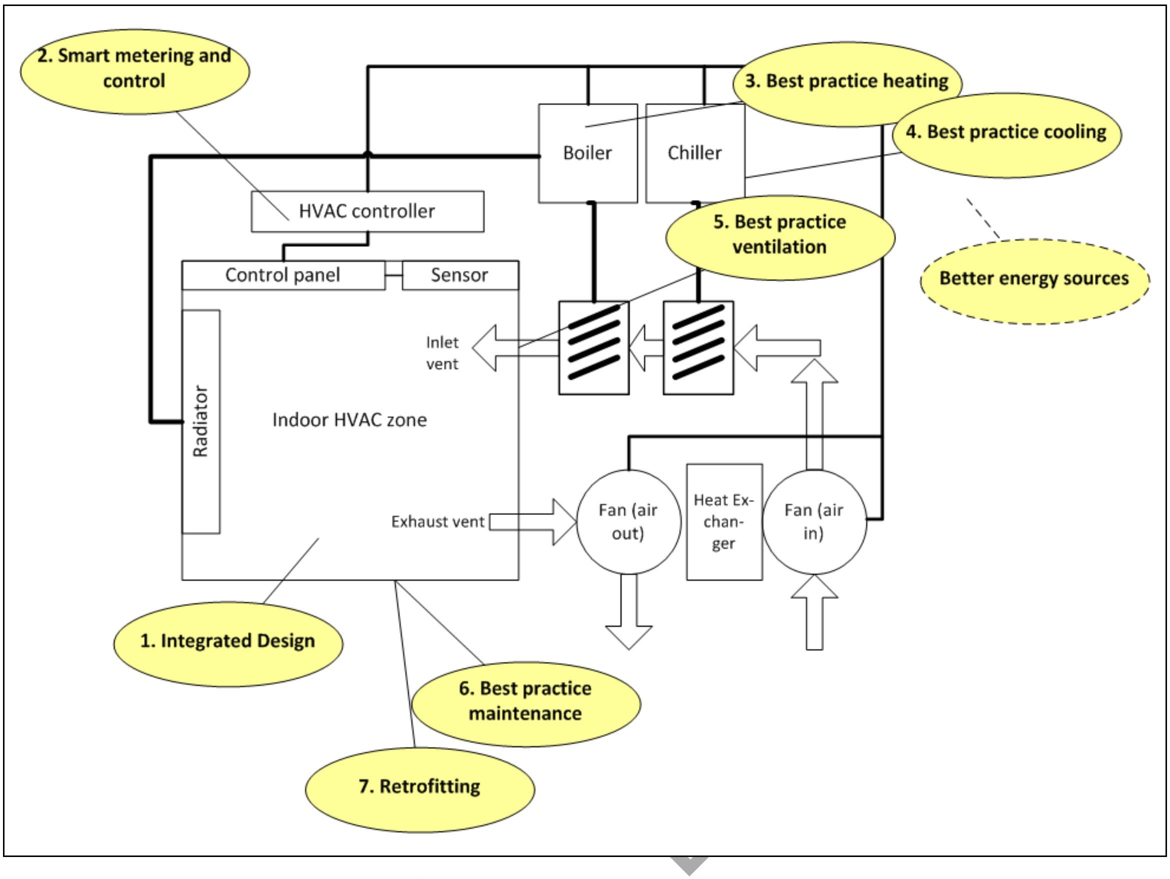

Figure 3.36: Approach and links of best practices on heating, ventilation and air conditioning

Integrated design

An integrative design of the thermal balance of the building can be considered best practice if the envelope performance is enhanced, if the project brief (for design or retrofitting) seeks for the best environmentally friendly option and the HVAC system is designed according to several premises, which can usually be assessed using optimisation models. Some of these are shown in Figure 3.36 and are described in the text below.

Each climatic zone would have differentiated HVAC design premises, due to the different heating or cooling needs and the solar gain achievable in each location. The indoor air quality requirements also influence the design due to the integration of filters, humidifiers and other devices. As explained, optimal integration would achieve the lowest energy demand of the building. Nevertheless, it could be difficult to predict an accurate value for the energy demand of the building. Also, optimal values would depend on energy prices and, therefore, solutions for different locations may differ. So, work on efficient energy modelling should be common practice during the design steps. Also, modelling of existing buildings would allow the setting of reasonable targets for energy performance, not only to the building designer, but also to the facilities manager.

For the best integrated design, thermal gains should be carefully considered in the design of the building:

- External gains or losses arise from the direct contact of the building with the outdoor environment. The most common are produced by convection, conduction and radiation and are usually measured as the U-value (see 3.4.1.1). The most important external gain is the heat from the solar radiation received, especially through glazing. This gain is usually significant and can benefit the indoor environment quality, reduce lighting energy consumption and reduce heat demand during winter. An integrated approach is always necessary, to optimise solar gain, also allowing a reduction of the excessive heat gain during summer, especially in warmer countries.

- Internal gains arise from lighting devices, occupants and special processes, such as kitchens, refrigerators, appliances in general, etc. Sometimes, designers have difficulty in knowing how these special needs are going to be arranged in the future, and therefore system oversizing may occur.

When designing a new building (or renovating an existing one), the optimisation of the HVAC system has to consider, before choosing the HVAC elements, the following aspects:

- envelope performance of the building
- potential solar gain: glazing and shading
- air leakages avoidance, air entrances (doors, gaps, etc.), air change rate fixing, heat recovery from exhaust air
- lighting system design (using natural sources as much as possible) and avoiding heat gains from lighting
- potential internal gains (from foreseen occupants, from internal appliances, waste heat from internal processes, etc.). Heat recovery from internal processes may be a source of 'free heat' leading to lower performance, e.g. from the refrigeration cycle or from waste hot water.
- monitoring and optimal control (which reduces maintenance and repair), flexible range of indoor air temperatures (19 – 26 °C)

One consequence of the lack of integrated design can be oversizing. An Ashrae (15) calculation for US stores stated that almost 60 % of the energy demand for HVAC is wasted due to oversizing (Ashrae, 2008). The main reasons for this are:

- bad insulation and significant air leakages
- inefficient monitoring and control system
- for warmer climates, heating systems designs are oversized due to higher cooling demands.

System oversizing leads to less efficiency. Moreover, poor humidity control, condensation problems, and poor mixing (stratification of air) are related problems and the indoor air quality is reduced. Thus, since the system is less efficient, costs considerably increase, as the lifetime of compressors is reduced and the maintenance needs are higher.

A simple solution example for the calculation of the energy demand of the heating system is the integrated approach proposed under the Passive House concept, which establishes a maximum power consumption of 10 W/m^2, and uses a normalised calculation procedure, summarised in Figure 3.30.

Zoning and energy management strategy concepts should also be incorporated into the design. The building should be divided into differentiated thermal zones. The energy use or demand of the different zones can be very different. These zones have to be distributed in accordance with the building size, load requirements, the space layout, function, number of occupants and special needs. The use of zoning increases energy efficiency, achieving savings of 20 – 30 % from the HVAC energy consumption. Also, heating or cooling strategies, combined also with lighting strategies can save a significant amount of energy, allowing payback in a shorter term.

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(15) ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

Smart Control and Metering

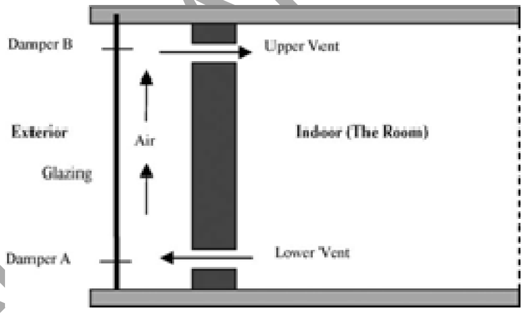
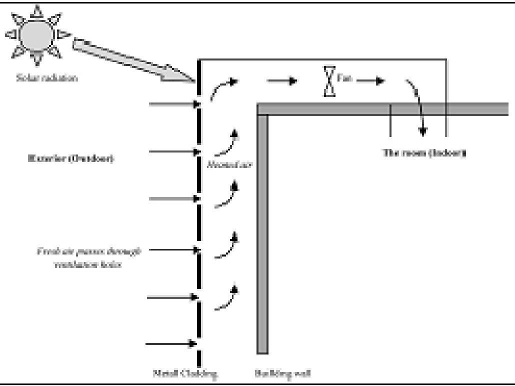
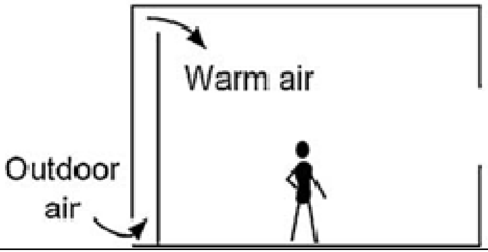
The use of on-demand control of the ventilation (using, for example, CO_2 sensors) would allow minimising the energy loss in exhaust air. Some Member States have high threshold values so that the required air flow is large and does not allow for achieving efficient heat recovery. Also, controlled and schedule ventilation rates (even without sensors may be considered best practice). Wherever possible, users and building managers should be able to individually control temperature and ventilation in specific building units (rooms, offices, etc.). Separate metering and controlling separated in zones should be possible when this issue has been considered, especially for non-residential buildings, with installed building management systems (see 6.5.2.1).

Heating technologies

Under the premises of the proposed integrative approach, the application of some available technologies for the heating system may be considered as best practice:

- **Passive solar air heating** coupled with natural ventilation strategies (Chan, et al, 2010). Table 3.49 shows a schematic representation of this and describes the working principle of each technology option.

Table 3.49: Passive heating technologies

Technology description	**Working principle scheme**
Trombe wall is a massive wall covered by an exterior glazing with an air channel. The function of the wall is to absorb and store solar heat through the glazing. Part of the energy is transferred into the room through conduction, while a convection mechanism is established between channels placed in the lower and upper part of the wall. As it can provoke some undesired effects, e.g. during the night it can remove heat to the outdoor environemnt, the design is usually changed and the wall is attached to a indoor insulated wall, creating a second channel (called Trombe-Michel wall). It can be used also for cooling.	
Solar façade consists of an unglazed wall covered by a metal layer with holes. The metal is heated by solar radiation and with mechanical ventilation, the heated air is sucked into the HVAC intake.	
The purpose of the **solar chimney** is to generate airflow through a building, converting thermal energy into kinetic energy of air movement. Different densities create this movement through convection, so ventilation is provided for cooling in summer and heating in winter.	

Source: Chan et al., 2010

- **Solar thermal systems** with evacuated tube collectors are a common and highly efficient form of simple solar heat collectors. Sunrays pass through the tube glass and are absorbed by metal stripes, in which the heat medium flows. The absorbing metals are situated in a vacuum surrounding in order to obtain good isolation and to achieve the best absorbing efficiency. The operating cycle of such a system consists of the collector, a heat storage tank (usually with the capability of storing heat for 2-3 days), the heat cycle medium (usually a mixture of water and glycol) the heat cycle and an electricity-driven circulation pump.
- **Horizontal ground heat exchangers** usually are polyethylene ducts, which are installed at 1-2 m below the surface. A standard household application requires a total duct length of 100-200 m, and is installed in circular loops to minimise land requirements. The heat medium, usually a water and glycol mixture, is pumped through the duct to get warmed up to soil temperature. The soil temperature, depending on season and influenced by solar radiation, air temperature and rain, varies between 4 °C and 13 °C. As hot water usually requires temperatures of around 60 °C and floor heating temperature levels of approximately 35 – 40 °C, the temperature gap has to be closed with a pressure increase and peak level heating. Special attention is drawn to an efficient heat pump, proper storage and especially proper operation of the heating system. Experts highlight, that no other systems' efficiency (e.g. heating seasonal performance factor (HSPF)) depend that much on operational and installation habits. Complex systems and inefficient storage loading strategies, as well as oversizing and inefficient hydraulic systems are further general areas for improvement.
- **Heat pumps** extract and upgrade low grade renewable heat stored in surrounding air, water, ground, etc., so that it can be circulated within HVAC systems to provide space and water heating. They also work in reverse to extract heat from building HVAC systems and expel it to the surrounduing environment. Heat pumps function according to thermodynamic principles underpinning the basic refrigeration cycle. The external energy required by heat pumps to transport and upgrade heat from a heat source to the point of heating, and vice versa for cooling, is lower than the amount of heating or cooling energy provided by the heat pump, potentially resulting in significant energy savings compared with conventional heating or cooling systems. Heat exchange media may be: (i) ambient air (air-source heat pumps); (ii) water, including groundwater (water-source heat pumps); (iii) the ground, close to the surface or at depth (ground-source heat pump). To consider heat pump as a best practice, the most important aspect is the utilisation of ground- or water-source heat pumps where feasible according to space, geological and economic considerations (more expensive than air-source heat pumps). Another important aspect of best practice with respect to a heat pump application is installation of a low temperature distribution (HVAC) system, which in turn is most effective where relatively low heat demands have been achieved through a good quality building envelope. Thus, optimised heat pump applications depend on an integrated approach to building design.
- **Automatically fed wood pellet boiler:** indirect heating appliances for the residential sector, such as central heating systems, are mostly characterised by a nominal heat output of 50 to 300 kW. Herein, an automatically fed pellet boiler is one of the actual state-of-the-art products for solid biomass combustion. The automatic feeding system allows continuous and stable combustion performance. Heat storage tanks can level a volatile demand for heat and hot water. These two features guarantee stable input and output conditions for the pellet boiler and hence enable a continuous combustion process. Continuous and automatic feeding of pellets into the combustion chamber is the key to stable combustion conditions with low emissions. Automated systems can metre the fuel input and can adjust the combustion air flows accordingly. In particular, sophisticated air staging (splitting the combustion air into a primary air flow directly to the flame and a secondary air flow to the direction of the combustion gases) will help to optimise the combustion, by guaranteeing a minimum level of excess oxygen in the combustion zone and enough oxygen above the zone. The injected secondary air will increase the low-temperature outer-flame volume and fully oxidise partially oxidised species such as hydrocarbons, black carbon and carbon monoxide. Heat storage tanks allow for long operational times at full and nearly-full load levels by serving excess demand with stored heat and absorbing excess supply into the storage facility. In general, start-up and shut-down numbers, especially for low levels of

short time heat demand, can be reduced to about 3 – 5 start-ups and shut-downs per day for pellet boilers.

- **Automatically fed wood chip boilers** are another indirect heating appliance with basically the same working principle as automatically fed pellet boilers. Instead of reproducing large parts of the technique description of pellet boilers, this part moreover highlights differences between these two systems, highlighting advantages and disadvantages of wood chip boilers compared to pellet boilers. The boiler construction and heat cycle should be equal, though there will be differences in the performance indicators. Since wood chips mostly consist of wood scrap and bark, the average heating value is expected to be lower than for wood pellets. As wood chip boilers and pellet boilers are nearly equal, they are competitive products. Wood chip boiler appliances exist for the same heat output range, for large domestic appliances usually between 50 and 300 kW. Accordingly, automatic are assumed to be superior to manual feeding systems and the heat storage tanks has a significant role for efficiency maximisation and emission reduction. Boilers with dual fuel use (pellets and chips) exist alongside boilers that are only usable with pellets or chips. Chip boilers usually have a fuel stoking system, whereas pellet boilers can be equipped with a simpler pellet metering system.
- **Adjustable high-efficiency circulation pumps** are good substitutes for old circulation pumps, as they reduce the electricity consumption. High-efficiency pumps use new drivetrains with higher efficiency factors (up to +25 %). Adjustable pumps can reduce the power needs and do not work at just one single point of operation. This principle is especially important for times of low operation (which is most of the time).

Cooling technologies

Space cooling best practices are mainly are for demand reduction through the use of some of the following techniques:

- heat absorption during daytime in summer by increasing the size of heat sinks
- use of cool roofs (reflecting incoming radiation from the sun)
- green and brown roofs (cooling by evaporative absorption).

These measures above should be regarded only as complementary to other mainstream technologies.

Passive cooling involves cooling without using mechanical apparatus that consume power. For this, the urban microclimate is the major factor influencing the performance of passive cooling technologies (Hughes et al., 2011)via:

- Optimal insulation, shadings and overhangs and air change rate. Integrated designs between internal heat gains during summer and how to release this heat to the surroundings should be studied in detail. These passive measures should be incorporated into an overall integrated approach (see 3.4.2).
- Openable windows to promote natural ventilation and cooling when temperature difference is appropriate (e.g. during night time). Night ventilation (cross or single sided ventilation) can produce energy savings when studied and optimised according to the surroundings (Geros et al., 2010). For non-residential buildings, mechanical ventilation is distributing night air.
- Wind towers. This is a well known technology, used for more than three thousand years and used in traditional architecture. Currently, it is used as an element of natural ventilation installations, reducing the energy consumption of mechanical ventilation and reducing the temperature of indoor climates (Figure 3.37). Wetted wind towers can remove the need for active cooling, through evaporative cooling in warm, dry climates (Hughes et al., 2012).

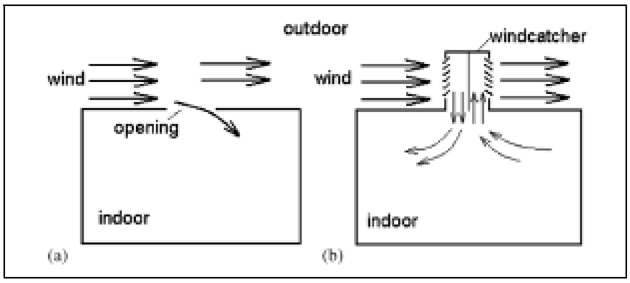


Figure 3.37: Windtower options: a) single opening, b) common windcatcher

Designers should consider all the possibilities of passive cooling in the inception of a new building design, as the energy performance would always be much more positive. Then, if a building cannot be cooled using passive means, active cooling strategies should be considered. The main technologies for active cooling involve high pressure compression, consuming a significant amount of energy, but achieving coefficients of performance in the range of 3 up to 8 (Hughes et al., 2011).

For commercial buildings, the package terminal air conditioning system is a very common technology. The condensing unit is usually outdoors and the evaporating unit is usually indoor, cooling indoor air. Most efficient systems include the use of water cooled air conditioning systems, although the investment and maintenance needs have higher costs. The use of heat exchangers to cool down incoming ventilation air without an increase of humidity or with dehumidifiers also increase the efficiency of the cooling system and has become a common technology in warm climates.

Some innovative and commercially available technologies for active cooling are:

- **Desiccant and evaporative cooling** (DEC) is an open air conditioning system, i.e. it does not have an intermediate cycle but cools air directly. Herein, DEC systems also achieve humidity control, thereby making separate dehumidifiers obsolete, as they need dehumidification of the nair to maximise the effectiveness of evaporative cooling. As open systems need fresh air as input, DEC combines the tasks of ventilation, dehumidification and air conditioning. At first, fresh air is dehumidified by an adsorption process, where special materials such as lithium chloride on cellulose, silica gel, metal silicates or zeolites adsorb water into their structure. The adsorption energy is passed onto the air, so that warm and dry air is the product of this process. The air is pre-cooled with cold discharged air via an air-to-air heat exchanger. Afterwards, a humidifier provides liquid water, which evaporates and thereby reduces the air temperature, as the evaporation energy needed is withdrawn from the fresh air. The adsorption process needs a regeneration phase, where adsorbed water is desorbed. Desorption is achieved by warming the discharged air after the heat exchanger to higher temperature levels (50 – 100 °C, depending on the adsorbing material used and the degree of humidification), which allows the adsorbed water to desorb and be discharged with the air. Heat can be provided by directly gas-fired heat exchangers or an external source such as central heating systems. New developments arise in integrated solar thermal heat generation into DEC systems, as this does not produce any emissions and may use excess collector heat.
- **Absorption chillers** are closed systems and use the principle of thermal compression to provide cooling. Herein, a refrigerating medium is absorbed and another is evaporated, usually liquid medium, thereby drawing heat from the surrounding and passing heat onto another surrounding. In typical household applications, water is used as the refrigerating medium and evaporates under low pressure at usually 10 mbar and 4 °C, thereby extracting heat from the surrounding, and is then absorbed onto gaseous lithium bromide (LiBr). When this process is allocated in an indoor air-H_2O/LiBr heat exchanger, the indoor air provides this heat and is consequently cooled down. In order to provide continuous heat withdrawal at a closed loop system, the water has to be evaporated off

the H_2O-LiBr complex at another place of the system, the regenerator. Regenerating LiBr is done by heating the substance up to temperature levels of 80 – 110 °C at standard pressure in order to split the complex into steam and LiBr. Heat may be provided by thermal combustion, solar thermal heat or heating networks (see Section 2.1.6.). The attractiveness of using solar thermal heat or heating networks is that these systems face shrinking demand in times of high air conditioning demands. The majority of absorption chillers have one absorption cycle. In order to increase system efficiency, two cycle systems with two absorption steps have been developed. But as efficiency increases, installing the second cycle leads to increasing investment and higher temperature needs (140 – 160 °C).

Ventilation technologies

Ventilation is a key factor influencing the thermal behaviour of a building. In fact, occupant behaviour is an issue that, usually, strongly influences the energy performance predicted or estimated by common methodologies, which typically assume constant air change rates or full day ventilation for small residential houses. Therefore, this uncertainty should be considered during design by, e.g. limitating windows opening during certain day periods or by agreeing on an adaptative thermal comfort level.

With respect to available technologies, a technique which can be considered as a best practice is the recovery of heat from exhaust ventilation in a heat exchanger with incoming ventilation air. This technology, well known in moderate and cold climates, is essential to reduce substantially the heat demand of a building. For its application, a certain degree of air tightness is needed and centralised mechanical ventilation is required, so, applicability to existing buildings can be quite limited.

A simpler solution can be novel air collectors. The use of solar **air collector**, which is a feeding apparatus for ventilation systems, substitutes classical mechanical ventilation systems and can be installed in an existing system. Air collectors are placed at the outer wall or roof and use the solar energy to preheat air and regulate the humidity. The system consists of the collector itself, a ventilation fan and in most cases a filter for air quality reasons.

The **earth-to-air heat exchanger** is another outstanding technique used for ventilation and includes a baseline temperature control mechanism. Earth-to-air heat exchangers are available as closed, open and hybrid systems. Closed systems are characterised by an air-cycle, which takes warm indoor air, cools it down in the heat exchanger and provides the cold air. Open systems do not take indoor air, but use fresh, outdoor air instead. Hybrid systems form a mixture of both systems. Herein, a focus on open systems is made, as these provide fresh air to satisfy indoor air quality issues with regard to CO_2 and O_2 shares. Open systems extract fresh outdoor air filtered by the soil, over approximately 3 meters of filtration length, and filtered mechanically with additional particle filters and then supply the air via ducts (the earth-to-air heat exchanger) to the ventilation system. The ventilation system itself may have an in-house air-to-air waste heat exchanger and air heating installation, which allows the temperature to rise to the demand level. Air will be filtered by a drainage system, which enables providing the air at soil temperature and allows a filtration of solid particles, bacteria and other substances by gravels. The earth-to-air heat exchanger ducts are installed with a falling gradient to allow condensing water to be accumulated at a single point away from the drainage system. The air inlet should not be next to large roads and other locations of especially polluted air and the soil has to be checked for radon concentration. Radon is a harmful gas in the soil and should not be introduced into the house ventilation system. Systems installed at places with high radon concentrations should have special geomembranes at the drainage system in order to protect the ventilation system.

Retrofitting and maintenance

When an HVAC system is retrofitted, the four aspects given below also have to be covered (LBNL, 2001).

- System upgrading: to change to modern and efficient equipment, to include zoning concepts, to improve or change ducts, etc.
- Sizing: oversized HVAC systems have to be optimised; if improvements in the building envelope are introduced, the HVAC system could use considerably less energy, but it will become oversized.
- Integrating systems: the waste heat from internal processes (warm waste water, refrigeration, exhaust air, etc) may be recovered to reduce the energy consumption for heating.
- Avoiding mould and odour: this is essential since it leads to an unhealthy and nuisance situation for occupants.

For the air distribution, existing systems have to be checked according to:

- duct leakages
- air flows at registers
- air handler flow
- exhaust and supply fan flow
- refrigerant charge of the air conditioning system
- envelope leakage
- moisture-related aspects (mould and odour):
    - visualisation/odour
    - electrical inspection for moisture.

In Table 3.50, a checklist of retrofitting and maintenance actions for HVAC is proposed. The diagnosis of the building would help designers and architects to decide what main aspects should be retrofitted in order to improve the energy efficiency of the HVAC system.

Table 3.50: Checklist for aspects and potential retrofit actions

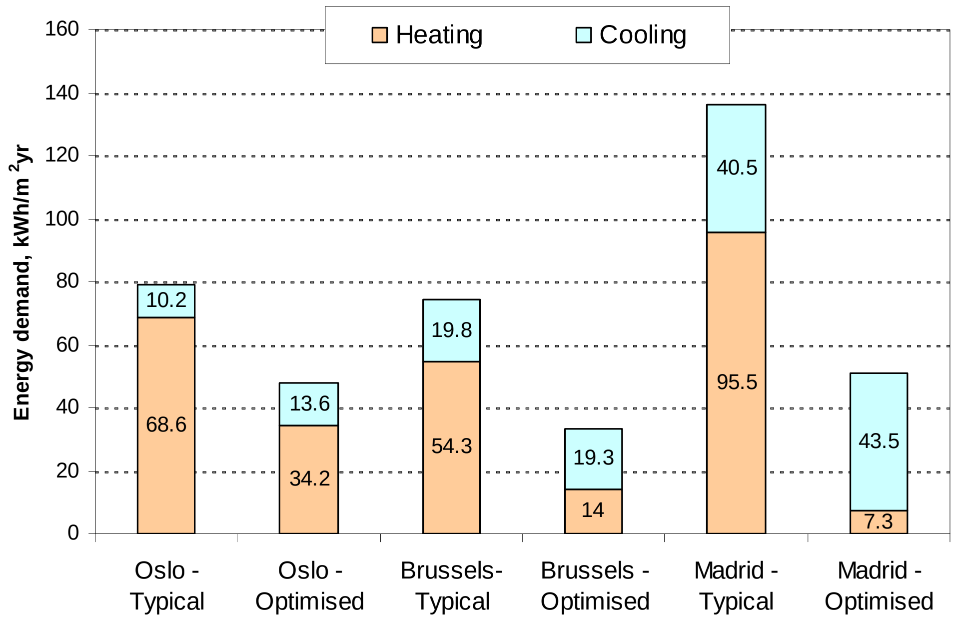
Observation	Potential retrofit action
Duct leakage	Add seal ducts: aeroseal/tape/mastic
Bad duct insulation	Add insulation to ducts
Air flows at registers	Replace registers, open/close dampers, reduce system flow resistance by straightening existing ducts or replacing them with straight runs of new ducts
Low air handler flow	Replace filters, fix duct restrictions, change fan speed, replace fan with a high-efficiency unit, add extra returns in return-restricted systems
Bad filter condition	Replace filter
Incorrect thermostat setting	Raise thermostat in summer and lower it in winter to account for better distribution, mixing and envelope improvements
Spot ventilation	Replace fans if necessary. If possible, remove spot ventilation and use ducts and central ventilation
Spot ventilation: high power consumption	Replace with a higher efficiency unit, remove/reduce duct flow restrictions, clean fan and ducting
Equipment capacity	Replace with correct size
Refrigerant charge	Add/subtract refrigerant
Age and condition of HVAC system	Clean the system and repair damage or replace the system if >15 years old
Location of HVAC system equipment and ducts	Seal and insulate duct locations. If applicable, move system location
Window A/C units	Replace with central unit or improved distribution
Multiple systems/zoning	Ensure correct damper operation, check capacity of each system/zone load calculation
Moisture testing	Improve source control — better venting in sensitive zones, fix flashing/detailing, seal crawlspaces in high humidity climates, replace windows, add insulation to walls, floors and ceiling
Occupant survey - asking customers to report problems	Create moisture removal strategies; install new windows, change register type, airflow and location to improve mixing/remove drafts, add envelope insulation, etc.

It has to be noted that all of the described techniques are always applicable to existing buildings. However, the cost of retrofitting would be prohibitive for some of them. Therefore techniques should be considered from the very beginning of the design process (Maisey, 2007).

Achieved environmental benefits

Integrated savings

Schlenger (2009) calculated the heating and cooling demand for a model office in several locations across Europe. Taking into account the typical building of each location, the heating and cooling needs for the office was estimated. The optimisation of the building envelope (wall, roof, shading systems and glazing) led to remarkable results, shown in Figure 3.38. The heating and cooling demand for three different locations were calculated: Oslo as a cold zone, Brussels as a moderate zone and Madrid as a warm zone. The heating needs can be drastically reduced but the air cooling energy demand can increase. The improved air tightness and insulating properties of the envelope would lead to a higher influence of the internal and solar gains. The fact that there would be less heat loss through the building envelope compensates for the gains and, after the calculation, the cooling needs are very similar to a conventional situation. The worst initial scenario of warmer climates leads to great savings (more than 50 % for Madrid). Although the cooling demand can increase, the heating demand of the optimised building is significantly minimised.



Source: Schlenger, 2009

Figure 3.38: Energy use in EU locations

The final impact of optimised and integrated measures taken during design can have a huge impact in the selection and performance of HVAC technologies, making some techniques more relevant when compared to others. For instance, a building demanding 50 kWh/m^{2}yr for heating would need of a major heating system (higher than 30 W/m^2), so the investment is likely to be made in better energy sources, e.g. wood boilers, rather than e.g. on an exhaust air heat recovery system producing a lower impact. Nevertheless, for an insulated, air-tightened building consuming 20 kWh/m^{2}yr, heat recovery can save up to 50 % of the total heating energy consumption.

Technology-specific environmental benefits

Passive solar heating can produce huge savings to the energy consumption of HVAC. When combined with good orientation, proper building structure, optimised envelope and construction materials, and internal heating gains recovery, the overall efficiency is significantly increased. Total heat loss can be reduced by 35 % using passive solar methods (Chan et al., 2010). In some demonstration projects, savings up to 917 kW per square metre of wall can be achieved, with payback times between two and three years (IEA, 1999).

Solar thermal systems do not have relevant impacts during the operating phase. But the production of collectors is energy, CO_2 and especially material-intensive. Therefore, the total energy balance becomes positive after two to three years usually (energy payback time), depending upon site specific such as type of collector, solar intensity, etc.

Wood burning mainly produces CO_2, CO, NO_x and hydrocarbons (volatile and condensable organic compounds) as gaseous emissions, as well as ash, soot and black carbon as solid residues in form of flue-gas particles and bottom ash. Herein, CO, hydrocarbons, soot and black carbon particles are the major pollutants which can be reduced by using continuously operating pellet boilers. These substances indicate incomplete and imperfect combustion performance, and occur especially during phases of transition (start-up, shut-down, load variations) and low-load operation. As wood chips have a lower heating value than wood pellets and contain higher shares of ash and volatile compounds, combustion is not as efficient as wood pellet combustion. Heating appliances without any **heat storage tanks** face many load changes and phases of low load operation, thereby producing large amounts of partially oxidised compounds. Pellet boilers themselves allow air staging, combustion chamber optimisation and continuous fuel feeding, so emissions will be kept low during stable load phases. Additionally, air and fuel feeding systems improve combustion performance at loads between 50 and 100 %.

Adjustable high-efficiency circulation pumps reduce electricity demand and the overall CO_2 and pollutants emissions from power production. If, for example a 45 W circulation pump can be replaced by a 20 W pump and both run at design output, the high efficiency pump saves 25 W per hour. Assuming the German electricity mix with a CO_2 emission factor of 572 g CO_2 per kWh, this means a reduction of 14.3 g CO_2 per hour.

Several **cooling technologies** performances are reported by Hughes et al., 2011. The information of several case studies, regarding the cooling power, investment and coefficient of performance, COP, are reported in Table 3.51. This table is not comprehensive and should be regarded as examples only. The coefficient of performance, COP, is representative for each technology, although there could be available appliances and installations with better performances.

Table 3.51: Performance of several space cooling technologies

Technology	Price, EUR	Cooling Power, W	EUR/W	COP
Mechanical night ventilation	-	unknown	-	4-6
Wind Tower	3800	200	19	-
Packaged terminal air conditioner	200	1100	0.18	2.6
Air handling unit	530	20000	0.03	1.3-1.8
Dessicant cooling	200000	55000	3.6	0.6
Absortion cooling	17000	11000	1.5	0.7

Source: Hughes et al., 2011

As seen, dessicant or absortion cooling performance is low and their cooling power needs improvement to be competitive. Wind towers are not a pure cooling technology and their economic performance should also be regarded comparatively to other mechanical and natural ventilation systems. Classical, conventional units seem to be the most interesting from the economic point of view, although the best performance is achieved with night ventilation. The COP of night ventilation can be further improved if natural convention mechanisms are used more efficiently.

The best practice of **heat pump technologies**, when applied to buildings with low, optimised heating demand produces great savings. The EU flower ecolabel criteria are disclosed in Table 3.52, for heating systems and Table 3.56 for cooling systems. These values can be used as a benchmark for the selection of efficient equipments.

Table 3.52: Minimum heating efficiency requirements for heat pumps according to the EU Flower ecolabel criteria under various operating conditions

Heat pump type	Min. COP (elec.)	Min. COP (gas)	Min. PER	Outdoor unit (temp., °C)	Indoor unit (temp, °C)
Air/air	2.9	1.27	1.16	Inlet DB: 2 Inlet WB: 1	Inlet DB: 20 Inlet WB: 15
Air/water	3.1	1.36	1.24	Inlet DB: 2 Inlet WB: 1	Inlet DB: 30 Inlet WB: 35
Brine/air	3.4	1.49	1.36	Inlet: 0 Outlet: –3	Inlet DB: 20 Inlet WB: 15
Brine/water	4.3	1.89	1.72	Inlet: 0 Outlet: –3	Inlet DB: 30 Inlet WB: 35
Water/water	5.1	2.24	2.04	Inlet: 10 Outlet: 7	Inlet DB: 30 Inlet WB: 35
Water/air	4.7	2.07	1.88	Inlet: 15 Outlet: 12	Inlet DB: 20 Inlet WB: 15

NB: Additional lower COP and PER values are indicated in EU Flower criteria based on higher output temperatures.
COP= Coefficient of performance PER = Primary Energy Ratio
DB = dry bulb thermometer, WB = wet bulb thermometer.

Source: EC (2007).

Table 3.53: Minimum cooling efficiency requirements for heat pumps according to the EU Flower ecolabel criteria under various operating conditions

Heat pump type	Min. EER (elec.)	Min. EER (gas)	Min. PER	Outdoor unit (temp., °C)	Indoor unit (temp, °C)
Air/air	3.2	1.4	1.3	Inlet DB: 35 Inlet WB: 24	Inlet DB: 27 Inlet WB: 19
Air/water	2.2	0.97	0.9	Inlet DB: 35 Inlet WB: 24	Inlet DB: 23 Inlet WB: 18
Brine/air	3.3	1.45	1.3	Inlet: 30 Outlet: 35	Inlet DB: 23 Inlet WB: 18
Brine/water	3	1.32	1.2	Inlet: 30 Outlet: 35	Inlet DB: 23 Inlet WB: 18
Water/water	3.2	1.41	1.3	Inlet: 30 Outlet: 35	Inlet DB: 23 Inlet WB: 18
Water/air	4.4	1.93	1.8	Inlet: 30 Outlet: 35	Inlet DB: 27 Inlet WB: 19

NB: Additional lower EER and PER values are indicated in EU Flower criteria based on lower output temperatures.
EER = Energy efficiency ratio, PER = Primary Energy Ratio
DB = dry bulb thermometer, WB = wet bulb thermometer.

Source: EC (2007).

Appropriate environmental indicators

The specific heating and/or cooling demand per year and per square metre should be used. This indicator, quite useful in terms of primary and final energy demand, indicates the overall thermal performance of the building as a whole. Nevertheless, the exact definition of how it is calculated should be provided when assessing a building: type of energy (final or primary), time of building use (an office building lifetime may not be comparable to other types of building) and area (useful area, floor area, corrected area with height, etc.). Other usable (but indirect) indicators can be the amount of CO_2 emissions per year expressed in specific terms (e.g. per square metre).

The heating Seasonal Performance Factor (HSPF) is a common indicator to assess the performance of heating devices (AHRI, 2008). It is the total space heating required during the space heating season divided by the total electrical energy consumed by the heat pump system during the same season. It is more an operational indicator. As it represents the energy output in kWh, indirect emissions due to the use of electricity can be derived by assuming the use of the national mix of electricity. 1 kWh heating energy will need 1/3 kWh power (assuming a HSPF of 3.0). As a reference, the specific CO_2 average emission for Germany in 2008 has been 572 g/kWh([16]), therefore a German heat pump will induce emissions of 190.67 g/kWh on a theroretical level with its HSPF of 3.0. Therefore, systems are usually characterised by achievable HSPF-values of 3 to 4.5.

The heat pump efficiency is calculated as the ratio between the total heat output or heat removed for cooling and the primary energy input, calculated according to a standardised methodology, EN14511: 2004. The Coefficient of Performance is the common way to express heating efficiency: $COP = Q_H/W$, where Q_H is the delivered heating energy and W is the electricity consumed to circulate and compress the refrigeration plus the ventilation consumption.

For the efficiency measurement of heat pumps, the European Commission has developed some definitions in 2007/742 (EC, 2007):

- Coefficient of performance (COP) is the ratio of heat output to electricity or gas input for a specified source and output temperature (for heating mode of heat pumps).
- Energy efficiency ratio (EER) is the ratio of cold output to electricity or gas input for a specified source and output temperature (used for the cooling mode of heat pumps).
- The primary energy ratio (PER) is given by: COP × 0.40 (or COP/2.5) for electrically driven heat pumps and by COP × 0.91 (or COP/1.1) for gas driven or gas absorption heat pumps, where 0.40 is the current European average electricity power generation efficiency including grid losses, and 0.91 is the current European average gas efficiency including distribution losses

Cross-media effects

Insulation and increased air tightness lead to a significant reduction of heating needs. Nevertheless, a better envelope may increase cooling needs for buildings with large occupancy rates. This cross-media effect should be carefully studied for specific cases, although it is probable that specific energy consumption for the HVAC will reduce by the application of best practices, even if the cooling demand is increased (see Figure 3.38). If the initial U-value of the envelope is already very low, the energy consumption reduction may not be as significant as expected. A significant cross-media effect to face will be the indoor air quality of the building environment. The ventilation and air flow systems have to be carefully designed, as the reduction of air leakages can provoke more humidity, unwanted odours and, therefore, nuisance for the occupants.

From the life cycle perspective, heat pumps use refrigerants with important global warming potential. Leakages can provoke that equivalent CO_2 emissions avoided through the reduction of energy consumption are compensated through the emission of other greenhouse effect gases. So, the use of low GWP, e.g. applying the EU Ecolabel criteria for heat pumps, should be considered for best practice application of these systems.

Operational data

The calculation of the heating and cooling demand of a building depends on a number of factors including:

- status of the envelope and its insulating properties
- climatic conditions (latitude, humidity, proximity to the sea, etc.)
- building use
- building occupancy profile

([16]) Development of the specific CO_2 emissions of the German electricity mix, March 2010, www.umweltbundesamt.de.

- internal gains and heat recovery systems
- temperature control.

For **solar thermal collectors**, vacuum tubes minimise heat losses to the surrounding by enlarging isolation effects, so that especially in combination with aluminium or copper as absorbing metals and anti-reflex plate glass, collection efficiency can be raised up to 70 – 80 % and overall system efficiency to 30-40 %. Proper systems use efficient circulation pumps, as inefficient pumps reduce overall efficiency and have higher electricity costs. According to German consumer advice centres, inefficient pumps may use 15 % of the energy generated by the system, whereas efficient pumps can reduce the share down to 3 – 4 % ([17]).

Table 3.54 shows an example of the calculations made for several purposes of a specific solar thermal collector according to several simulations (SPF, 2011).

Table 3.54: Simulations of solar thermal collection system needs in several scenarios

Description	Surface demand (Number of collectors)	Fractional solar savings*	Solar yield
Production of domestic hot water (daily energy demand of 10 kWh , 4-6 people)	5.25 m^2 (2.4)	60 %	484 kWh/m^2
Water pre-heating (consumption of 10 000 l/day for 200 people)	67.2 m^2 (30.6)	25 %	715 kWh/m^2
Space heating system (Energy demand of 12 140 kWh/yr, 4-6 people)	16.8 m^2	25 %	321 kWh/m^2

N.B. Cold water 10 °C, collector orientation south; * Fractional solar savings is the proportion of the final energy that, thanks to the solar system, can be saved compared to a reference system
Source: SPF, 2011

The use of solar thermal collectors may encompass **passive solar space heating**. A number of examples were developed by the International Energy Agency on the *low cost, high performance solar air-heating systems using perforated absorbers* (IEA, 1999). Several demonstration projects proved to produce important energy savings. These case studies are shown in Table 3.55.

Table 3.55: Passive solar heating case studies performances

Size of wall absorber	Porosity	Energy efficiency	Energy saving, kWh per m^2 of wall and per year	Cost (EUR/kWh in 20 years)
1877 m^2 (Canada)	2 %	57 %	917	0.09
420 m^2 (Japan)	2 %	72 %	754	0.21
343 m^2 (Germany)	1 %	63 %	250	0.11

For ground heat exchangers with heat pumps, pressure levels, peak temperatures and the energy needed for circulation determine the overall energy demand, usually in the form of electricity. German DENA standards define a heat pump to be 'efficient' if it has a HSPF above

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([17]) German consumer advice centre „Energiesparen im Haushalt', http://www.energiesparen-im-haushalt.de/energie/bauen-und-modernisieren/hausbau-regenerative-energie/energiebewusst-bauen-wohnen/emission-alternative-heizung/heizen-mit-der-sonne-solar/solar-pumpe.html.

3.0, and 'very efficient' if it is above 3.5. During summer times, HSPF is expected to be lower than in winter times, as in summer, most hot water required is tap-water, which needs higher temperatures than hot water for room heating. The soil temperature is only at a maximum of 14 °C in Germany, this limits the maximum achievable temperature and further increases have to be done with the use of electricity. Hence more power is required and the HSPF decreases. Studies of selected heat pumps across Germany showed average HSPFs of just above 3.0 for the summer and around 4.0 between October and March.

Standardised **pellet boilers** have been analysed under the Eco-design directive preparatory study for solid fuel combustion (EC, 2009). Table 3.56 shows the best performance figures, which have been used to characterise the pellet boiler (reference O_2 content: 13 %-vol.).

Table 3.56: EcoDesign performance indicators for pellet boilers

Energy efficiency (NCV)	94 %
CO emissions [mg/Nm³]	30
PM emissions [mg/Nm³]	10
Organic compounds emissions [mg/Nm³]	1.5

Source: EC, 2009

As a comparison, the EN 303-5 (the corresponding EN-standard for automatic biomass boilers with nominal heat output of 50 to 150 kW) sets the emission limits for classes 1 (dirtiest class) and 3 (cleanest class) at the levels shown in Table 3.57.

Table 3.57: EN 303-5 test stand emission limit values for pellet boilers

	Class 1	Class 3
Energy efficiency (NCV)	67 + 6 log (Q_N)	47 + 6 log (Q_N)
CO emissions [mg/Nm³]	12 500	2 500
PM emissions [mg/Nm³]	200	150
Organic compounds emissions [mg/Nm³]	1 250	80

Source: EC, 2009

The required efficiency herein can vary according to the nominal heat output Q_N in kW. Studies have shown that optimising the combustion process leads to nearly zero large particle emissions, but contrarily creates more fine particle emission (diameter < 0.1 µm). Optimised combustion leads to higher combustion temperatures and flue-gas velocities. This effect enlarges the discharge of mineral ashes (in the form of fine particles) via the flue-gas. Therefore, particulate emissions cannot be reduced to zero without further secondary abatement techniques, such as electrostatic precipitators and fabric filters.

Additional electronic precipitators reduce PM emission by 50-70 %. Additional after-burning catalysts are able to reduce carbon monoxide and volatile hydrocarbon emissions by enhancing complete combustion.

The EN 303-5 emission limits for the various small combustion installations show the broad range of combustion performances along each type of installation. The Eco-design study emission figures for best performance of pellet boilers shows the large improvement potential in residential solid fuel firing, even for class 3 combustion installations, if pellet boilers replace actual solid fuel installations.

Regarding specific CO_2 emissions, many directives state a primary energy factor of 0.2, for emissions due to production and transportation of pellets. For the combustion process itself, CO_2 emissions are defined as being zero, since pellets are defined as being renewable. Nevertheless, pellets contain carbon, which is emitted as black carbon, CO and CO_2. As the NCV of pellets is 18 MJ/kg and wood consists of roughly 50 % carbon, carbon burnt per kWh heat output (NCV efficiency shall be 0.9) is 111g. Subtracting black carbon and CO, specific CO_2 emission gives range between 350 and 400 g/kWh heat output. The power demand of pellet boilers is moderate compared to other available heat generation principles. In addition, automatic feeding systems require more power than manual feeding systems.The pellet boiler itself is normally located in a separate room, usually in the basement or in a building extension. Unlike the boiler itself, pellet storage needs quite a large space. In most cases, outdoor shelters are used. Static issues and nearby storage usually prevent installation above the ground floor.

The EcoDesign preparatory study accounts the emission differences between sole pellet boilers and dual fuel pellet and wood chip only in terms of PM (i.e. dust) emissions, as can be seen in Table 3.58. CO and organic compound emissions can be expected to be higher.

Table 3.58: EcoDesign performance indicators for pellet boilers and combined pellet/ wood chip boilers

	Pellet	**Wood Chip**
Energy efficiency (NCV)	94 %	92 %
CO emissions [mg/Nm³]	30	30
PM emissions [mg/Nm³]	10	20
NO$_x$ emissions [mg/Nm³]	90	90
Organic compounds emissions [mg/Nm³]	1.5	1.5

Source: EC, 2009

According to the authors, these EcoDesign values represent the current best available technique for these boiler types in the European Union. Table 3.59 reproduces TÜV(18) and NUA(19) test results for three types of currently available 300 kW wood chip boilers, which show the variability of emissions depending on the selected type. Special attention is drawn to the partial load results, which are on the right side of the full load results.

Table 3.59: Performance comparison of three 300 kW wood chip boilers with EN 303-5 Class 3

	Type 1	Type 2	Type 3	EN 303-5 C3
Energy efficiency (NCV)	92.4 %/92.2 %	91 %/92 %	90.5 %/90 %	81.22
CO emissions [mg/Nm³]	10/3	22/17	5/209	2,500
Dust emissions [mg/Nm³]	35/26	63/34	29/37	150
NO$_x$ emissions [mg/Nm³]	113/75	158/154	40/45	-

These test results show the varying range of applicability and individual strengths of each type. Type 1 is much more adequate for partial load operations, whereas type 3 has been optimised for low emissions at full load. Nevertheless, these values far outperform the requested EN 303-5 Class 3 values and show the tremendous development between 1999 and now in domestic stand-of-the-art solid biomass combustion.

Simple **circulation pumps** usually are standard products without adjustable output and hence operate all the way through the range at 45, 65 or 90 W. The high-efficiency pumps have a new drivetrain and the ability to adjust the output, leading to average power consumption of 5 – 20 W, depending on overall heat demand. This reduction can lead to overall reductions of up to 80 % in electricity consumption for the pump operation.

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(18) German Technical Inspection Association (Technischer Überwachungsverein)

(19) Public institution for environmental protection in Lower Austria (Niederösterreichische Umweltschutzanstalt)

Applicability

Integrated approaches

The nature of integrated approaches in different climates may differ. This is further explained in Section 3.4.2. Specific needs and availability of renewable energy sources should be carefully considered. Also, the building ownership can be a main barrier for the applicability, as the main benefit of applying energy retrofitting of HVAC systems benefits the tenant and, in principle, the main investment should be made by the owner.

Air tightness and mechanical ventilation is regarded as one key element for best integrated approaches. Nevertheless, for existing buildings, technical and economical feasibility should be considered carefully.

Technology-specific applicability

In general, **solar thermal collectors** can be installed everywhere. Since the system and economic efficiency depends on sunlight exposure and requires a minimum size, practical applicability is limited to southward orientated rooftops and large free areas.

Sunlight exposure and hence collected thermal energy increases with the amount of sunny and warm days, which is why in general south European installations will have higher heat production rates than central and northern European installations.

Pellet and chip boilers with heat storage tanks theoretically have no limit of application. The wood pellet market should allow for a Europe-wide access to pellets. Boilers are available at various sizes, but high investment costs imply large scaling effects, favouring larger installations (> 50 kW/80 kW).

High efficiency pumps can be installed and retrofitted to every system. The economic advantage of these pumps is especially large for oversized systems, as adjustable pumps can downsize the power input. Therefore advantages are highest in new and freshly renovated buildings.

Economics

Any implemented measures for increasing energy efficiency will always produce cost savings because of a reduced energy consumption. Nevertheless, the achieved results will also depend on the applied approach, considering the building as a whole.

A simple estimation has been made for the renovation of HVAC systems: one saved kWh per m^2 in a retailer building (EC, 2011) would produce, for a model 2000 m^2 store, EUR 150/yr savings in a warm climate, EUR 120/yr savings in a moderate climate and EUR 70/yr savings in a cold climate. Combined with other refurbishments options, this would lead to the savings shown in Table 3.60 (Petersdorff, 2006).

Table 3.60: Potential economic savings (estimated) from HVAC system renovation

Savings from retrofitting HVAC in a warm climate (kWh/m^2)	Total savings in a 2000 m^2 model store, retrofitting HVAC in a warm climate (EUR/yr)	Savings, retrofitting HVAC and envelope in a warm climate (kWh/m^2)	Total savings in a 2000 m^2 model store, retrofitting HVAC and envelope in a warm climate (EUR/yr)
95	11 200	140	16 520

Some information on the economic performance of cooling systems, both passive or active can be found in Table 3.51.

The German research and advice foundation 'Stiftung Warentest' has tested 12 types of **solar thermal heating** systems in 2008 and has rated 10 of them as 'good' and 'very good' with prices between EUR 3 700 and EUR 5 700 (2008) for the complete system for a 4-person household (excluding installation costs). In general, flat plate collectors are in the lower price range, whereas evacuated tube collectors are in the upper price range. Economic payback depends largely on whether the use of solar thermal collectors is for hot water only or for space heating support as well. Obviously, solar thermal systems with space heating support are characterised by shorter payback periods. Across the litreature, experts and manufacturers, large time ranges concerning payback periods exist, since governmental subsidy, total price, net heat output, etc. are highly site specific and future energy prices speculative.

The installation of **ground heat exchangers with heat pumps** is costly, since it requires a lot of manpower or heavy machinery, especially larger installations and installations in greater depths. Additionally, equipment costs are high, making the ground heat exchanger with heat pump a high investment alternative. In Germany average equipment prices for standard systems are expected to be around EUR 10 000, adding installation and other costs (ca. 50 %) let total installation costs rise up to EUR 15 000.

Wood boilers are estimated to need an investment of EUR 15 000 – 20 000 for modern detached houses (approx. 10 kW net output). Wood chip boiler prices should roughly be in line with pellet boilers. Small application equipment prices are expected to be around EUR 5 000, a UK-based wood chip boiler manufacturer offers 20/30 kW boilers at GBP 3 200 to 4 350 (excl. VAT) onwards. A German manufacturer offers small installations in the same price range, and 125 kW and 250 kW installations for roughly GBP 25 000 and GBP 40 000 (excl. VAT) respectively. Heat storage tanks in recommended sizes roughly double the price. For a complete economic evaluation, total installation costs, rather than equipment costs have to be accounted for. Installation costs can vary widely. About raw materials, wood chips produced from wood scrap and by-products of the wood processing industry form a type of recycling product and are consequently cheaper than wood pellets.

Best adjustable **high-efficiency pumps** have market prices of EUR 350 – 450, and simple pumps prices of EUR 100 – 180. According to the authors, it takes three to four years for adjustable high-efficiency pumps to break even with the simple pumps.

Driving force for implementation

The better environmental performance and the reduced energy consumption would be sufficient grounds for the implementation of the described measures. Other motivations will also push retailers to implement energy efficiency measures in the HVAC system: fulfilment of existing and future regulations, achievement better conditions for clients inside the building, reduction in the greenhouse gas emissions, etc.

Reference organisations

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3.4.4 Lighting

3.4.4.1 Demand reduction through lighting concepts, strategies and integrated daylight optimisation

Description

Generally, lighting is responsible for a significant fraction of the energy consumption of any building, so energy savings on electrical lighting could reduce significantly the environmental performance during building use. The use of light can be divided in two categories:

- Natural light: directly comes from the sun through glazing. The orientation of the building, building surroundings and the availability of external light are the main factors affecting natural light systems. The availability of natural light may affect the thermal balance of the building, especially if the insulation capacity of windows is not sufficient. Again, an integrative approach may be needed for these techniques.
- Artificial light. Artificial lighting consumes a significant amount of electricity. Two types of artificial lighting have to be considered:
    - basic lighting: light supplied for the basic needs of building occupants
    - special lighting: designed to support lighting needs for special purposes.

There is not a unique solution nor measure for energy savings in the lighting concept. Lighting, as an energy consumer, has to be optimised with a fixed strategy, i.e., first, reduce the energy demand and second, use efficient devices. Reduction of demand can be achieved by using more natural light, but also with smart strategic concepts and control systems. Efficient devices refer to efficient lamps but can also be considered with efficient skylight systems.

<u>Lighting strategies and energy management.</u> A correct lighting strategy is able to produce significant energy savings (Philips Dynalite, 2010). The strategy for reducing lighting energy consumption should be included in the energy management system of the company: the energy policy and the energy objectives and targets should reflect the strategy for lighting as one of the most efficient measures to reduce lighting consumption. In addition, lighting should be considered one of the main sources of energy and costs savings. Philips Lighting (Philips Dynalite, 2010) gives some advice on setting up a comprehensive lighting strategy with enhanced energy performance (Table 3.61). For new buildings, any lighting strategy should be integrated in the building management system by defining lighting needs in lumens per zone and per day period. The use of daylighting controls and the use of high efficacy (lumens per W) devices can lead to very efficient and low energy lighting installations.

Table 3.61: Lighting management concerns and energy-saving strategies

Strategies	Measures
Limit time of use: Eliminate unnecessary lighting energy use outside normal hours. Lighting that is not required can be switched off or dimmed.	Occupancy sensors, dimming, enhanced control, on-line systems
Optimise light output	Lamps efficiency upgrade
Design illumination	Grid relocation, de-lamping, illumination management control, occupancy sensors, step dimming
Daylight integration Enable sunlight to displace artificial lighting with sensitivity to occupants.	Dimming, occupancy sensors, daylight harvesting
Life cycle operating costs Programmed lamp replacement is cost-effective	Maintenance
Enhanced lighting monitoring	Central control, online systems, maintenance
Low utilisation areas	Occupancy sensors, time control
Tariff sensitive control	Central control

Source: Philips Dynalite, 2010

Daylighting Daylight is generally preferred above electric lighting. Energy savings and increased comfort can be achieved, when the combined use of natural and artificial light is optimised for building design and use of appropriate technical solutions. A proper integration of daylight and artificial lighting is important, as well as a detailed analysis of the user demands, as savings of energy depend very much on their behaviour.

Daylighting is the practice of careful placing windows, skylights, translucent wall panels or sunlight transport devices and reflective surfaces so that during the day natural light provides effective internal lighting. Its success depends on the proper placement of windows, skylights, etc. (see following list of technical options) and its combination with appropriate artificial lighting in a hybrid system.

In some ways, overcast skies typical of northern climates provide a better lighting source than sunny days, because the light is more diffuse and even. Daylighting is most challenging in the sunny climates of the south because of the immense amount of illumination from the sun which must be reduced and carefully controlled. Windows which are subject to a glaring effect must be provided with an adjustable antiglare screen. This will allow the entry of daylight to be reduced, which in return enables a reduction of daylight incidence.

Techniques for increasing the use of daylight in a building depend on the local required and available illuminance, the available space and the optical characteristics of the used systems:

- Windows: Windows are the most common way to let daylight into a space, usually multiple orientations must be combined to produce the right mix of light for the building. Some ways to improve the amount of light available from a window are to place the window close to a light coloured wall, to slant the sides of window openings so the inner opening is larger than the outer opening and to use a large light coloured window sill to project light into the room.
- Skylights: Rooflight openings admit strong bright light (nearly three times the amount of vertical openings) and are an efficient lighting technique for the top floor of buildings. They are frequently found in northern climates, where daylight availability is lower. This technique is preferred for space uses such as museums because of the intensity and the flexibility in managing the distribution of light over the space. Many translucent insulating building products are available that allow light into a building without letting

heat in or out, which was a typical concern with skylights and large windows in the past. The optimum number of skylights is usually 4 – 8 % of the floor area, however often skylights are not needed to achieve good daylighting results until beyond 8 m of the perimeter windows.

- Sunlight-Transport-Devices: These devices collect sunlight on the roof and funnel it via fibre optics or tubes with reflective coating to different rooms – completely eliminating the need for artificial lighting. This can even be combined with fluorescent lamps in one system for continuous lighting.
- Light shelves: Light shelves are horizontal protrusions (installed internally or externally) that divide the window into two parts. The upper surface of the light shelve reflects the incident light through the upper window to the ceiling and inner room spaces. The shelf also acts as a shading divide for the lower part of the window obstructing intensive (and thus annoying) high angle solar radiation. Similar innovative techniques based on shading and reflection exist, for example prismatic panels and laser-cut panels that are both designed to cut off specific ranges of sunlight angles. Prismatic films work in a similar way. They are produced by a special etching process and placed on the internal side of a double glazed window. As these panels and film are semi-transparent, they do not provide a clear view out and may thus in some cases only be applied to the upper parts of the window. For all these techniques, obstructions in the light's path should be avoided and the ceiling's reflectivity should be enhanced.
- Reflection: The light in a given room can be maximised by choosing light colours and reflective materials for walls, ceilings and floors. Light-coloured and shiny flooring options, such as linoleum or polished wood can reflect ambient light, brightening up the space.
- Combination with control system (daylight harvesting): Daylight Harvesting is the term for a control system that reduces artificial light in building interiors when natural light is available, in order to reduce energy consumption. Such a system can at the same time implement a whole lighting strategy (light zones, scheduling of lighting needs).

Achieved environmental benefits

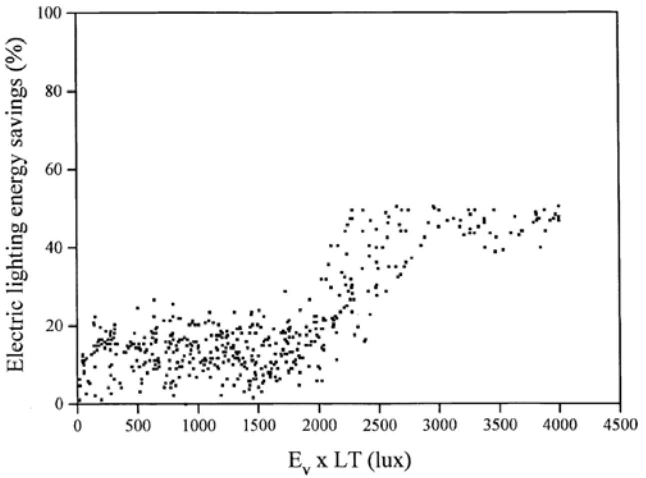
The need for the artificial lighting of buildings is reduced, as well as space cooling, both leading to large energy savings and reductions of CO_2 emissions.

Table 3.62 shows exemplar lighting energy consumption of two newly built office buildings as a reference.

Table 3.62: Two examples of newly built office buildings that use daylighting concepts

	Office building in Düsseldorf, Germany (BINE, 2005)	**Building in administrative centre in Eberswalde, Germany (BINE, 2009)**
Year of construction	2000 – 2003	2007
Rentable area	27 500 m²	4 878 m² (total centre 17 131)
Gross room volume	84 435 m³	20 127 m³
Average room height	2.88 m	3.00
Primary energy demand (referring to rentable area) Heating Cooling Lighting	 36 kWh/m²a 16 kWh/m²a 23 kWh/m²a	 25.5 kWh/m²a 6.1 kWh/m²a 33.5 kWh/m²a
Building cost Technical equipment Total cost	-	849 €/m² 413 €/m² 1263 €/m²

For the integration of daylight, a good example of the correlation between daylight availability and lighting energy savings can be found in Li and Lam, 2001. Proper design and orientation of the buildings and the optimisation of building lighting control, integrating daylight can lead to significant energy savings.For an office building, savings are higher than 50 %, as shown in Figure 3.39. Achieved annual savings are around 16 kWh/m^{2}yr (from an overall consumption of 23 kWh/m^{2}yr). This supposes 30 % average savings without the replacement of any lighting device (36W T8 tubes) but with smart daylight control. This daylight control allowed the reduction of installed lighting power density, LPD, from 17 to 14.3 W/m^2 (maximum).



Source: Li and Lam, 2001.

Figure 3.39: Electric lighting savings and daylight availability (ExLT)

The Lighting Energy Numeric Indicator (LENI) as defined in EN 15193 is a value expressing the annual energy consumption for lighting per square metre kWh/m^{2}yr. Office buildings used to consume an average of 15 to 25 kWh/m^2, although new technologies of lighting are able to reduce this to levels lower than 10 kWh/m^{2}yr, especially when integrating daylight (Dubouis and Blomsterberg, 2011). Another useful indicator is the lighting power density, LPD, whose average used to be even higher than 20 W/m^2, but the use of efficient lighting devices has led to this being reduced to an average of 7 – 11 W/m^2, e.g. when using T5 fluorescent or LEDs (see 3.4.4.2).

The European Standard EN-15193 proposes benchmarks prescribed for office rooms, depending on the lighting strategy (Table 3.63). Preferred levels can be considered appropriate benchmarks of excellence for lighting best practices.

Table 3.63: Installed LPD, reduction factors and LENI for several lighting strategies

Room	**LPD, W/m^2**	**Reduction factor**			**LENI, kWh,/m^{2}yr**		
		Manual control	**Absence/ presence control**	**Daylight control**	**Manual control**	**+ Absence/ presence control**	**+ Daylight control**
Individual office rooms >10 m^2							
Oblig	10	0.8	0.75	0.56	20	15	8
Pref.	8	0.8	0.75	0.56	16	12	7
Large office rooms >12 m^2							
Oblig	12	1	0.9	0.77	30	27	21
Pref.	10	1	0.90	0.77	25	23	17
Corridor							
Oblig	8	1	0.75	0.57	20	15	9
Pref.	6	1	0.75	0.57	15	11	6

Dubois and Blomsterberg developed an assessment of the relative saving potential of several lighting strategies (Table 3.64).

Table 3.64: Energy saving strategies and relative energy saving potential

Energy saving strategy	Relative saving potential
Improvement in lamp technology	10 % (T13 to T8), 40 % (T12 to T5)
Improvement in ballast technology	4 – 8 %
Improvement in luminaire technology	40 %
Use of task/ambient lighting	22 – 25 %
Improvement in maintenance factor	5 %
Improvement in utilisation factor	Depends on building use
Reduction of maintained illuminance levels	20 %
Reduction of total switch-on time	6 %
Use of manual dimming	7 – 25 %
Use of switch-off occupancy sensors	20 – 35 %
Use of daylight dimming	25 – 60 %

Source: Adapted from Dubois and Blomsterberg, 2011

Appropriate environmental indicators

The main environmental indicator for integrated lighting concepts is the (annual) energy consumption per area of a building.

Besides direct measurement of annual energy consumption, a similar value can be calculated using several influencing factors: The Lighting Energy Numeric Indicator (LENI) as defined in EN 15193 is a value expressing the annual energy consumption for lighting per square metre kWh/m^{2}yr. It is based on the wattage of installed lamps, their daylight and non-daylight time usage, an occupancy factor and other factors.

The installed lighting power per square metre (lighting power density, LPD) is also an indicator that can be easily benchmarked, as it reflects the integration of efficient devices, daylighting control, smart strategies and zoning concepts. Nevertheless, it does not reflect the final energy consumption.

Several qualitative indicators have to be considered too, as a successful daylight building is the result of a combination of architecture and engineering, of an integrated design process, and is not simply a technology that is installed once the building is complete. The main design issues are illuminance levels, contrast ratios, window to wall ratios, ceiling to skylight area percentages, and a reduction in unwanted glare.

Cross-media effects

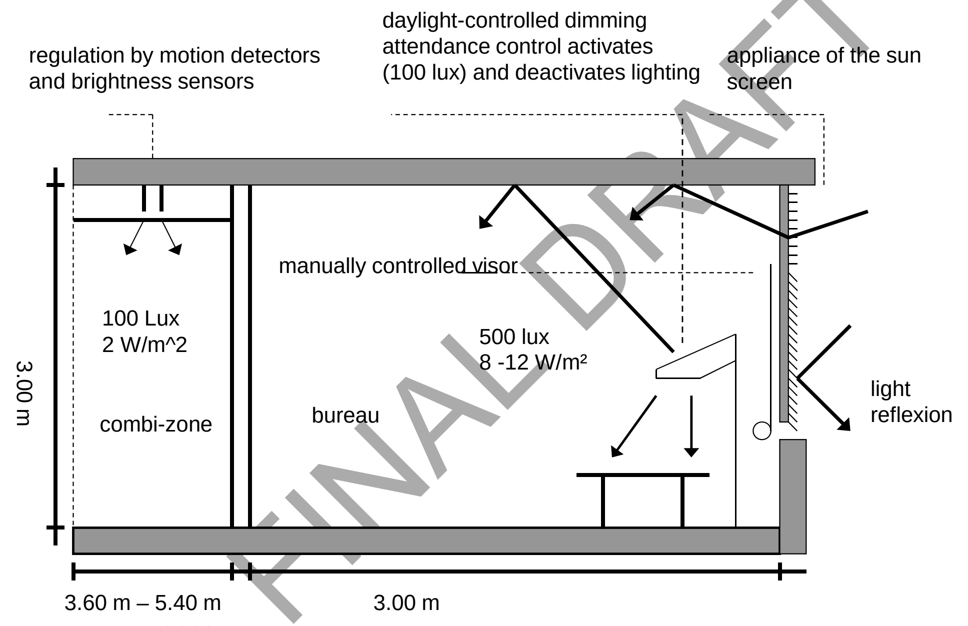
With the increasing proportion of glass surfaces in building façades, the heat gain during summer periods also generally increases. This can lead to an increased cooling requirement. The proportion of glass surfaces is to be optimised in terms of the use of daylight, the use of passive solar energy and the avoidance of active cooling. Shading is an option to avoid heat input in summer. An integrated approach (building envelope, HVAC, windows glazing and shading) should be covered by designers to avoid any undesired cross-media effect.

Operational data

The benefit of daylight is affected by seasonal differences. Daylight varies by nature constantly in intensity, colour and luminance distribution. Because of this, solutions must be found which maximise the daylight income in winter, but guarantee an effective sun protection in summer. Furthermore, especially in winter, there is dull sky and the daylight concept must be adjusted for this. Systems, which deflect direct sunlight, can only be an additional solution. Innovative daylight and control systems make sure that even with changing sky conditions, the lighting stays constant.

Lighting strategies for rooms: In the case of façade windows, the depth of the daylight area is determined by the window height. The available light-directing systems generally cannot change this geometrical rule, but they can partially compensate for issues such as the influence of surrounding buildings. Rooms, which need for functional reasons great depth, and which are lighted by daylight, must be supplied from more than one side with daylight. In this case the spatial and functional task sharing between the facades can vary seasonally or by the sky situation.

Basic functionality of systems for automatic control of shading: Outside sunshade blinds should be in two sections and when closed the light enters the room depth through the upper part (see Figure 3.40). An automatic regulation of lighting adapt the shading to desired temperature and illumination (the interior glare protection can be positioned individually). This technique considers aspects such as daylight proportion, current room brightness, room temperature and attendance. The optimal combination of natural and artificial lighting reduces electricity costs distinctly. Artificial lighting adapts to the actual natural light. Several additional benefits are possible using this automatic control of blinds: For example if a room is not used, blinds are closed to reduce energy consumption of the air conditioning. Another benefit is increased security, as in the case of fire the shading appliance can be returned to their initial state to allow evacuation of the building.



Source: BINE, 2009

Figure 3.40: Office combining daylight and artificial lighting concept

Control requirements for different scenarios: Several control strategies are possible. Technical options range from simple switching systems to dimming systems, from individual autonomous operating luminaire to room based systems or even building-wide systems. These options, as well as the selection of open loop systems (where only sunlight is measured, rather inexpensive) or closed loop systems (where sunlight and artificial light are measured) depend on the building equipment (part of a lighting management 'under' a bus system or stand-alone solution), the number of occupants in a room and their time of occupancy and on the required illuminance. Table 3.65 gives an overview of different daylight responsive lighting control strategies depending on room use characteristics. The comfort needs of occupants also need to be considered. For more information see IEA, 2001, reference.

Table 3.65: Overview of suited scenarios for different daylight responsive lighting control strategies

Daylight, suitable shading and lighting	yes											no
Management (BUS) system for lighting	no										yes	-
Number of people	1					2 or more					-	-
Time of occupancy	Short		Long		Irreg -ular	Short		Long		Irreg -ular	-	-
Required illuminance	< 400	>= 400	< 400	>= 400	-	< 400	>= 400	< 400	>= 400	-	-	-
Closed loop, room based,		x	x	x	x							
Closed loop, luminaire based		x	x	x	x		x	x	x			
Open loop, building based											x	
Open loop, room based											x	
Occupancy on/off		x		x	x							
Occupancy dimming		x		x	x		x	x	x			
Possibility to Integrate with other functions											x	

N.B. Open loop: Sensor only for daylight (outside); closed loop: Sensor inside building measuring also total light (feedback)

Time scheduling control consists in setting automatic timers which turn lights on and off at prearranged times. Time control helps avoiding energy waste, e.g. by preventing occupants leaving lights on all night. Timers can be connected to light switches, wall plugs or light sockets.

Lighting controls are mainly based on the use of two types of sensors:

- Occupancy sensors, which detect activity within a specified area. They turn lights on automatically when someone enters and turns them off when the last occupant has left, which reduces costs and energy use considerably. Occupancy sensors are particularly helpful in community rooms where users tend to forget turning off the lights, such as conference rooms.
- Photosensors, which measure light intensity and turn on lights when it gets dark. These are particularly effective with lights that stay on all night - outdoor security lights or even small night-lights inside.

Applicability

User acceptance has been a problem for some daylighting concepts in the past. It is important to include a zoning plan that is adapted to the users' needs and allows them to individually control the illumination of zones according to their needs. The sun insolation of the specific geographic region (frequency of weather changes, prevalence of blue sky or clouds, etc.) also plays a major role concerning the selection of a suited control system.

Lighting controls are most commonly used in office buildings, where they can prove to be particularly effective due to the number of occupants and the high energy demand for lighting. They are also increasingly being used in residential applications, where they also offer great saving potentials. The different techniques can be applied in a building depending on the type of use of each area. The combination of occupancy sensors and daylight sensors provides the greatest flexibility and energy savings.

Economics

No detailed data is available on integrated concepts; for some exemplar costs (investment for total technical equipment and annual lighting cost per m²) of two office buildings with integrated lighting concepts see Table 3.62.

There is a variety of technical solutions for daylighting and of daylight responsive control systems on the market. According to IEA, 2001, actual savings from different types of daylight responsive control systems do not differ much; more important are differences in the user interface and adaptability to user demands.

Some studies suggest that productivity increases by 6 – 16 percent when natural light is added to a workplace, with a 1 % productivity increase equalling the total energy cost in offices (Edwards and Torcellini, 2002).

Concerning individual techniques, investment costs for some of the innovative reflection devices are given table Table 3.66.

Table 3.66: Investment for selected innovative reflective techniques

System	€/m²
Prismatic panels	200 – 400
Prismatic films	40 – 80
Laser-cut panels	100 – 130
Sun directing glass	200

Source: BRITA, 2008

Appropriate lighting controls can also help achieve significant cost-effective lighting energy savings, reducing the electricity consumption for lighting in non-domestic buildings by up to 60 % (savings typically range from 30 – 35 %). The payback period typically ranges from 2 to 4 years. The use of occupancy sensors to turn lights off when areas are unoccupied can help reduce energy waste and costs by between 35 and 45 %.

Driving force for implementation

Energy consumption can be drastically reduced if smart strategies, daylighting and other approaches are used. Also, the indoor comfort is enhanced. Legislation compliance is also an important driving force: in some EU Member States, legislation requires a minimum level of daylighting opening size, given as a percentage of the treated floor area (Italy: 12.5 %, Greece 10 %), a minimum daylighting factor (Norway: 2 % for living rooms) and sometimes also on the location of openings for ensuring view and minimum brightness levels (BRITA, 2008).

Reference organisations

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3.4.4.2 Increasing the efficiency of lighting devices

Description

The use of efficient devices should be considered in an integrated manner, allocating best glazing options, daylighting, strategies and zoning concepts that lead to best performance. Furthermore, efficient devices could be considered as the way to reduce energy consumption of the lighting system. Three concepts are very important in the design of an efficient lighting system.

- **Luminous efficacy** is the luminous energy perceived by the human eye, generated per unit of consumed energy. It is defined as the amount of luminous flux per installed light power. The unit is lumen (lm). This is a key concept in the design of the building lighting system: taking into account the number of lumens per m^2 (i.e. illuminance) needed by the customer, the luminous efficacy of different devices can help to minimise of energy consumption. Illuminance, measured in lux or lm/m^2, is a measure of intensity of light (as perceived by the human eye) that passes through a surface.
- **Colour Rendering Index**, CRI. It is essential for the reproduction of colours. It should be maximised if required by the further users of the building. Also, the use of low CRI light sources with reduced energy consumption, as low pressure sodium lamps, should be applied for activities not requiring specific values of illuminance, such as external parking, warehouses, corridors, halls, etc.
- **Lifetime.** This is also an essential aspect of lighting devices. The economic balance and the energy consumption for lighting strongly depend on the lifetime of devices. Hence, lifetime is a very important aspect for the maintenance of buildings.

Table 3.67 shows typical values for the luminous efficacy, CRI and lifetime of several lighting devices.

Table 3.67: Properties of several lighting devices

Lighting device	Luminous efficacy, (lm/W)	CRI	Lifetime, h
Incandescent tungsten	<20	~100	500 – 1 500
Fluorescent T12, magnetic ballast	<60	50-85	5 000 – 20 000
Fluorescent T8, electronic ballast	80 – 100	75-85	20 000 – 30 000
Fluorescent T5, electronic ballast	70 – 110	85	20 000 – 30 000
White LED, 4W	50 – 150	80	35 000 – 50 000
White LED, 13W, freezer application	50 – 150	70	35 000 – 50 000
Low pressure sodium lamp	100 – 200	5	<20 000

To achieve efficient lighting, the specific power (W/m^2) varies form 20 to 40 and may be minimised, maintaining a correct illuminance (lm/m^2 or lux) to levels of 10 or less W/m^2. Relatively high illuminances should be avoided; daylight systems may be used to reduce the energy consumption and the illuminance of zones without intensive use should be minimised (see 3.4.4.1)

After illumination optimisation, another important aspect to consider is selection of the lighting devices. There are a significant number of options and suppliers, with enhanced technologies often offering the best efficiencies. Apart from the integration of natural light into the lighting control system and other technologies, preferred options are given below.

Using efficient lighting technology (when artificial lighting is needed) can lead to significant reductions in electricity consumption. In this section, the main types of light bulbs are described mainly focusing on interior lighting (mainly residential buildings, offices, etc.).

In European legislation on efficiency requirements and in bans of inefficient lamps, a distinction is made between 'household'-bulbs (standard incandescent and halogen bulbs, compact fluorescent lamps with integrated ballast), regulated by Directive 2005/32/EC and fluorescent lamps with separated ballast, regulated by Directive 2000/55/EC. These regulations set minimum energy efficiencies (using the energy efficiency classes A to G for household lamps and A1 to D for discharge lamps), with a stepwise increase and planned future reviews for additional requirements. With regard to the whole life cycle energy consumption (and thus cost) of bulbs and whole lighting systems, it is advisable to strive for the most efficient light source available when constructing or refurbishing a building.

Incandescent light bulbs: Light results from heating a filament; only 5 % of the energy is transformed into light, while some 95 % released as heat. The lifetime is low (often as low as 1000 hours), and consequently in most cases, other types of illumination are clearly to be preferred. A stepwise ban of incandescent bulbs for general use is set out in European legislation (2005/32/EC).

Halogen lamps: This type of incandescent bulb is filled with a halogen gas allowing smaller bulbs and higher efficacy (but lower than fluorescent or LED lamps). Some work with low voltage (transformer), bulbs for standard AC current are used for higher wattages; with both types achieving lifetimes of 2000-4000 hours. These bulbs are often used for indirect or accent lighting, they are less suited as desk lamps due to UV radiation (unless UV filters are used).

Linear Fluorescent lamps ('neon lights'): A gas-discharge lamp which uses a tube filled with mercury vapour. The mercury atoms are electrically excited to produce short-wave ultraviolet light that then causes a phosphor coating on the tube to produce visible light. Compared to incandescent light bulbs with the same wattage, they emit about 5 times as much light, but differences in efficiency of lamps and ballast exist, as well as EU legislation on increasing minimum efficiencies. As for all gas-discharge lamps, fluorescent lamps require a ballast to control their amount of current. Electronic ballasts are preferred to (old) magnetic ballasts, which had energy losses of about 10 % of power input and flickering.

Their lifetime is also a multiple of light bulbs, although this can be shortened by frequent switching. This type of lamp is widely used in offices and other large rooms, but is also suited for general lighting in residential buildings. It is currently the most widespread source of artificial light. Spent lamps should be properly disposed of as hazardous waste, as they contain a small amount of mercury. As for all non-incandescent lamps, the emitted light is not a complete spectrum. However, different types of fluorescent lamps exist, that simulate this or special light temperatures (bright daylight or warm reddish light).

Compact fluorescent lamps (CFL, often called 'energy-saving lamps'): These are compact fluorescent lamps with a light yield of up to six times that of a light bulb. The required ballast (newer electronically ballasted CFLs do not flicker or hum) is either integrated in the socket or separate as for standard fluorescent lamps. Traditional weaknesses of this type of lamp (such as long starting time, lamps cannot be dimmed, flickering, unnatural light temperature) are in general overcome in modern lamps, however in some cases at increased cost.

Induction lamp: The variant 'induction lamp' is an electrodeless lamp in which the power needed to generate light is transferred from the outside of the lamp envelope by means of (electro)magnetic fields. Advantages of this type are (although at higher cost) the extended lamp life, the use of high efficiency light-generating substances that would react with metal electrodes in normal lamps, and improved collection efficiency because the source can be made very small.

Light emitting diode lamp (LED lamp): The functionality of LEDs is based on semiconductor diodes. In general, LED lamps offer the longest lifetime and highest efficiency of all lamps types for residential or office use, but initial costs are currently higher than those of fluorescent lamps. Besides high efficiency, they offer longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliability. However, they are relatively expensive and require precise current and heat management. LED lamps can be used for many installation situations, especially as accessibility to lamp housing is not needed. In contrast to other lighting technologies, LED light tends to be directional. This is a disadvantage for most general lighting applications, but can be an advantage for spot or flood lighting. LEDs using the colour-mixing principle can produce a wide range of colours.

Special lamps (gas discharge lamps mainly for outdoor, industrial and commercial use):

- Mercury-vapour lamps: A mercury-vapour lamp is a gas discharge lamp that uses mercury in an excited state to produce light. They are often used because they are relatively efficient. Phosphor coated bulbs offer better colour rendition than either high- or low-pressure sodium vapour lamps. Mercury vapour lamps also offer a very long lifetime, as well as intense lighting for several special purpose applications. The use of mercury vapour lamps for lighting purposes will be banned in the EU in 2015.
- Metal halide lamps: A kind of high-intensity discharge (HID) lamp that produces high light output for size, making them a compact, powerful, and efficient light source. They need an electrical ballast and are mainly used for high light demand applications such as flood lighting outdoors, or lighting for warehouses or industrial buildings. Concerns exist about possible eye damages due to UV light emissions.
- Sodium vapour lamps: These are gas discharge lamps that use sodium in an excited state to produce light. There are two varieties of such lamps: low pressure and high pressure. Sodium vapour lamps are often the source of urban illumination. Their limited spectrum light causes less light pollution for astronomical observatories. High-pressure sodium (HPS) lamps are smaller and contain additional elements such as mercury; they are favoured by indoor gardeners for general growing because of the wide colour-temperature spectrum produced and their relatively high energy efficiency.

Achieved environmental benefits

The main environmental benefit is the reduction of electricity consumption. Integrated approaches are needed, as the reduction of the thermal gain from lighting devices may affect the performance of the HVAC. For new buildings, lighting gains should be taken into account, while for existing buildings, there is a risk on oversizing/undersizing the HVAC system. Efficient devices, such as LED, can offer huge energy savings (up to 50 %). Nevertheless, the main benefit is achieved from the integration of efficient devices in an overall lighting strategy. Therefore, it is recommended to consult section 3.4.4.1 and Table 3.64.

Appropriate environmental indicators

Energy consumption per square metre and year is an appropriate indicator. This is also called LENI under the EN 15193 standard. In order to be comparible to other energy consumption processes, primary energy should be considered. Also, building use time and useful area should be determined. LPD, lighting power density, in W/m^2 is also an important indicator of the energy performance of lighting systems.

Other important technical parameters regarding the performance of lighting devices are:

- luminous efficancy [lm/W] (alternatively energy efficiency class)
- minimum lifetime
- lumen maintenance [% over certain number of hours]
- switch on-off cycles [number]
- use of harmful substances, e.g. mercury
- colour rendering index (CRI).

Cross-media effects

The environmental impact of lamps is mostly during their use phase, up to 90 % depending on the lamp type. Fluorescent lamps contain small amounts of mercury, which complicates their disposal, as appropriate recycling methods have to be used. Concerning old or cheap fluorescent lamps, there have been some concerns regarding health and comfort issues in the past. These include headaches and discomfort due to flickering and unnatural light colours. However, for modern high quality lighting (especially those lamps having an EU-ecolabel), these issues have been resolved.

Operational data

The different approaches to reducing the lighting energy consumption usually agree on the main target: to reduce the lighting load while increasing of the luminous efficacy of installed devices. Table 3.68 shows the technical characterisation of some lighting technologies.

Table 3.68: Comparison of wattages and features for different types of light bulbs

	Incandescents	**Halogen**	**Compact fluorescent lamps**	**Fluorescent lamp**	**LEDs**	**Other gas discharge lamps**
Luminous efficacy [lm/W]	5-16	14-25	35-75 (higher end with electronic ballast)	50-105 (higher end with electronic ballast) 3 bands 58 W, T8, elec.: 81 3 bands 49 W, T5, elec.: 93	10-100 (white)	Sodium high pressure: 70-150 Sodium low pressure: 100-200 Metal halide lamp: 60-100 Mercury vapour lamp: 30-60
Light Output [lm] 450 300 - 900 1100 - 1300 1600 - 1800 2600 - 2800	Required power [W] 40 60 75 - 100 100 150		Required power [W] 8 - 12 13 - 18 18 - 22 23 - 30 30 - 55		Required power [W] 4 - 5 6 - 8 9 - 13 16 - 20 25 - 28	
Frequent On/Off Cycling	some effect	some effect	shortens lifespan	shortens lifespan	no effect	shortens lifespan
Turns on instantly	yes		slight delay		yes	several minutes
Heat Emitted	high	high	medium	medium	low	medium
Sensitivity to temperature	some		yes	yes	no	
Sensitivity to humidity	some		yes	yes	no	
Hazardous Materials	none		5 mg mercury/ bulb		none (potentially in electronics)	some: mercury
Replacement frequency (50k hours)	40+		5		1	

Source: EE, 2011.

In the following, criteria for choosing a household-type light bulb are summarised:

- EU energy label: For common household light bulbs, the EU energy label shows the energy efficiency categories from A to G (A being the most energy efficient), as well as giving some additional information (the luminous flux of the bulb in lumens, the electricity consumption of the lamp in watts, the average life in hours).
- Lumen output: To maximise energy savings, choose the product that provides the most lumens at the lowest wattage.
- Shape:

  - Triple-tube bulbs provide high light output in small spaces, ideal for desk and reading lamps.
  - Flood lamp CFLs work well for recessed and track lighting.
  - Globe shapes work well in bathrooms and above vanity mirrors where aesthetics are important.
- Light colour: A CFL's colour is indicated by the Kelvin (K) temperature. Higher temperatures (5000 K or 6000 K) correspond to cooler, bluer colours, while lower temperatures (2700 K or 3000 K) give off a warm glow similar to incandescent lamps.

Applicability

In general, there are no limitations to install high-efficiency lamps instead of older less efficient products (that are slowly vanishing from the markets). A change of light bulbs (from incandescent to CFLs) is easily done in existing buildings. However it is usually preferable to use dedicated fluorescent fixtures as they allow higher energy savings, and provide better light, reliability and lifespan.

Typical application areas for different types of lamps at present and projected for the near future are shown in table Table 3.69. This table, made by a German industry association, shows the importance of LED lighting.

Table 3.69: Current and projected application areas for different lamp types

	City / Street	Office	Shop	Hotel / Residential	Museum	Emergency lighting
LED						
Today 2010	xx	x	x	x	xx	xx
In 3 years	xxx	xxx	xxx	xxx	xxx	xxxx
In 10 years	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Fluorescent lamps						
Today 2010	x	xxxx	xx	xx	xx	xx
In 3 years	x	xxx	xx	xx	xx	x
In 10 years		xx	xx	xx	xx	
High pressure sodium lamps						
Today 2010	xxx		xx			
In 3 years	xx		xx			
In 10 years	x		x			
Metal halide lamp						
Today 2010	xxx		xxx		xx	
In 3 years	x		xx		x	
In 10 years			x		x	
Halogen lamps						
Today 2010		x	xx	xxxx	xxx	
In 3 years			x	xx	xx	
In 10 years				x	x	

Source: FGL, 2010.

Economics

In general, investment in efficient artificial light sources is more than compensated by the lifetime savings. However, exact numbers depend on individual products and conditions of application.

Compact fluorescent lamps have higher purchase costs, but taking into consideration energy savings over their whole lifetime, the total cost are lower than for incandescent light bulbs (which additionally have much lower lifespans).

LED as a source for interior lighting is currently characterised by high initial costs, but these are in general more than compensated by whole lifetime costs. Their price is expected to decrease over time, as their diffusion in the market is just beginning. The following two tables, Table 3.70 and Table 3.71, show exemplar calculations for comparing economics of fluorescent lamps and LEDs for workplace and corridor lighting.

Table 3.70: Cost comparison of halogen lamps and LED for a typical workplace lighting in industry

	LED-Spot	Halogen-Spot
Purchasing price	€300	€200
Electric power	3 * 3 W	20 W
Lamp durability, about	50 000 h	2 000 h
Maintenance costs, lamp changes	-	25 * 45 EUR = 1125 EUR
Energy costs (50,000h, 0.18 €/kWh)	€81	€180
Total costs	€381	€1505
Savings Break even point	€1124 About 4500 hours of operation	

Source: FGL, 2010.

Table 3.71: Cost comparison of halogen lamps and LED for a typical corridor lighting

	LED	Fluorescent lamp
No of installed lights	4	4
Purchasing price, cumulative	€800	€400
Electric power	104 W	244 W
Maintenance costs	-	200 €
Energy costs (30000h, 0.21 €/kWh)	€655	€1537
Total costs	€1455.20	€2137
Savings Break even point	€682 About 3.8 years	

N.B. Corridor length 20 m; 4 down-lights with fluorescent lamps (2*26W each) or LEDs (26 W each); ten years of operation 12 hours daily for 250 days per year
Source: FGL, 2010.

Driving force for implementation

In general, efficient electrical lighting significantly reduces electricity consumption and thus the whole lifetime cost for lighting. It is thus ecologically and economically advisable to strive for the most efficient light source available when constructing or refurbishing a building.

Increasing legislative pressure aims to further accelerate the change to efficient lighting to further reduce energy consumption and thus CO_2 emissions. In European legislation efficiency requirements and bans on inefficient lamps are already included. For both 'household'-bulbs (standard incandescent and halogen bulbs, compact fluorescent lamps with integrated ballast), and fluorescent lamps with separated ballast, minimum energy efficiencies are defined (using the energy efficiency classes A-G for household lamps and A1-D for discharge lamps), with a stepwise increase and planned future reviews for additional requirements.

Reference organisations

Not applicable

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3.4.5 Use of renewable energy sources

Description

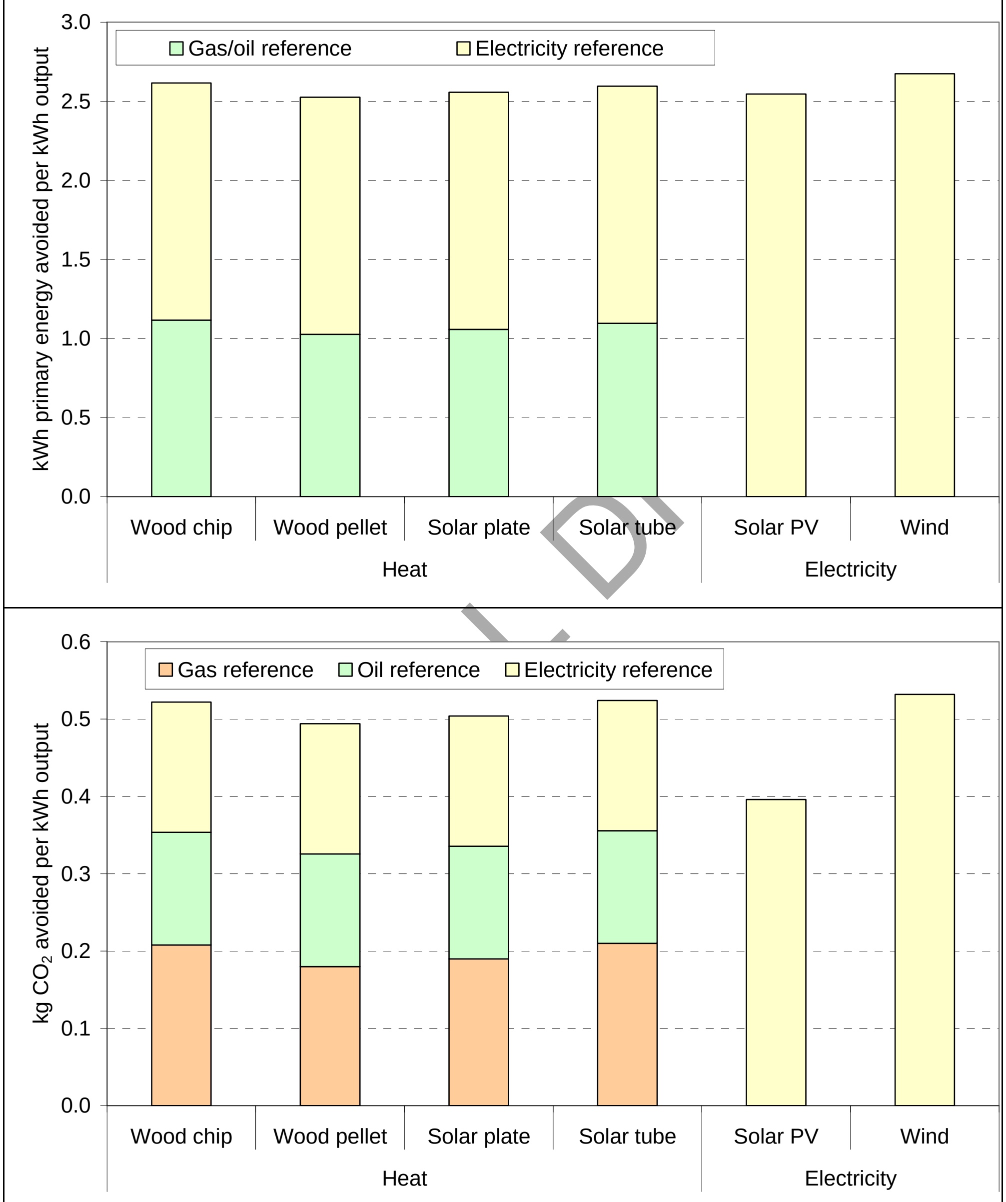
The use of renewable energy sources should be regarded as a best environmental management practice after the implementation of measures to reduce energy demand, preferably using integrative approaches as described in Section 3.4. Active utilisation of renewable energy sources exploits energy carriers that do not necessitate the depletion of finite reserves, and that do not release significant quantities of carbon sequestered in fossil resources. Usually, the decision on the implementation of renewable energy on site involves planning by the designer in order to adapt facitilities to the specific renewable energy option proposed, although building users can also make the decision during the use phase or as part of a refurbishment. The description of this technique has been adapted from the reference document for the best environmental management practice document for the tourism sector (EC, 2012). Table 3.72 summarises the main best practice renewable energy options for buildings. Heat pumps and geothermal systems utilise renewable aerothermal, hydrothermal and geothermal energy but also require significant amounts of conventional energy (typically electricity) to operate.

Table 3.72: Descriptions and applicability of major best practice renewable energy options for buildings

Renewable energy technology	**Best practice description**	**Applicability**
Offsite renewable energy	Where it is not efficient to exploit renewable energy directly on site, the preferred best practice measure is to invest in renewable energy schemes, to install a renewable energy generating capacity off site, or to purchase 'green' electricity that can be traced to a specific renewable source that is not accounted for in national average (emission) factors for grid supplied electricity as per GHG accounting guidelines provided by BSI (2011).	All buildings typologies.
Biomass heating	The main source of biomass heating is wood or pellet boilers that may be used to heat water feeding DHW and HVAC systems. The use of gasifying boilers fed by logs also represents best practice. Best practice operation of wood boilers involves continuous operation at partial load wherever possible, in order to minimise emissions to air.	Best suited to non-urban areas with a local wood supply and where combustion emissions pose a lower health risk.
Solar thermal	Flat plate or evacuated tube solar collectors can be placed on building roofs or in adjacent areas to heat DHW. Solar thermal water heating is particularly well suited to buildings where occupancy and peak DHW demand occurs in summer, coinciding with peak solar irradiance.	Any building with suitable exposure to the sun. Potential contribution to DHW heating is limited for large urban buildings.
Solar photovoltaic	Solar photovoltaic cells can be installed on, or integrated into, the building envelope – in particular roofs, exterior walls and shading devices – to generate electricity. Generated electricity may be used for onsite processes or fed into the grid in order to avail of feed-in tariffs for solar electricity.	Any building with suitable exposure to the sun. More effective at lower latitudes and in sunny climates, but most cost-effective where high solar feed-in tariffs are available
Wind turbines	Building-mounted wind turbines with a capacity of 1-6 kW are an emerging technology with low electricity outputs and typically poor return on investment compared with alternative RE options. Therefore, best practice is to install on-site free standing turbines of tens to hundreds of kW capacity where space and wind conditions allow, or to invest in large offsite wind turbines of MWs capacity.	Wind turbines are a good option for green electricity investment by all building users (see above).

Achieved environmental benefit

Figure 3.41 displays primary energy and GHG emission avoidance per kWh useful heat and electricity output for different renewable energy options. Compared with conventional heating and electricity options, renewable energy technologies reduce GHG emissions by between 76 % (solar PV) and 97 % (wind turbines). Thus, the type of energy displaced has a greater influence on primary energy and GHG emission avoidance than the type of renewable energy option applied. For example, displacing inefficient direct electric resistance heating with a wood-chip boiler results in a GHG saving of 0.52 kg CO_2eq. compared with a saving of 0.21 kg CO_2eq. when natural gas heating is the reference. Primary energy savings range from 1.03 kWh per kWh heat delivered for wood pellet heating replacing gas heating, to 2.67 kWh per kWh electricity delivered for wind turbines replacing grid electricity.



N.B.: Avoided primary energy and GHG emissions are calculated relative to gas heating, oil heating, electric resistance heating and average grid electricity supply. Assume 90 % boiler efficiency and 5 % additional emissions from boiler manufacture and maintenance.

Figure 3.41: Life cycle avoided primary energy consumption (above) and GHG emissions (below) per kWh useful heat or electricity generated by different renewable energy technologies, relative to conventional reference heating and electricity options

Appropriate environmental indicator

Off-site renewable energy

The most direct and verifiable way to invest in off-site renewable energy is to do so directly by contributing to renewable energy schemes. The annual generating capacity of off-site renewable installations directly supported by building user investment can be considered equivalent to on-site renewable generation. In order to keep a link to energy demand and consumption, usually referred to as energy per useful floor area and year, the energy generated on site (or off-site by building user investment) may be also be reported per square metre of useful area and per year.

Attributing additionality to purchased 'renewable' electricity is a complex task for which a European methodology is being developed (EPED, 2012). According to the UK Publicly Available Specification (PAS) 2050 for the calculation of GHG emissions of goods and services (BSI, 2011), off-site renewable energy generation can only be considered valid if the following conditions can be demonstrated:

- Off-site energy generation is of the same form (e.g. heat or electricity) as that used on-site;
- the generated renewable energy has not been accounted for as renewable energy consumption by another process or organisation and is excluded from the national average emission factor for electricity generation.

The PAS 2050 specification is primarily concerned with avoiding double accounting of renewable energy consumption. However, the requirement for traceability and exclusive accounting of renewable energy consumption provides a useful indication of additionality. Therefore, where accommodation enterprises can trace purchased renewable energy to specific generation in accordance with the above conditions, such energy may be regarded as genuine purchased renewable energy.

RE performance

The energy performance of renewable energy technologies can be expressed as primary energy ratios (PERs), and compared with PERs for conventional energy sources.

Life cycle GHG emissions, expressed per kWh heat or electricity produced, is another environmental indicator of renewable energy performance that is useful for sustainability reporting. Table 3.73 presents default PER and life cycle CO_2 burdens for different renewable energy technologies, taken from the GEMIS LCA database.

Table 3.73: Primary energy ratios and life cycle GHG burdens per kWhth or kWh_e delivered energy for different RE technologies from the GEMIS life cycle assessment database

Technology / energy carrier	PER	CO_2eq./kWh
Wood chip boiler	0.08	0.028
Wood pellet boiler	0.18	0.056
Flat plate solar collector	0.14	0.046
Vacuum tube solar collector	0.10	0.026
Solar PV	0.48	0.154
Wind turbine	0.03	0.018
Source: GEMIS (2005)		

Cross-media effects

The main cross-media effects and options to mitigate them are summarised for each main technology in Table 3.74 below.

Table 3.74: Cross-media effects for different renewable energy options

Technology	Cross-media effects	Mitigation options
Wood boilers	Wood burning emits CO, NO_x, hydrocarbons, particles and soot to air and produces bottom ash for disposal. These substances indicate incomplete combustion performance, and occur especially during start-up, shut-down and load variation. Wood chip boilers typically emit slightly more polluting gases than pellet boilers owing to lower fuel homogeneity, but emissions are low compared with other solid fuel boilers.	CO, hydrocarbons, soot and black carbon particles can be reduced by using continuously operating wood chip or wood pellet boilers.
Solar thermal	The production of solar thermal collectors requires energy and materials, and emits gases such as CO_2. The energy embodied in solar thermal cells is typically paid back within two to three years of operation depending on site specific application, so that energy produced over the remaining ~20 year operating lifetime creates a large positive balance.	Maximise output through optimised siting and installation (e.g. south orientation), and ensuring long operational lifetime.
Solar PV	As with solar collectors, the production of solar PV cells requires energy and materials and emits gases. Owing to lower conversion efficiencies and more complex production methods, payback times are estimated at three to four years against 30-year operating lifetimes (US NREL, 2004). It is expected that payback times will be reduced to approximately one year with anticipated thin-film technology.	As above.
Wind turbines	Embodied energy in wind turbines typically represents less than one year's electricity output over typical operating lifetimes of 20 years.	Maximise output through appropriate siting (e.g. in areas of high and consistent wind speeds).

Operational data

Biomass heating

Wood fuel supplies can vary significantly from one location to another in terms of reliability and cost. Before installing a wood boiler, it is essential to ascertain the local availability, reliability and price of wood fuel. Owing to the lower energy density of wood fuel compared with oil, wood boilers require relatively large fuel storage areas for the chips or pellets, usually at ground or below ground level. Operational measures to reduce operating emissions from wood boilers are described below.

Combustion efficiency in wood boilers is optimised through air staging (splitting the combustion air into a primary air flow directly to the flame and a secondary air flow in the direction of the combustion gases) to avoid excess oxygen in the combustion zone and ensure sufficient oxygen above the combustion zone. Secondary air injection increases the low-temperature outer-flame volume to ensure full oxidisation of hydrocarbons, black carbon and carbon monoxide following combustion.

Boilers connected to small hot water storage tanks operate under variable load conditions throughout the day, thereby producing relatively large quantities of partially oxidised compounds. Air and fuel feeding systems can ensure optimised combustion performance at loads of between 50 – 100 %. The installation of large hot water storage tanks can enable wood boilers to operate for longer periods at peak or close to peak load, and reduce the number of start-ups and shut-downs during the day, thereby reducing emissions.

The EN-standard for automatic biomass boilers with nominal heat output of 50 to 150 kW (EN 303-5) establishes the emission limits shown in Table 3.75 for pellet boiler class types 1 (worst) to 3 (best).

Table 3.75: EN 303-5 test stand emission limit values for pellet boilers

	Class 1	Class 3
Energy efficiency (NCV)	67 + 6 log (Q_N)	47 + 6 log (Q_N)
CO emissions [mg/Nm³]	12 500	2 500
PM emissions [mg/Nm³]	200	150
Organic compounds emissions [mg/Nm³]	1 250	80

Source: EC, 2009

Meanwhile, a preparatory study for solid fuel combustion under the Eco-design directive (EC, 2009) proposes best performance emission parameters for wood pellet and wood chip boilers that may be used to guide selection of the most environmentally friendly boilers during procurement (Table 3.76).

Table 3.76: EcoDesign performance indicators for pellet boilers and combined pellet/ wood chip boilers

	Pellet	Wood Chip
Energy efficiency (NCV)	94 %	92 %
CO emissions [mg/Nm³]	30	30
PM emissions [mg/Nm³]	10	20
NO_x emissions [mg/Nm³]	90	90
Organic compounds emissions [mg/Nm³]	1.5	1.5

N.B.: reference O_2 content: 13 % vol..
Source: EC, 2009

Studies have shown that optimising the combustion process can almost completely avoid large particle emissions, but can lead to higher emission of fine particles (diameter < 0.1 µm). Secondary abatement techniques such as electrostatic precipitators and fabric filters are therefore necessary to minimise emissions of fine particles, and can reduce total PM emission by 50-70 %. After-burning catalysts are available to reduce carbon monoxide and volatile hydrocarbon emissions.

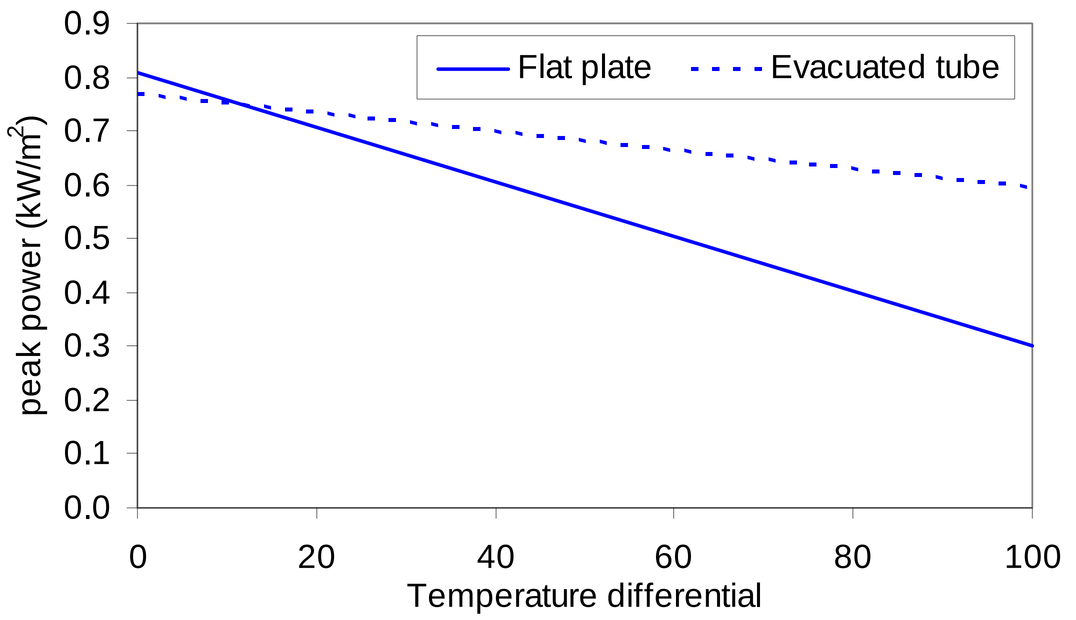
Solar thermal
The heating output from solar collectors is highly dependent on the situation, especially:

- annual quantity incident solar radiation (function of latitude, cloud cover, shading)
- orientation
- tilt angle
- temperature difference between heated water and outside air.

Situation specific annual incident solar radiation and heat output can be calculated based on latitude and local climatic data, planned collector type and installation orientation and tilt. In Switzerland, south facing collectors can provide over 850 kWh/m^{2}yr water heating (SPF, 2011). However, Ecocamping (2010) report that, on average, flat plate collectors installed in Germany can be expected to generate approximately 350 kWh/m^2/yr water heating, and evacuated tube collectors generate approximately 450 kWh/m^{2}yr water heating (Ecocamping, 2010).

The ideal situation for solar panels is on a south-facing roof with a tilt angle of 30º to 45º. However, in typical mid- to high- latitude (40º to 60º N) European situations, output is reduced by just 5 % when oriented SE or SW, and solar panels function adequately on E- and W-oriented roofs. When selecting solar collectors, the European Solar Keymark provides assurance of compliance with European standards (http://www.estif.org/solarkeymark/regcol.php).

Climatic, seasonal and system design features also influence operating efficiency via the temperature differential between ambient outdoor air and maximum heated water temperature. This effect is greater for flat plate than for evacuated tube collectors (Figure 3.42). Solar collector output can be maximised by reducing the maximum water temperature required, for example by using solar thermal to provide lower temperature water pre-heating. Reducing the maximum temperature differential (i.e. system maximum water temperature) by 20 ºC can increase peak heat output by 5 %, and 13 % for flat plate and evacuated tube collectors, respectively.



Source: SPF (2008)

Figure 3.42: Variation in standard test peak power output from two solar collectors relative to temperature differential (maximum water temperature minus ambient temperature)

Calculated heat output for the specific situation can then be used to calculate optimum collector area, too large an area leads to redundant capacity in summer months, and is therefore uneconomic. It is usually economically attractive to cover up to 60 % of hot water demand with solar heating, and a general guide for campsites in Germany is to install 0.1 to 0.2 m^2 of flat-plate collector area per pitch (25 % less area required for evacuated tube collectors). Seasonal variations in water demand must also be considered.

Installed hot water storage capacity should be calculated according to the area of solar collectors, and be at minimum:

- 100 L per m^2 flat-plate collector;
- 133 L per m^2 evacuated tube collector (Ecocamping, 2011).

Storage tanks and all pipework should be insulated. A minimum of 50 mm insulation is recommended for storage tanks, preferably factory fitted, while pipe insulation should be of a thickness at least equivalent to the outer diameter of the pipes (SEIA, 2010).

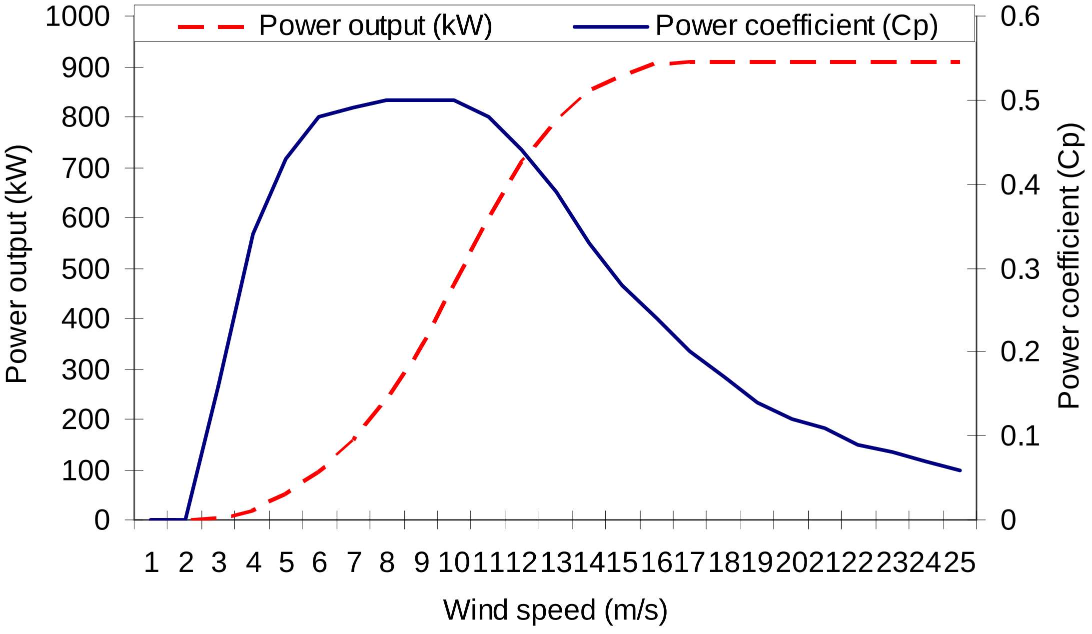
It is important to install an expansion vessel and pressure release valve to protect the solar heating loop from overheating and excessive pressure during periods of high solar gain. A control system is required with sensors on the solar collectors and in the water tanks to switch on circulating pumps when sufficient solar radiation is reaching the collectors and when water requires heating.

Solar PV

Factors affecting output from PV panels are similar to those described above for solar thermal panels. Aspect and tilt angle are important. In addition, more recent developments in PV cell technology make it feasible to apply solar PV cells onto vertical façades and shading devices. Cells must be cleaned at least once per year, more often where there are sources of deposition such as air pollution, sea spray, or a high concentration of birds, etc.

Wind

The main limiting factors for larger wind turbines are the availability of sufficient space and sufficient wind speed. Turbines operate from wind speeds of around 4m/s, but work best in locations with mean wind speeds of 7 m/s or higher (Carbon Trust, 2008). Figure 3.43 shows the relationship between wind speed, power output and conversion efficiency (coefficient of performance, Cp) for a large 900 kW turbine (Enercon, 2011).



NB: Wind speed measured at hub height (45 m)
Source: Enercon (2011)

Figure 3.43: Evolution of power output and conversion efficiency (Cp) with wind speed for a 900 kW turbine

In the first instance, indicative information on wind speeds can be obtained from meteorological data from the nearest weather station, or from national databases such as the BERR/NOABL Wind Speed Database in the UK: www.bwea.com/noabl/. However, local topography and buildings can significantly influence local wind speeds and generate turbulent flow patterns so that site surveys should be carried out before the installation of wind turbines.

The economic viability of installing a wind turbine can be calculated by comparing total investment costs with annual electricity output and output value (electricity prices and any feed-in tariffs available), as described under 'Economics'. The annual electricity output from a wind turbine of given capacity can be calculated based on the average annual wind speed according to product performance specifications, such as those presented in Figure 3.43, according to the following equation:

$E_a = C_{kw} \times T \times Cp$

where E_a is annual electricity output in kWh; C_{kw} is turbine capacity, in kW, T is time 'online' expressed as hours per year; Cp is the average coefficient of performance (based on average wind speed).

Assuming the 900 kW turbine for which output data are displayed in Figure 3.43 is online all year (8760 hours) at a site with an average wind speed of 12 m/s (Cp = 0.44), the annual electricity output would equate to: 900 x 8760 x 0.44 = 36 468 960 kWh, or 36 960 MWh.

Larger wind turbines may require an Environmental Impact Assessment to be carried out, and potential interference with aviation and telecommunications must be assessed. There are very few maintenance requirements but a service check should be performed at least every two years (Carbon Trust, 2008).

Applicability

The potential to exploit particular renewable energy resources on-site depends on the location- and site- specific factors such as climate, shading, available space, etc, as summarised in Table 3.72. These issues are not barriers to investment in off-site renewable energy installation, although the opportunities for investment in off-site renewable energy may depend somewhat on the national prevalence of renewable energy schemes.

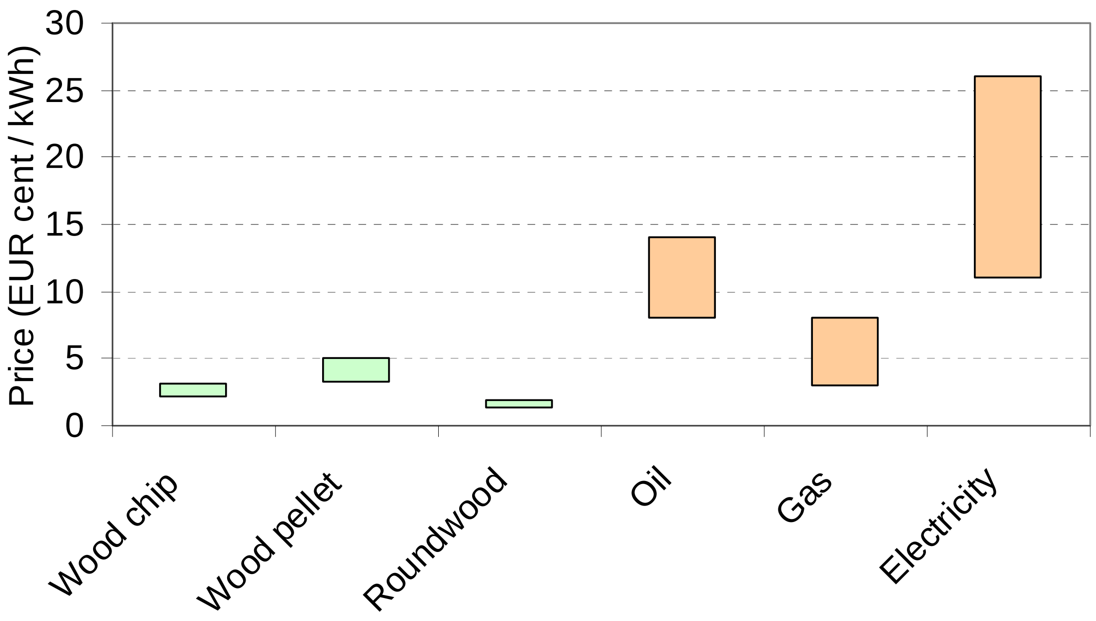
Economics

Subsidies may be available for the installation of many RE technologies, reducing net installation costs and payback periods. Such schemes vary across countries. In the UK, the capital cost of many RE technologies can be offset against tax under the Enhanced Capital Allowance scheme. In some countries, RE electricity fed into the national grid is eligible for feed-in tariffs significantly above market electricity prices.

<u>Biomass</u>
Wood is a relatively cheap fuel per unit energy content although prices vary considerably depending on sources, transport distance, quantity purchased and preparation, from less than EUR 1.50 per MWh for delivered roundwood (logs) to over EUR 5 per MWh for delivered pellets (Figure 3.44).

Wood pellet boilers of 125 kW and 250 kW capacities are available for prices of EUR 30 000 to EUR 45 000 (excl. VAT), respectively. Installation of the complete heating system, including water storage tanks, approximately doubles the price, leading to total installation costs from approximately EUR 230 up to EUR 530 per kW installed capacity (Carbon Trust, 2008). Payback periods are estimated at five to 12 years.

Subsidies may be available for the installation wood heating systems, reducing net installation costs and payback periods. For example, biomass boilers are covered by the Enhanced Capital Allowance scheme in the UK.



Source: Carbon Trust, 2009; Energy.EU, 2011
NB: Prices per delivered fuel, including taxes, and chipped/pelleted wood

Figure 3.44: Price range for wood fuel in the UK, and price range for oil, gas and electricity across the EU, expressed per kWh energy content

Solar thermal

As with other RE options, installation costs vary considerably depending on situation-specific factors, especially the location of the collectors relative to the water storage tanks. In Germany, the retail price of flat plate solar collectors is approximately EUR 400 per m^2, although wholesale prices for large projects can be significantly lower (EUR 170 to EUR 250 per m^2). Total installation costs may be upwards of EUR 850 per m^2 of flat plate solar collectors, and upwards of EUR 1 000 per m^2 of evacuated tube collectors (Carbon Trust, 2008).

Figure 3.45 presents indicative payback times for a system costing EUR 850 m^2 to install, with outputs ranging from 200 to 800 kWh per m^2 per year, and at different energy prices. For installation costs to be paid back within the maximum collector operating lifetime of 25 years, energy prices need to be above EUR 0.04 per kWh for a high output system, and EUR 0.17 per kWh for a low output system. A typical payback time, for a system with an output of 400 kWh per m^2 per year and an energy price of EUR 0.10 per kWh (electricity), is approximately 20 years. In some circumstances, where systems achieve high output and displace expensive electric heating, payback times can be as low as five years. These payback times do not consider interest or discount rates. In practice, payback times may be significantly reduced if government financial assistance is provided for solar thermal system installation.

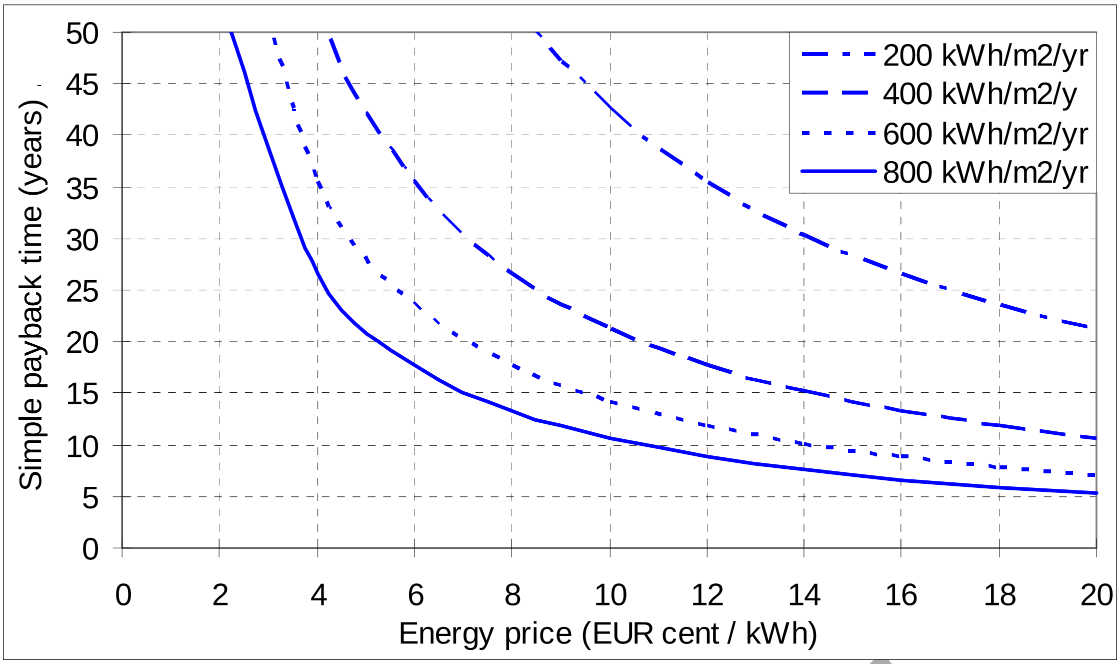


Figure 3.45: Simple payback time for solar thermal systems at different energy prices and annual thermal output, assuming an installation cost of EUR 850 per m^2

Solar PV

The price of solar PV cells has declined rapidly over recent years. The Carbon Trust (2008) quoted installation costs of approximately EUR 6 000 to EUR 9 500 per kW capacity, whilst a typical UK installer quotes installation costs ranging from EUR 2 100 to 3000 per kW installed capacity depending on system size (South-facing, 2012).

Many countries now implement a feed-in tariff for electricity generated by solar PV electricity. The value of this tariff in the UK varies depending on installed capacity, from EUR 0.10 to EUR 0.255 per kWh (Table 3.77), is guaranteed for 25 years at an inflation-indexed rate, and can be claimed whether the electricity generated is used on site or exported. Feed-in tariffs provide an additional return on investment over and above savings made through avoided purchasing of grid electricity.

Based on the above information, assuming electricity output of 850 kWh per kW installed capacity in the UK, and an electricity price of EUR 0.1 – 0.2 per kWh, payback times of eight to 11 years are achievable. Solar PV payback times will vary significantly depending on country-specific feed-in tariffs and electricity prices.

Table 3.77: Feed-in tariff rates for electricity generated by solar PV systems of different capacity in the UK

System size (kW)	0 – 4	4 – 10	10 – 50	50 – 250	250 – 5000
FI tariff (EUR/kWh)	0.255	0.198	0.179	0.152	0.10

Wind

The lifetime of a wind turbine is approximately 25 years. The capital costs of small-scale turbines rise to about EUR 22 000 for a 20 kW model (Carbon Trust, 2008). Additional costs are associated with the site suitability survey, applying for planning permission and grid connection and metering. The return on investment for wind turbines involves a number of components, and is highly dependent on local and enterprise specific aspects. Firstly, demand from the grid and associated electricity prices can be avoided. Secondly, electricity may be sold to the grid. Thirdly, produced electricity may be eligible for government support such as feed-in tariffs. Returns are therefore heavily dependent on the price of electricity and any government support schemes, but may be optimised by controlling the quantity and timing of generated electricity used onsite and exported to the grid. For example, it may be worthwhile to invest in battery storage in order to store electricity generated overnight and sell electricity generated during the day at higher daytime electricity rates. The payback period ranges from 2.7 years (52 MWh annual output valued at EUR 0.2 per kWh) to 11 years (26 MWh annual output valued at EUR 0.1 per kWh).

The payback period for large free-standing turbines of 0.5 to 5 MW capacity is typically between four and eight years on appropriate sites (Carbon Trust, 2008). Building users may avail of such returns directly by installing free-standing turbines in rural areas, or indirectly via investment in off-site wind farms.

Driving force for implementation

The main driving forces for installation of RE are:

- government financial assistance for RE installation
- feed-in tariffs for generated RE
- to reduce GHG emissions
- corporate social responsibility
- to improve business image.

Reference litreature

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3.4.6 Water Systems

Best environmental management practices in the design of buildings are related, mainly, to water efficient fittings, rainwater harvesting and heat recovery from wasted domestic hot water. Monitoring, management and leakage detection systems are described under building operation (see Chapter 6), as they are more related to the final use of the building, even if the decision-making process starts during the design or predesign stages.

3.4.6.1 Environmentally friendly water drainage systems

Description

As stated in Section 2.2.2, urban development has an impact on the built surface by reducing the permeability, an effect called soil sealing. This is usually the case for buildings, roads and other civil constructions. Significant impacts are derived from soil sealing: it especially affects water flows because of reduced infiltration and reduced evapotranspiration, performed by plants, as a consequence of removing soil and green areas in the development of a construction project (Woods-Ballard et al., 2007). In addtion: changes on the morphology of waterways provoke erosion problems and water quality is thus seriously affected. Also the risk of flood events increases and there maybe impact to aquatic habitats.

With regard to building projects, policy approaches and tools are described in the land planning section (Chapter 2). For this section, details on the techniques are provided, with a short description of them shown in Table 2.4.

Drainage systems to be considered as best environmental management practice should fulfil a series of requirements for an integrated approach, i.e. how they are planned, designed, optimised and integrated with the surrounding urban environment. For this, the approach taken under the 'Sustainable Drainage Systems', SUDS, philosophy is considered to be best practice as it follows outstanding principles:

- It seeks the improvement of water run-off quality, reduces surface run-off, contributes to the biodiversity and creates amenity value.
- It tries to replicate, as closely as possible, the natural drainage before development.
- The approach has an integrated management hierarchy of prevention, source control and site control. The use of regional control systems for water drainage should be considered for planning new urban areas.

Prevention

Prevention practices consist of site selection and best design options (e.g. choosing the appropriate slope for the surroundings), in order to increase the possibility of infiltration and avoiding water accumulation zones. Also, good housekeeping can avoid problems of the run-off water quality.

Preventive design for the drainage system can be considered best environmental management practice when an integrated approach is taken into account. In fact, the rationale given by Woods-Ballard et al., 2007, about SUDS, constitutes best environmental management practice. The main issues regarding drainage design are:

- Construction:
    - Buildability
    - Construction programme
    - Construction process
    - Construction site
- Integration
    - Local environmental objectives
    - Urban landscape
    - Ecological value
    - Groundwater risks
    - Previous performance
- Planning
    - Linking site with regional-urban drainage systems
    - Ensuring long term operation
    - Developing management plans
- Hydrology
    - Run-off estimation

- Hydraulic design of the site

Regarding these issues, a compendium of environmental criteria may be used for the development of the drainage system. As an exemplar approach, Table 3.78 shows design criteria proposed in SUDS.

Table 3.78: SUDS design criteria (summary)

Criteria	Design event	Design Objective
Hydraulic		
Protection against flooding from water course	Catchment, 100 or 200 yr event	Control risks to people and property. Floor levels = maximum river level plus appropriate freeboard
Protection against flooding from drainage system	Site 10/30 yr event	No flooding on site, except where planned and approved
	Site 100/200 yr event	Control risks to people and property. Floor levels = maximum flood storage levels + freeboard
Protection against flooding from overland flows	Site 100/200 yr event (short duration)	Planned flood routing and temporary storage accommodated on site
Protection against flooding from adjacent land	Adjacent catchment, 100/200 yr event	Planned flood routing.
Rate of discharge	Catchment, 1 yr event	Attenuation storage to control 1 year site discharge rate to <1 in 1 year greenfield peak rate or 2 L/s/ha
	Catchment 100/200 yr event	Rate less or equal to greenfield peak rate
	All events	Where possible, interception storage to prevent run-off from first 5 mm of rainfall
Volume of discharge	Catchment, 100 yr event	Long-term storage or infiltration mechanism to control 1 in 100 year discharge volume less or equal to 100 year greenfield volume. Usually applied to 6 hr event
Water quality		
Protection of water course	For the whole site, <1 yr	Interception storage to prevent run-off from first 5 to 10 mm of rainfall
		Train of SUDS components depending on the level of treatment required
Amenity		
Managing public safety	-	Safe maintenance
		Fencing and vegetation barriers
		Shallow benches in water ponds
		Signing
Visual impact		Aesthetic appeal
		Create recreation opportunities
		Joint education initiatives
Ecology		
Improving ecological value	-	Native planting
		Diversified natural ecosystem
		Aquatic bench
		Maintenance

Although the approach is highly relevant for the environment, it can be seen as a scheme with a much wider approach, oriented not only to avoid undesirable environmental impacts (e.g. water quality, flooding, groundwater pollution, erosion, etc.) but also aimed at efficient hydraulic systems that enhance the ecological value of sites (compared to other similar developments), with the amenities having a positive economic impact on the buildings property values.

Source Control

Source control techniques are those techniques installed very close to the run-off point and, usually, increase water infiltration to become potentially groundwater. For this purpose, exemplar techniques should include pollution removal. Pervious pavements allow water to drain easily through them, with even less pollution than conventional impervious pavement, due to the absence of a hard, thick sub-base in pervious pavements, allowing rainwater to drain after some filtering process.

Other source control mechanisms improve the transport or conveyance of water, allowing infiltration, and avoiding undesired accumulation and pollution, and implementing some retention mechanisms. For this, SUDS, propose filter drains, vegetated swales and filter strips, which may be connected to soakaways. Green roofs (see section 3.4.1.3) are also considered a source control mechanism, with their main benefit being the detention of a large proportion of rainwater on the roof, avoiding large surface run-off quantities and water pollution.

Site and regional control

Techniques to consider on site and regional control are those for the management of run-off from a site or several sites, typically through water routing, infiltration in soakaways, detention basins, ponds and/or wetlands.

Water ponds are depressions used for storing and, in many cases, treating water sedimentation and, usually, filtration through aquatic vegetation when the pool is permanent. Wetlands are shallower and have continuous flow, filtering water through aquatic vegetation. These two techniques are also able to create some amenity value in neighbourhoods. Detention basins may be underground and are thought to regulate flow during a specific retention time. Some detention basins are also designed for water infiltration, but keeping it in a closed basin for a specified time. For regional control, bioretention areas can be designed, e.g. vegetated areas, retaining and filtering water before discharge or infiltration.

Quality control

Some techniques are designed to improve water quality, thus avoiding pollution of water discharged to waterways or avoiding undesired contamination of groundwater. Many of the techniques using vegetal species to increase water infiltration have some cleaning capabilities. Sedimentation is a primary removal of pollutants, due to the change of flow characteristics of water in ponds or other detention basins.

Selection of water drainage techniques

Once the designer is aware of the availability of techniques (prevention, source control and site and regional control), an appropriate selection mechanism of suitable techniques for the management of water run-off should be implemented. SUDS (Woods-Ballard et al., 2007) gives a comprehensive list of criteria to be considered when applying drainage systems. All of them are focused or achieving the best solution for water management (higher quality with reduced flood risk), at lowest costs, and with enhanced amenity and environmental values of the site. The criteria are grouped according to:

- Land use characteristics
- Site characteristics
- Catchment characteristics
- Quantity and quality requirements
- Amenity and environmental requirements.

For a full description, see Woods – Ballard et al., 2007. Below, a summary list of design criteria for best drainage systems is shown in Table 3.79.

Table 3.79: Summary of water drainage techniques selection criteria proposed by SUDS

Land use	Site characteristics	Catchment characteristics	Quantity and quality	Amenity and Environmental performance
Low developed areas Roofs Roads Non-residential developments Industrial developments Construction sites Brownfield sites Contaminated land	Soils state Water table Draining area Slope Height and profile Availability of space	Ecologically protected Aquifer for public water supply Coastal water Catchments for amenity uses Catchment with water quality restrictions Regulated flow depending on local habitats Areas with flood risk Discharge is done to sewerage	Requirement of: Total suspended solids removal Heavy metals removal Nutrients removal Bacteria removal Should remove fine particles or dissolved solids A run-off coefficient less than X is required.	Kind of maintenance required Acceptability by community Cost of construction and maintenance Safety Habitat creation Other (educational, research, etc.)

Achieved environmental benefit

Generally speaking, the development of new construction sites with a result on urban growth reduces groundwater availability, and not only for dry regions (Zellner and Reeves, 2012). Therefore, it is essential to implement best practices to increase groundwater availability and to improve or maintain its quality. In order to quantify the benefits of the techniques to be applied for best water drainage, Table 3.80 shows some performance values collected from litreature.

Table 3.80: Performance of several water drainage systems elements

Water drainage element	Environmental performance	Reference
Pervious surface: grass-concrete surface	Run-off coefficient of 0.05 (compared to 0.78 for the same surface made of concrete). Pollutant concentration was higher from the run-off of the pervious surface but with a significant lower pollutant load. Soil was able to retain 75 % of phosphorous, 70-80 % of nitrogen and high percentages of heavy metals.	Day et al., 1981. (Pratt, 2004)
Pervious surface: permeable concrete (15 - 24 % unsealed voids)	Geotextile layer was applied. Small migration of pollutants was found. Heavy metals are located next to the surface. Able to retain most of the fine particles. Higher concentration of nitrite, nitrate, ammonia and chlorides in water run-off was detected compared to conventional pavement.	Hogland et al., 1990. (Pratt, 2004)
Pervious surface: grass concrete grid compared to conventional pavement	Run-off peak from grass grid was about 10 % of the run-off of conventional pavement (21.6l L/s for grass grid and 223.6 L/s for asphalt)	Smith, 1984 (Pratt, 2004)
Pervious surface: impact on soil pollution.	Several studies show that soil is able to retain heavy metals with no significant impact on groundwater. Some results from different sub-bases show great removal efficiency for lead, cadmium, copper and zinc. Therefore, for a high groundwater table, it is advisable to build drainage techniques other than only infiltration. Oil is mostly retained and degraded (60 - 90 %), although soil can become saturated (although not a main problem as it is evenly spread over time).	Pratt, 2004. Dierkes et al., 2002. Bond, 1999.

Table 3.80: Performance of several water drainage systems elements

Water drainage element	Environmental performance	Reference
Settling basins	Removal of suspended solids by 70 %.	Chocat et al., 1999 (Pratt, 2004)
Infiltration basins	Contamination of soil particulates with oil and heavy metals was detected, although they may be within legal limits.	Chocat et al., 1999 (Pratt, 2004)
Swales and filter strips	Removal efficiencies higher than 70 % of suspended solids are achievable. Also, heavy metals are retained, although some nutrients are accumulated when using swales. These should be regarded as a transport mechanism to other treatment processes. A number of swales in Scotland reduced the water run-off up to 53 %, reducing considerably the water peak flow and reducing significantly pollution load.	Several authors.(Pratt, 2004)
Detention basins	Efficiencies higher than 78 % on the removal of suspended solids and a slightly increase of dissolved solids is detected. BOD, TOC and COD is removed with an efficiency of 60 - 80 %. Nitrite is increased and resuspension of some pollutants takes place.	Several authors (Pratt, 2004)
Detention ponds	Detention ponds, usually designed only for hydraulic control, can have a great influence on water quality. Nevertheless, BOD is removable by 45 % and suspended solids by 80 %. This can be achieved through shallow ponds, well oxygenised in the interface between water and sediments. Heavy metals can be reduced by up to 93 %	Jefferies et al., 2001 (Pratt, 2004)
Filter drains	Filter drains are effective traps for water quality during storm events, usually higher than 90 % for heavy metals.	Several authors.(Pratt, 2004)
Infiltration trenches and soakaways	A study shows the comparison of a conventional catchment and an infiltration one. Differences show groundwater recharge in the traditional system from 464 to 751 mm/year in the infiltration, while surface run-off varies from 660 to 161 mm/year and evapotranspiration varies from 524 to 735 mm/year. Nevertheless, water quality is a main concern in the design of water infiltration devices and should be coupled with other treatment techniques.	Imbe et al., 2002.

Performance data of pervious pavements, published by a report on soil sealing of the European Commission is shown in Table 3.81.

Table 3.81: Some performance values of pervious pavements performance

Soil/pavement type	Uses	Unsealed surface	Run-off coefficient	Cost / asphalt pavement cost
Lawn, Sandy soil	Limited	100 %	<0.1	<0.02
Gravel Turf	Pedestrian, parking	100 %	0.1 - 0.3	0.5 - 0.6
Grass grids (plastic)	Pedestrian, small vehicles parking	90 %	0.3 - 0.5	0.75
Grass grids (concrete)	Pedestrian, parking, traffic	40 %	0.6 - 0.7	0.75 - 1
Water bound surfaces	Pedestrian, parking	50 %	0.5	0.5
Permeable pavers	Pedestrian, parking	20 %	0.5 - 0.6	1 - 1.25
Porous asphalt	Pedestrian, parking, traffic	0 %	0.5 - 0.7	1 - 1.25
Asphalt	Pedestrian, parking, traffic	0 %	1	1

Source: EC, 2011.

Appropriate environmental indicator

The hydraulic performance of the drainage system of a building can be controlled through the following parameters (already described in the Berlin case study of section 2.2.2).

- **Total run-off** is the difference between long-term annual average precipitation values and real evaporation.
- **Real evaporation** for a site is calculated from the amount of precipitation, the potential evaporation (depending on the climate characteristics) and the storage capacity of the evaporation area.
- **Surface run-off** is the total run-off that drains into the sewage system (separated or combined).
- **Seepage** is the difference between total run-off and surface run-off and, thus, corresponds to the basic contribution to new groundwater formation.

These indicators usually refer to an area covering the performance of several sites, so it can be considered as a land use indicator. The contribution to soil sealing and the increase of surface run-off of new developments can be easily illustrated by the percentage of site area covered by impervious pavement. With this indicator and good computing models, based on actual design and climate data, total run-off, real evaporation, surface run-off and the seepage of the site, can be calculated. In addition, the application of sustainable drainage systems can be controlled through some qualitative parameters:

- use of pretreatment techniques (sedimentation, filtration, detention basins), y/n
- use of rainwater harvesting, y/n
- use of physicochemical treatments, y/n
- use of biological treatments, y/n
- monitoring: periodic chemical control of soil and groundwater, y/n
- periodic maintenance plan of drainage systems (site cleaning, sediments removal, retrofitting, replacements, etc.), y/n

Cross-media effects

Construction of new developments, as residential areas, commercial areas or road infrastructure, increase land take and, therefore, soil sealing, which has, in general, a negative effect on the environment (such as less fertile soil, removal of soil function, reduction of aquifers, increase of flood risk, reduction of soils' ability in carbon sequestration, landscape fragmentation, increase of noise in cities, heat island effect). So, for instance, the SUDS objective of replicating the natural water flows in built environment can be considered exemplar, as those impacts are avoided and the hydraulic performance is enhanced.

Nevertheless, the increase of infiltration rates in urbanised areas frequently produces an undesired cross effect: groundwater contamination and soil pollution. Rainwater is usually polluted when it is in contact with the urban area, increasing the concentration of heavy metals, taking away organic compounds as lubricating oils, and dragging along suspended solids. Although some SUDS techniques based on vegetation have filtering capabilities, special attention should be paid to the infiltration of polluted water. For rainwater management, there are devices that include an automatic valve that conducts heavily polluted water produced during the first minutes to the sewerage (see 3.4.6.3)

Operational data

A huge number of techniques can be considered as environmentally friendly water drainage systems. Most of them are well described under design handbooks. One of the best examples is the CIRIA SUDS Manual (Woods-Ballard et al., 2007) where a detailed description of techniques can be found. Also, operational information for green roofs is provided in 3.4.1.3. In this section, some indications of the most important water drainage techniques reflecting best practices are given.

Site management

Even when designing a drainage system, appropriate site management is supposed to be performed during the use phase of the facility. As stated before, pollutants are leached and washed off during rainfall events, so users should have a site management plan including (Woods-Ballard et al., 2007):

- Frequent sweeping of impervious surfaces to reduce pollutants accumulation
- Minimising the application of de-icing products or use of alternative de-icing methods
- Minimising the application of chemicals (e.g. fungicides) used on landscaped areas
- Ensuring that adequate procedures are in place to deal quickly with spillage of materials using dry rather than wet techniques
- Educating the public to reduce fertiliser application, minimise run-off from car or bin washing and disposal of liquid waste to surface drains.

Modelling of urban drainage

In Section 2.2.2, the Berlin case study shows a front-runner monitoring system, which is partially based on modelling software, called ABIMO, to calculate potential evaporation rates and water run-off based on climatic data and on the type of surface of the city. In general, there is an increasing awareness of the need for the development of environmentally friendly drainage systems, as shown by SUDS, but its development is slow, as, first, land planners are not aware of the potential of these techniques and, second, designers would require better training and design tools. Therefore, the availability of effective drainage modelling software acts as an encouraging element for the uptake of environmentally friendly drainage systems. Also, there are useful tools in the development of local water policies, which take into account biodiversity and other issues. Elliot and Trowsdale, 2007, published a review on the performance of the most acknowledged existing models for urban drainage. A non-comprehensive list of models is shown in Table 3.82.

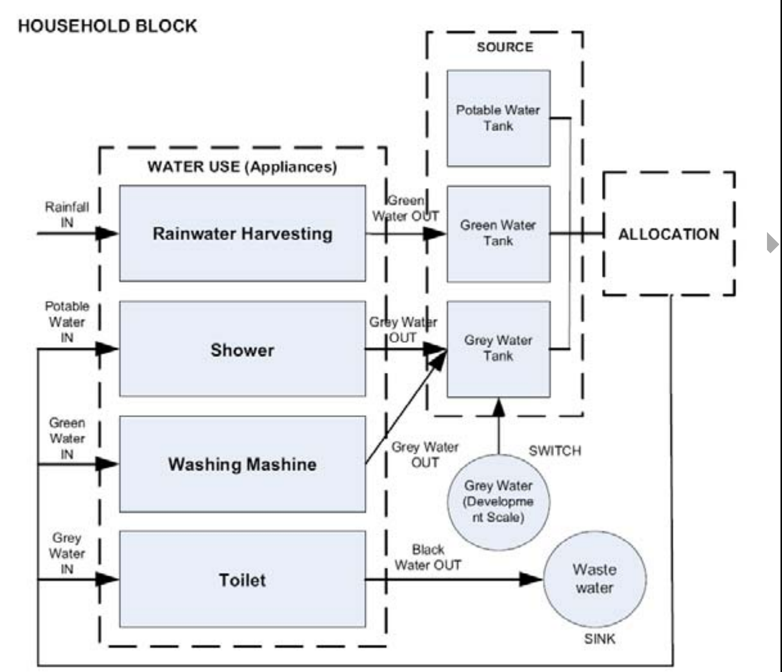
Table 3.82: Water drainage models (non-exhaustive list)

Name	Developer and Cost	Intended use
MOUSE	DHI Water (Denmark) ~ USD 5000	Detailed simulation of urban drainage
MUSIC	Monash University (Australia) ~ USD 300	Conceptual design for drainage systems, with emphasis on treatment devices.
P8-UCM	Walker. W.W. Free	Estimation of urban storm water pollutant load
PURRS	Newcastle University (Australia) ~ USD 800	Single site water use model. Originally for research but now includes commercial users, especially for rain tanks
RUNQUAL	Cornell University (US), Free	Preliminary planning or education
SLAMM	Alabama University (US) ~ USD 200	Planning tool for load of contaminants
STORMTAC	SWECO-VIAK ~ USD 2500	Management of lake catchments and conceptual design of storm water treatment. Applied in Scandinavia
SWMM	United States Environment Protection Agency. Free	Detailed model for planning and preliminary design.
UVQ	CSIRO and Monash University, Australia Small charge	Integrated water cycle, water reuse, Used mainly for research in Australia
WBM	Vancuver Region Basic model free.	Planning-level assessment of water quantity. Does not include water quality issues.

Source: Elliot and Trowsdale, 2007

According to Elliot and Trowsdale, 2007, there is no model for the full spectrum of water drainage design, although there are many useful tools for the planning and preliminary design of drainage systems. Also, existing models are able to model long-term water drainage and, usually, groundwater is simplified to a 'black box' and not tested. For water quality, models usually include sediments and nutrients and only a few include other pollutants such as heavy metals.

In fact, some researchers have found that modelling can help decision making during planning or preliminary design. As an example, Makropoulos et al., 2008, developed a decision-making tool taking into account individual household water demand, in a bottom-up approach. This type of models is able to develop a wide understanding of water management and its interaction with other environmental aspects. The system components of the model of Makropoulos et al., 2008, and their integration in the household model are shown in Figure 3.46.

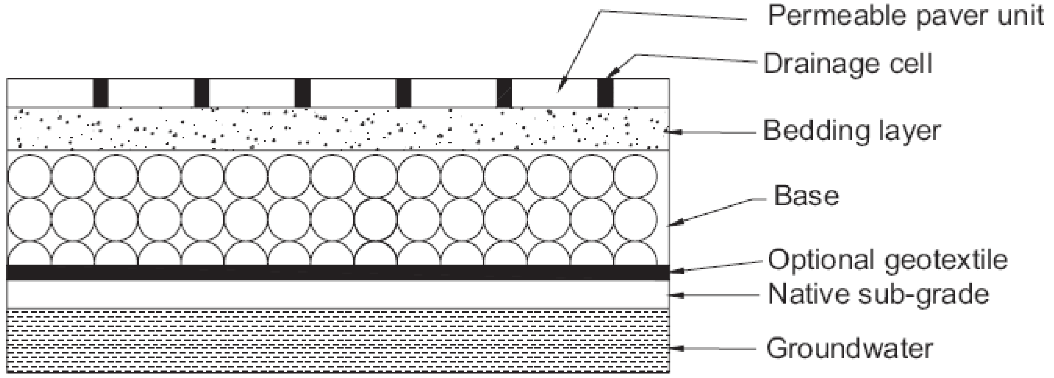


Source: Makropoulos et al., 2008

Figure 3.46: Components of a model in a household block (example)

Pervious pavements performance

Pervious pavements are usually installed, for example, on vehicular access (driveways, firelines, and utility accesses), e.g. for erosion control and slope stabilization; also in golf courses, parking areas, pedestrian walking lanes and biking lanes. The design, shown in Figure 3.47, is intended to recharge groundwater by infiltrating surface run-off. The use of pervious pavements should also be regarded as a way to control groundwater pollution, as, for instance, the use of geotextile and certain plant species act as a filter to retain oil and heavy metals, while other pollutants may be removed by biodegradation during infiltration (Scholz and Grabowiecki, 2007). There are four distinct elements in a permeable pavement: pavers and bedding layer, unsaturated zone of the base material, saturate zone of the base material, and sub-grade, usually native. Geotextiles prevent sand from migrating to the base, as well as helping to retain and degrade oil.



Source: Scholz and Grabowiecki, 2007

Figure 3.47: Typical schematic layout of a permeable pavement

The operational performance of a pervious pavement is usually dependent on many factors and, normally, should be modelled with the Green-Ampt equations. To achieve the best infiltration of pervious pavements, appropriate site management is needed. Also, any foreseen silt deposition on the pavement will saturate the system and, therefore, other pre-treatment and/or infiltration mechanisms may be required.

Regarding pollution, pervious pavements are able to retain suspended solids and some nutrients, such as nitrogen. Nevertheless, their performance depends on the type of application. Usually, road run-off is more polluted than the run-off from roofs. The main composition of rainfall in a study of 60 European sites was summarised by Dierkes et al., 2002: BOD5 1 – 2 mg/L, sulphate 0.56 – 14.40 mg/L, chloride 0.2 – 5.2 mg/L, ammonia 0.1 – 2.0 mg/L, nitrate 0.1 – 7.4 mg/L, total phosphate 0.01 – 0.19 mg/L, copper 1 – 355 mg/L and zinc 5 – 235 mg/L. The presence of metals, especially zinc from coatings, in contact with rainwater is a source of water pollution. In general, a pervious pavement acts as a filter, retaining key contaminants and reducing the contamination load to surface run-off and avoiding pollutants entering into contact with groundwater. Nevertheless, the adsorption of heavy metals by the pavement layers and the geotextile should be carefully studied to avoid pollution. Dierkes et al., 2002, conducted research to evaluate the behaviour of several pervious pavements under rainfall. Table 3.83 shows the main results.

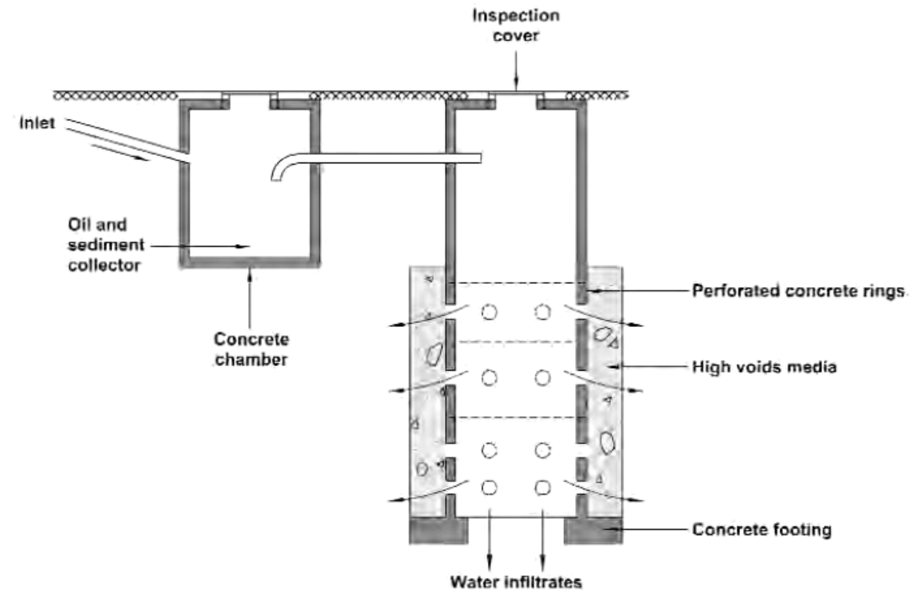
Table 3.83: Laboratory performance of several sub-based materials for heavy metal retention in pervious pavements

Analysed heavy metals	**Pb**	**Cd**	**Cu**	**Zn**
Synthetic rainfall, µg/L	180	30	470	660
Sub-base material	**Effluent, µg/L (% retained in subbase)**			
Gravel	< 4 (98)	0.7 (98)	18 (96)	19 (97)
Basalt	< 4 (98)	0.7 (98)	16 (96)	18 (98)
Limestone	< 4 (98)	3.2 (98)	29 (94)	85 (88)
Sandstone	< 4 (89)	10.5 (98)	51 (89)	178 (72)
Limits on disposal to ground, µg/L	**25**	**5**	**50**	**500**

Pervious pavement maintenance requires brushing and vacuuming, at least, three times per year, plus inspection, removal of weed, stabilisation and performance check. For pervious pavements including grass grids, remedial work may be needed for vegetation and cracks on the concrete structure (Woods-Ballard et al., 2007).

Soakaways

Soakaways are used to increase the rapid infiltration of rain water (Woods-Ballard, 2007). This system is quite common in the UK and can be applied individually or in larger areas. Nevertheless, they should be considered as the last discharge point and pretreatment is often required. They are not suitable for draining run-off from pollution hotspots. It is recommended not to use them when there is a high groundwater level and far enough (i.e. more than 5 m) from buildings or roads. Physically, soakaways are excavations backfilled with high voids media, supported by pre-cast concrete or plastic with holes to maximise infiltration to the surrounding. Figure 3.48 shows a soakaway diagram with a pretreatment device.



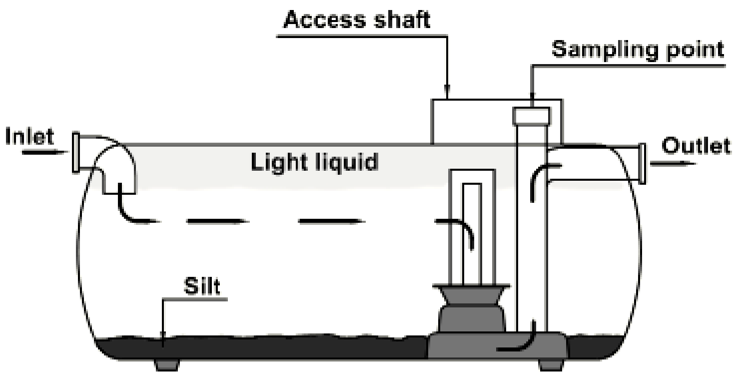
Source: Woods-Ballard et al., 2007.

Figure 3.48: Soakaway with pretreatment device

The maintenance and inspection of soakaways should be performed manually, removing sediments and replacing voids when necessary.

Oil/water separators and sedimentation tanks

This is usually a combined system that consists of a tank of water, separating oil by flotation and silt and sediments. These tanks need a certain retention time, so water flow should be independent of rainwater flow. They should usually be coupled with other detention basins or fast sedimentation sumps. Maintenance includes routine inspection, and the removal of oil and silt every six months or annually. Manufacturers usually offer this service.



Source: Woods-Ballard et al., 2007.

Figure 3.49: Oil separator working scheme

Applicability

In general, water drainage systems need to be determined on a case-by-case basis, as they are strongly dependent on the climate and the precipitation region of the affected region. Municipalities use to have an urban water management plan, where drainage has a major role. Nouh, 2001, distinguishes three main climatic influences: arid and semi arid, humid tropical - subtropical, and cold climatic zones. Europe has a wide heterogeneity of climates and, therefore, many different solutions are to be found.

Therefore, for the application of best environmental management practices to drainage systems, it is essential to develop separate solutions. Herewith, a number of techniques and common management practices are described and some special emphasis is given to flood risk. Nevertheless, when designing a building, the architect may not have any degree of freedom if there is an urban management plan already existing with restrictions on water drainage design. This is usually the case for rainwater harvesting, the use of combined sewerage, use of techniques of low impact (SUDS), etc. Storm water groundwater, and water-based ecological amenities management plans should be part of an overarching river basin water management plan (or *catchment* management plan). More on the planning and use of water resources can be accessed in the Reference Document for Public Administration.

Building designers should be familiar with those requirements from the administration and the particularities of the region. Usually, the application of suitable techniques in cold or humid climates fail when applied in dry regions (Nouh, 2001), mainly because of high spatial and temporal variability. There are a number of design aspects to be considered:

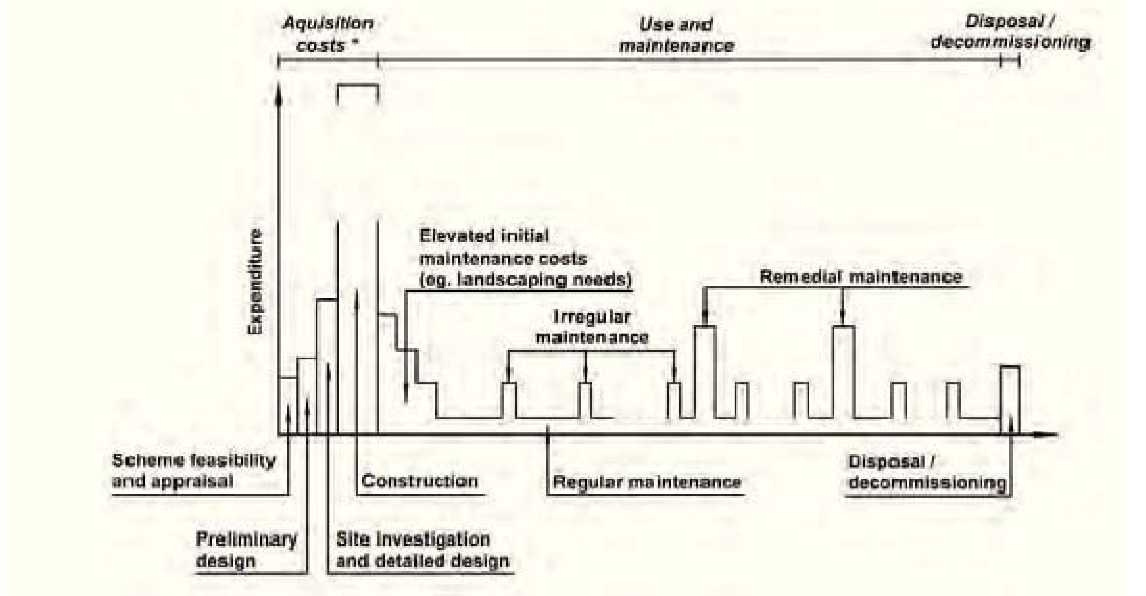
- **Rainfall**. Usually, calculation procedures are based on single rainfall depth, which are strongly variable in dry climates. The period between rain events in cold climates is usually adjusted to normal distributions in cold climates. This may not be valid for dry climates and deeper assessment of rainfall events may be required.
- **Evaporation**. This can lead to the overestimation of surface run-off, as the evaporation rate is higher.
- **Infiltration and sedimentation.** Flow regimes and particulates concentration are seriously affected by high temperature and low humidity.
- **Water quality.** Water quality is affected mainly by suspended sediments transported with flash floods. Therefore, it is not really dependent on climate, but on the degree of urbanisation, type of land use, densities of population, traffic, density of animal populations, etc.

Economics

The use of low impact drainage systems, e.g. SUDS, along with the creation of some added value amenities with ecological value, has a positive economic effect. A study carried out by the US Environmental Protection Agency concluded that environmentally friendly drainage techniques produce cost savings in the range of 15 up to 80 %, which is attributed to less site grading and preparation costs and less costs for paving and storm water infrastructure (EPA, 2007). Nevertheless, the application of best techniques for drainage do not always produce cost savings, as it depends on the amount of infrastructure needed and the availability of natural drainage systems, and if normally planned for several sites in the same local area. Also, the preparation of soil, the availability of space and connectivity to municipality network may require additional efforts.

In general, the use of more natural driven drainage requires less materials and less conveyance infrastructure, which also require slower installation costs. As for other environmentally sound techniques, it is necessary to implement a life cycle cost perspective when implementing water drainage techniques. According to Woods-Ballard et al., 2007, this approach gives an overview to the developer of the long-term investment required, while implementing robust decision-making procedures due to enhanced knowledge of techniques. Also, this can be integrated in a long-term risk assessment, which may modify the site management plan. The implementation of techniques such as those covered by SUDS will benefit from gained expertise, further reducing uncertainties.

Correct planning of SUDS should, therefore, take into account whole life cycle costs. Figure 3.50 outlines the magnitude of the different costs.



Source: Woods-Ballard et al., 2007

Figure 3.50: Life cycle expenditure profile

Many factors can affect the construction of a drainage system, such as soil type, groundwater management, design criteria, availability of space, hydraulic control characteristics, etc. A range of costs, given by Wallingford, 2004 as cited in the SUDS manual (Woods-Ballard et al., 2007) are shown in Table 3.84, where construction costs include, in addition to actual installation, materials, erosion and sediment control during construction, planting and landscaping.

Table 3.84: Water drainage construction and regular maintenance costs

Drainage element	Construction cost, EUR	Regular maintenance cost (annual), EUR
Filter Drain, per m^3 stored volume	130 - 180	0.3 - 1.5 (per m^2)
Infiltration trench, per m^3 stored volume	70 85	0.3 - 1.5 (per m^2)
Soakaway, per m^3 stored volume	>130	0.15 (per m^2)
Permeable pavement, per m^2 surface	40 - 50	0.6 - 1.5
Infiltration basin, per m^3 detention volume	10 - 20	0.15 - 0.4 (per m^2)
Detention basin, per m^3 detention volume	20 - 30	0.15 - 0.4 (per m^2)
Wetland, per m^3 treated volume	30 - 40	0.15 (per m^2)
Retention pond, per m^3 treated volume	19.5 - 32.5	0.6 – 2 (per m^2)
Swale, per m^2	10 - 20	0.15
Filter Strip, per m^2	5 - 20	0.15

After regular maintenance and construction, THE most important costs of environmentally friendly water drainage components are design fees (up to 30 % of construction costs) and unexpected maintenance (repairs). A 50 years assessment case study of life cycle costs revealed the need to minimise maintenance needs (Woods-Ballard et al., 2007). This case study, in Hopwood Services, applied SUDS to a parking area close to a motorway. Results show the relative high importance of maintenance, which can be 75 % of the total life cycle costs (see Figure 3.51).

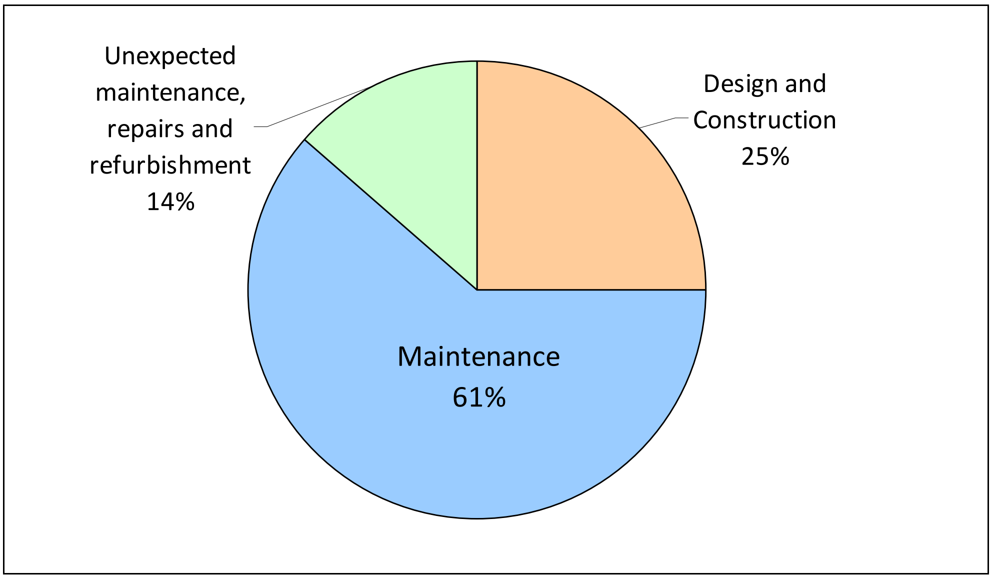


Figure 3.51: Hopwood Services Case Study Cost contribution to whole life cycle cost

Environmentally friendly drainage systems produce other benefits, which are not easy to quantify, but include hydraulic benefits (increase of water availability), increase of water quality, removal of pollution and, when compared to conventional systems, maintenance and materials costs may be lower. Also, amenities and recreational facilities can be created, increasing real estate property values.

Driving force for implementation

There are a number of drivers for the implementation of environmentally friendly drainage systems, especially those gathered under the term sustainable drainage system. In general, these systems drive implementation in several ways:

- Environmentally:
  - To prevent adverse effects of climate change, that will have an impact on the availability of fresh water. This, combined with increase pressure to water resources, will produce also undesired effects because of groundwater availability and pollution.
  - To prevent storm events, that will be more frequent, with high rainfall peaks. Improved drainage should also allow avoiding erosion, thereby reducing water pollution and flood risks.
  - To preserve and create new habitats, while protecting species.
  - To recharge groundwater at the same time of maintaining or increasing its quality.
  - To fulfil regulations, national, regional or local, in line with the European Union Water Framework Directive.
- Economically:
  - To reduce downstream flooding and, therefore, preventing property damage.
  - To increase the real estate value through the aesthetic value of created amenities
  - To reduce the conventional drainage system costs
- Socially:
  - To create public spaces and to increase quality of life.

Reference organisations

Construction Industry Research and Information Association (UK), CIRIA, publishes a significant amount of information on the application of Sustainable Drainage Systems, which are available from their website. The most important one for the understanding of drainage systems is the Suds Manual (Woods-Ballard et al., 2007), which has been used for the development of this document.

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3.4.6.2 Water saving plumbing fixtures

Description

Water efficient fixtures such as low-flow plumbing devices (water taps, toilets and showerheads) can help reduce a building's water consumption considerably. Toilet flushing usually accounts for 25 to 30 % of domestic water demand. Average flush volumes in EU households range from 6 to 9.5 litres per flush. However, depending on the toilet type water consumption can be much higher (up to 20 litres per flush for old style high-cistern gravity tank toilets) and account for 30 – 40 % of a households' water demand. The use of efficient devices is, usually, a decision coming from the final customer or from the developer of the construction project. Nevertheless, different approaches have been found, especially for commercial buildings, so this description is included in the design chapter, as water needs and water fittings are calculated or chosen frequently by designers.

The most demanding water-using products in households are usually water taps, toilets, and showers. Table 3.85 illustrates the most common water using products in residential buildings and their corresponding average daily water consumption.

Table 3.85: Water consumption of common water using products in residential buildings in Europe

Water Using Product	Average water consumption per use	Frequency of use per day	Average water consumption per day (L/household/day)	Range of water consumption per day (L/household/day)
WCs	6 – 9.5 L/flush	7 – 11.6	101.8	84.8 – 118.8
Showers	25.7 – 60 L/shower	0.75 – 2.5	91.8	37.5 – 146
Taps	2.3 – 5.8 L/use	10.6 – 37.9	74.6	61.9 – 87.2
Clothes washers	39.0 – 117.0 L/use	0.6 – 0.8	65.6	48.6 – 82.6
Dishwasher	21.3 – 47 L/use	0.5 – 0.7	24.3	15.1 – 33.4
Outdoor use	0 – 48.5 L/use	0 – 0.89	21.8	0 – 43.5

Source: EC, 2009

Water demand can be controlled by metering the consumption by installing water leak detection systems or by retrofitting existing equipment using water-saving plumbing devices and recycling waste water. Water wastage through leaky piping systems is common and can raise a buildings' water consumption significantly. By avoiding these problems, maintenance can play a key role in water management. In addition, water heating typically accounts for 10 to 20 % of the energy used in households. Most of this energy is generally lost as waste water is eliminated through the drain. However, it is nowadays possible to install a hot water heat recycling system to recover that energy.

Water leak detection systems and water monitoring, regarded as exemplar practice for building users, are described in Section 6.5.2.2. **Water recycling systems** are described in Section 3.4.6.3.

Water efficient devices. In public or commercial buildings, toilets are used more frequently, therefore presenting an even higher potential for water savings. Existing toilets can be replaced either with low-volume toilets (using less than 4 to 6 litres per flush), or waterless or composting toilets (requiring no water to flush). Another measure consists of retrofitting standard toilets with devices to reduce flush volume (typically using displacement devices, such as bottles, bags or bladders to displace water for flushing, or toilet dams). There are three different possible types of toilet cisterns: gravity tank, pressurised tank, or flush valves. The latter is the most adapted to public or commercial buildings, since it does not require long period cistern filling periods and can be used more frequently. This type of toilet has no storage tank, but is equipped with a valve which is directly connected to the water supply plumbing, and controls the quantity of water released by each flush. The flush valve toilet type also allows different water pressures at different points of the building. The minimum pressure required is usually within 175 – 275 kPa. Moreover, flush-valve operated toilets can be used to retrofit existing WCs. Regarding the flush type, dual flush toilets, which allow users to adapt water pressure to the quantity of waste to remove, appear the best performing option.

Instead of completely replacing existing toilets, retrofitting with new water-efficient devices is also possible. The simplest of these measures consists of placing a water-displacement device – such as a sealed bag or bottle full of water – in the back of the tank. This measure helps saving, per flush, the amount of water corresponding to the capacity of the displacement device. To reduce water-consumption of older-style toilets at a low cost, it is also possible to fit an early-closure (adjustable flapper) devices or water-retention mechanisms such as toilet dams. Finally, some toilet fixtures can be changed instead of replacing the whole toilet. It is either possible to convert the existing cistern to dual flush, or to retrofit a new dual flush cistern.

Standard urinals commonly consume 3 to 4 litres per flush. However, low-flow urinals use 1.5 litres per flush or less. As for toilets, there are several possible flush mechanisms for urinals. However for hygienic reasons, urinals flush traditionally operate automatically rather than by self-flushing. The most common flush mechanism is timed flush /cyclic flush, that operates automatically at regular intervals during the day, independently of the use frequency. This system is therefore highly inefficient. Another water-efficient type is the automatic flush, which is activated after each use through a movement-sensor. Automatic flush facilities are appropriate for refitting existing urinals.

The newest and latest water-efficient technique is waterless urinals, which require no water at all for operation. The latest models are equipped with a trap insert filled with a sealant liquid instead of water. This sealant liquid is lighter than water, and floats on top of the urine collected in the U-bend, preventing odours being released into the air. These models require some more maintenance, since the cartridge and sealant need periodic replacement. However, these systems are the most water efficient since they allow water savings by 100 %. Water consumption of urinals is estimated to be 50 – 100 m³ per urinal per year but can even exceed 500 m³ for some cyclic models.

Retrofitting water taps presents a large potential for water savings. Standard taps usually consume 15 to 20 l/min, but new low-flow models (e.g. low-flow screw down or lever operated taps) require less than 6 litres, down to less than 2 litres. The most common techniques are aerators, incorporating air to the flow and, therefore, giving the feeling of high flow, and spray taps, reducing droplet size to give the impression of higher flow.

To reduce water use in offices or high usage areas, the BREEAM report on sustainable office buildings (BREEAM Offices, 2008) also suggests the use of timed automatic shut-off taps or movement-sensor operated taps:

- Timed automatic shut off taps, such as push-taps. These types of taps are either lever or button operated and the integrated timers let water flow 10-15 seconds after operation. These taps can be combined with adjustable flow regulators. They are the most cost-effective solution.
- Electronic sensor taps for basins, which only turn on when hands are under the spout. This solution is the most hygienic and water efficient, but also the most expensive and maintenance demanding. They are adapted to high usage areas.

Water efficient water showers are those minimising not only water use but energy efficiency through optimised outlet temperature. For instance, thermostatic mix valves are fitted during shower installation and fit the ration hot/cold water to ensure a constant temperature. Push-button timers are also a suitable technique, but likely to be less acceptable for domestic use. The use of low-flow showerheads, incorporating aerators and with finer droplet size helps to achieve significant water savings.

Achieved environmental benefits

The achievable environmental benefit from the implementation of water saving plumbing fixtures depends on the actual user behavior. For instance, water use in hotels is usually higher than for domestic buildings, even if they provide similar or the same service.

Below, a summary table with the main improvement potentials derived from the Reference Document for the Tourism Sector (EC, 2012) is shown.

Table 3.86: Main benefits from the application of water saving plumbing fixtures

Device	Fitting	Savings potential
Showers	Aerators and low-flow showerheads	Up to 6 L/min
	Thermostatic mix valves	3 L per shower
	Push-button timers and water recirculation	27 L per shower
Toilets	Low-flush	6 L per flush
	Dual flush	33 % of total water
	Cistern displacement device	Up to 2 L per flush
	Delayed action valve	Up to 1 L per flush
Taps	Aerators and low flow taps	Up to 50 % of actual flow rate
	Spray taps	Up to 80 % reduction
Urinals	Low flush	Up to 3 L per flush
	Waterless urinals and flush timing control	Up to 300 m^3 per year

Source: EC, 2012.

Retrofitting an existing building would produce significant savings (see Economics section). A single urinal can save up to 150 m^3 per year (compared to an uncontrolled flush), while toilets, showers and taps are in the range of 10-20 m^3 per year.

Appropriate environmental indicators

The impact of water saving devices can easily be controlled by the water consumption of the building in absolute terms. Nevertheless, this indicator may be useless for comparison or benchmarking purposes. In fact, there are indicators suitable for every type of building as shown in section 6.5.2.2. As user behaviour is out of the scope of this technique, no benchmark for water use will be established for total water performance. Benchmarks should be established taking a sectoral approach, i.e. who the building user is.

Therefore, for designers, it is recommended to get the actual flow, in L/min as a good indicator for taps and showers, being a benchmark value of 4 L/min for taps and 7 L/min for showers achievable. Toilets performances should be measured per flush, with a benchmark of 4.5 L/min.

Cross-media effects

Mainly, cross-media effects can be considered positive, as waste water is reduced, as the energy consumption for heating water

Operational data

Taps and Showers

Water efficient shower heads include design features, such as in-built aeration and sometimes flow restrictors, nozzles to minimise water droplet size, and spray patterns that match the body cross-section. Spray showers may produce the cold feet effect because of the high cooling rate of droplets.

Usually, the performance of low flow showerheads or taps varies, partly in response to pressure. A pressure of at least one bar is required for effective operation, and low-flow showerheads might not work on electric-showers or gravity-fed systems that are extensively used in the UK and Ireland. Flow rate is exponentially related to pressure (pressure is related to the square of velocity through Bernoulli's equation), and system pressure therefore has a dramatic effect on flow rate in most showerheads that do not contain pressure restrictors. Even low-flow showerheads with in-built flow-restrictors can still use two-thirds more water than necessary when the system water pressure is high. These points emphasise the need to regulate building water system pressure and perform trials for low-flow fittings, especially showerheads. A lower cost option is to reduce the flow at showers or taps with built-in flow restrictors, which are screwed into standard fittings. Other options, for high pressure systems, are the isolating ball valves to restrict flow rate.

Public facilities incorporating public taps and showers can substantially reduce water consumption with push valves. For showers, restricted duration mechanisms can also be installed.

Toilets

The classical standard gravity tank is the most common type in use, which has lower installation costs but suffers from frequent water leakages. These are known as flap valve cisterns, which are refilled with water during flushing, so water consumption is increased by 17 % as an average. Cisterns containing siphon-controlled outflows are more expensive, but with slower refilling and, therefore, less water leaks. They are not suitable for high frequency use. One option is to use valve-operated flush toilets, more expensive, but no refill time is needed. They need higher pressures than gravity toilets, about 1.8 bar.

Applicability

Water saving plumbing fixtures can be implemented either during the design stage of the building or in the context of retrofitting. Aerators, flow restrictors and low flow taps and showerheads are inexpensive and suitable where pressure is at least one bar, though they cannot be used with gravity systems. System based on pressure tanks, e.g. some of the toilets described above, may require larger installations and should be implemented during major renovations.

Economics

The replacement of an older cistern can lead to the greatest savings, but can be expensive. The performance of toilets in terms of water demand and costs strongly depends on the functional characteristics of the toilet. Similarly, close coupled WC and slim line models impose restrictions. For valve operated cisterns, a check should be made for leaks using either a dye or dry paper test.

In commercial or public buildings, retrofitting water taps usually brings a reduction of 20 to 30 % in water consumption, within a payback period of less than 2 years.

According to the estimation of EC, 2009, an average household of 2.7 inhabitants applying different levels of retrofitting measures (Table 3.87) can save water by:

- First level/low-costs retrofitting to save 20-25 % of water demand. The measures applied include the installation of water bags in toilets cisterns to save 1l./flush; more efficient shower heads (12 to 8 l./min); more efficient taps (12 to 10 l./min).
- Best efficiency retrofitting to save up to 35 – 40 % water use, with measures such as replacement of toilets with 3 – 6 dual flush, reducing bath size, fitting water-efficient home appliances (washing machines, dishwashers, etc.).

Table 3.88 provides the costs analysis of water efficient fitting as developed by EC, 2012, for the Tourism sector. For the assessment, it is noticeable that many payback periods are short, ranging from 2 to 10 months. Some data are calculated in a worst case scenario (renovation of water fittings are made exclusively for water saving and replace recently installed conventional fittings). Also, the reduction of energy consumption due to efficient hot water supply is also quite relevant.

Table 3.87: Potential water savings within buildings

Water consumption within household	No behavioural changes		With assumed moderated behavioural changes	With assumed higher behavioural changes	Estimated cost per capita (assumption: 2.7 inhabitants)
	L/capita/day	% changes	% changes	% changes	EUR
No fixtures changes (base case)	150	0	20 %	30 %	0
First level retrofitting	120	20 %	33 %	40 %	15 - 35
Best efficiency fittings of key fixtures	90	40 %	50 %	55 %	100 - 300
Best fittings, plus water reuse	75	50 %	55 %	60 %	1200 - 2000

Table 3.88: Annual savings and payback period of selected water fittings.

Fitting	Cost, EUR	Saving, EUR/yr			Payback, Months
		Water	Heating (oil)	Total	
Low-flow basin taps (worst case)	100 - 200	29	24	53	23 - 45
Combined flow-restrictor and aerator	10	22	18	40	3
Combined flow restrictor and aerator	10	44	54	98	1
Shower push-button timer	150 - 200	164	203	367	5-7
Low-flush toilet (worst case)	70 - 150	23 (137 in public)	0	23 (137 in public)	36 - 78 (13 in public)
Cistern displacement or dual flush	20	23 (137 in public)	0	23 (137 in public)	10 (2 in public)

Source: EC, 2012

Driving force for implementation

The reduction of water consumption, apart from the evident environmental benefits produces costs savings, even with no behavioural changes. Apart from this benefit, ongoing learning processes of construction companies, designers, users and developers may produce intangible environmental benefits when incorporating these technologies, e.g. through the extended application of water efficient devices.

Also, water regulations and future ecodesign mandatory criteria in some Member States higher restrictions are the main driving force. In addition to this, there are many subsidy schemes available for new developments and renovations implementing water efficient devices.

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3.4.6.3 Non-potable water recycling systems

Description

Some water applications in buildings, such as toilet flushing and irrigation, do not require the use of potable water. These applications can be responsible for a large share of total water use. The use of water recycled from on-site rainwater or grey water collection systems can considerably reduce demand for potable water from the mains supply.

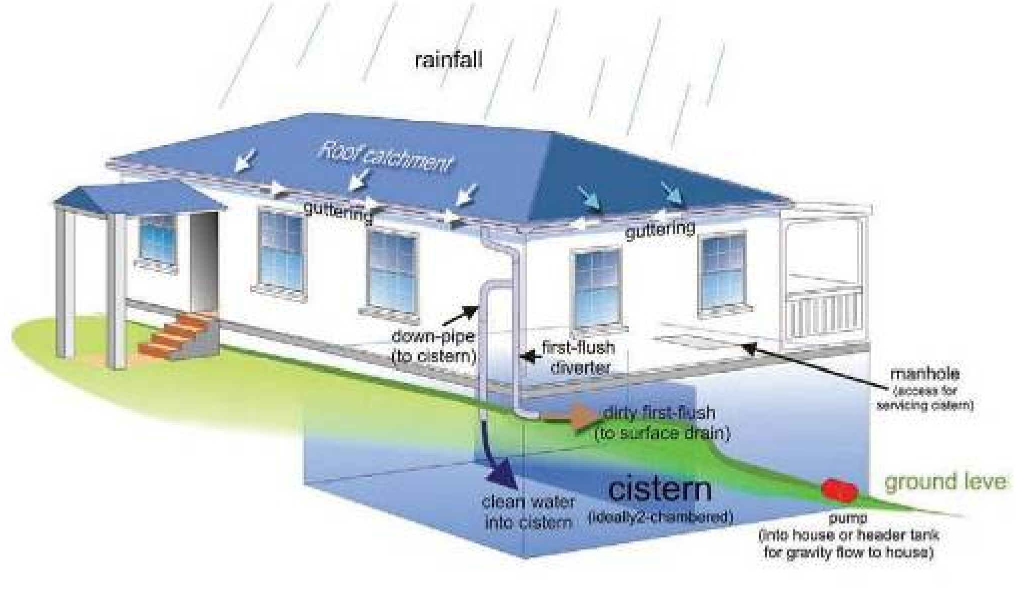
Rainwater collection systems divert rainfall water into storage tanks. Run-off systems can be installed on roofs and other impervious surfaces. The harvested water can be used for non-potable demand such as toilet flushing, washing machines, irrigation, cooling towers or general cleaning purposes. Thirty-five per cent of new buildings built in Germany in 2005 were equipped with rainwater harvesting systems.

Grey water is the term used to describe waste water from activities such as bathing, showering, laundry, dishwashers, and excludes 'black water' from toilet flushing. Grey water may be collected and reused for non-potable water applications such as toilet flushing and irrigation by the installation of separate waste water drainage systems for toilets and grey water sources.

Although usually too expensive and impractical to retrofit, water recycling systems can be installed at relatively low cost during construction, and at reasonable cost during major renovations. Smith et al. (2009) estimate water recycling systems can add 15 % to plumbing system costs during major renovations. The decision to install rainwater collection systems and grey water recycling should be based on a cost-benefit assessment that considers economic and environmental criteria, including the source and scarcity of water supply now and in the future. One potential alternative for buildings with certain demand for irrigation is the use of part of treated waste water for irrigation.

Rainwater collection for irrigation is regarded as a basic good practice measure. Best practice is considered to be:

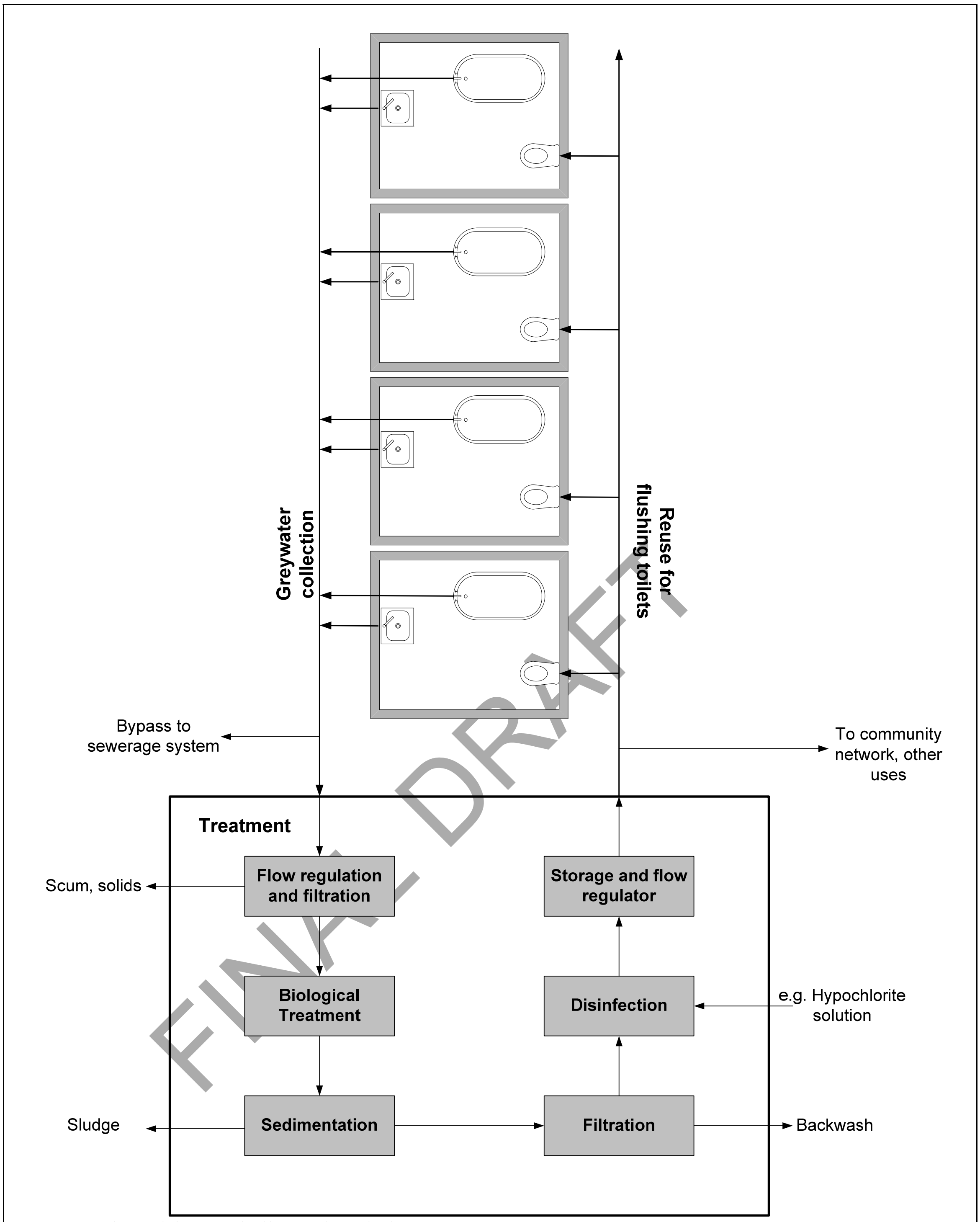
- installation of a rainwater collection and distribution system for use inside the building and/or reuse in other city areas due to a separate rainwater reuse network (see Figure 3.52). A rainwater harvesting system consists of four main elements:
    - Catchment area, usually a roof surface or pavement.
    - Conveyance system: piping and gutters transferring rainwater to the temporary water storage. Two different systems may be needed, depending on the cleanliness of the catchment area (e.g. first roof harvested water may not be appropriate for several uses).
    - Storage device: usually a tank, which should be accessible and can be installed over the roof, within the building facilities or underground.
    - Distribution system: this may consist of a simple solution, such as a container for the irrigation system, a piping system or, in several cases, water pumping devices. For a community or urban rainwater reuse network, the complexity of the system is likely to be much higher.



Source: UNEP, 2009a

Figure 3.52: Example of a domestic underground Rainwater Harvesting system

- installation of a grey water collection, treatment and distribution system for use either inside or outside the building. Grey water is the low polluted waste water from bathtubs, showers, hand-washing basins and washing machines. Water from recycled systems to be reused for toilet flushing and other external uses (e.g. irrigation) should fulfil four main criteria: hygienic safety, aesthetics, environmental tolerance, as well as technical and economical feasibility criteria. According to Nolde, 1999, the suitable treatment of grey water should follow a sedimentation stage, biological treatment, clearing stage and eventual UV or hypochlorite disinfection. The appropriate design of grey water recycling systems should take into account the variability of flows, therefore designing adequate storage tanks for the inflow and the outflow of the system, as well as a by-pass to the municipal sewerage network. In Figure 3.53, a systemic approach is described for households, adapted from Friedler and Hadari, 2006.



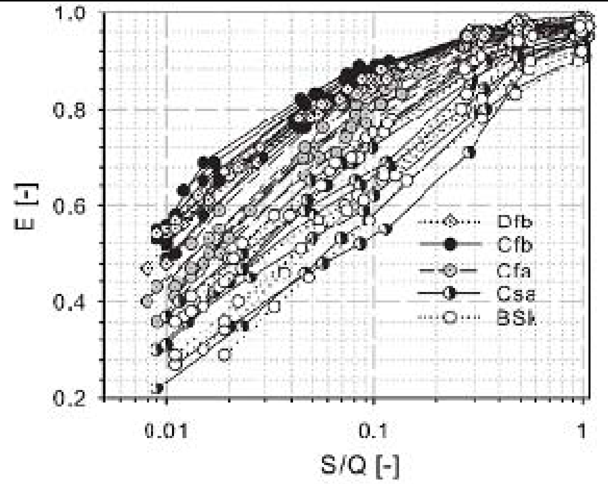
Source: Adapted from Friedler and Hadari, 2006.

Figure 3.53: Integration of a grey water recycling treatment and reuse in a building

Achieved environmental benefit

EC (2009) estimates that water recycling can reduce water consumption by an additional 10 %, after a 40 % reduction in water consumption achievable from implementation of water efficiency measures. In the sectoral reference document for the tourism sector (EC, 2012), these systems have special relevance, as tourism in zones affected by water scarcity produces a high pressure on water resources. Some outstanding examples can be found in the sector, such as rainwater recycling system installed in the 250 - room ETAP city-centre hotel in Birmingham, UK, which saves up to 780 m^3 of potable water per year (5 % to 10 % of consumption). This saving equates to about 6 % of best practice water consumption for this size of hotel (after implementation of all other water efficiency measures).

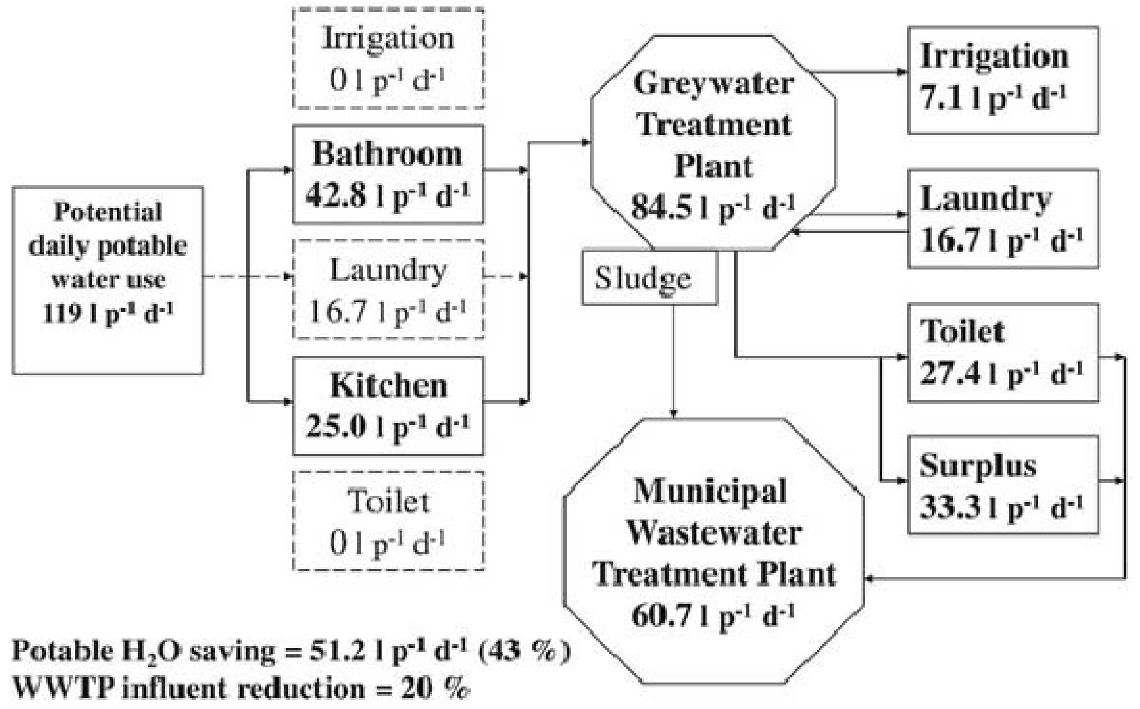
Dixon et al., 1999, measured the water saving efficiency as the ratio between the volume of rainwater supplied and the water demand for, e.g. toilet flushing for the assessment period. Palla et al., 2012, simulated how this parameter would evolve according to the storage capacity (called S/Q, where Q is the total rainwater in a certain period and S is the storage volume). The results are shown in Figure 3.54. In the figure, 5 climates are represented. Dfb is a cold climate (e.g. Stockholm, Helsinki, Berlin), Cfb (e.g. Paris, Frankfurt, Lyon), Cfa (e.g. Milan, Belgrade, Split) and Csa (e.g. Genoa, Lisboa, Malaga) are temperate climates and Bsk are arid climates (Madrid, Methoni, Valencia). As shown in the chart of Figure 3.54, highest storage capacity, for all locations, improves water efficiency to 0.95 – 0.98. The graph is normalised per total rain water, so the influence of the total amount is excluded. Due to the economic performance of the system, the storage capacity may need to be optimised to a level high water recovery rates. Warmer climates are less efficient than colder climates, depending on the rainfall event frequency and volume. Therefore, the higher frequency of rainfall events improves the storage range and, therefore, increases rainwater recovery efficiency.



Source: Palla et al., 2012.

Figure 3.54: Water saving efficiency, E, vs storage fraction, S/Q, in the main 5 European Climates

The impact of grey water recycling in water use is huge. Figure 3.55 shows a block diagram of different water uses and the impact of a grey water treatment plant.



Source: Revitt et al., 2011.

Figure 3.55: Water uses per process measured in litres per person per day

According to Revitt et al., 2011, very important savings are achievable (43 %), with a strong impact on the performance of waste water treatment plants. However, the treatment process only removes efficiently the biodegradable fraction, while other persistent chemicals and heavy metals are not removed or controlled within these systems.

NH Campo de Gibraltar hotel (Spain) substitutes 20 % potable water with filtered and treated grey water from showers, used to flush toilets. In a study made on grey water recycling in multi-storey buildings (Friedler and Hadari, 2006), an average water savings of 55 L per person per day is foreseen for a bigger scale treatment (i.e. 34 % water savings).

There are some cross-media effects associated with rainwater collection and grey water recycling (see below). The overall environmental benefit will be highest where local (perhaps seasonal) water shortages exist, and where water is imported from other areas or desalinated. In such areas, modest reductions in water consumption may lead to significant reductions in water stress (with associated benefits, including for biodiversity), and/or energy requirements for desalination.

Appropriate environmental indicator

The most relevant indicators of water recycling implementation are:

- installation of a rainwater recycling system that supplies internal water demand
- installation of a grey water recycling system that supplies internal or external water demand
- quantity of rainwater and grey water reused, m^3/yr
- percentage of annual potable water consumption substituted with recycled rain- or grey-water
- The rain water saving efficiency is defined by Dixon et al., 1999, as:

$$E = \frac{\sum_{t=1}^{N} Y_t}{\sum_{t=1}^{N} D_t}$$

Where Y_t is the rainwater used at a time step and D_t is the water demand at each time step. The concept of 'time step' should be used when simulating the behaviour of the designed rainwater system efficiency. Especially in areas where seasonal water scarcity is a problem, this indicator may be disclosed per season.

The impact of rainwater or grey water recycling system on water performance of buildings can also be an indicator for the implementation of this best practice: e.g. % of water savings, saved volume per person and per year with a consequence on the economic performance of the building, etc.

As the performance of these systems depends on a number of important factors, the proposed benchmark is the installation of a rainwater recycling system that supplies internal water demand, or a grey water recycling system that supplies internal or external water demand, and when connection to community networks is available.

Cross-media effects

Reused rain water can have a higher energy and carbon footprint than mains supply water owing to infrastructure and pumping requirements. The carbon footprint of a domestic sized rainwater harvesting system over 30 years has been estimated at approximately 800 kg CO_2 eq. However, this is minor compared with total household carbon emissions from energy use, which can be 100 times higher.

Rainwater reuse systems essentially bypass the natural water cycle. Where drainage water would otherwise soak into the ground, and where groundwater levels are locally declining, and where water is supplied from a (nearby) area with greater water availability, widespread rainwater harvesting could exacerbate local water stress. Such situations are unlikely, however. On the contrary, widespread rainwater harvesting could reduce flooding risk during high rainfall events.

Operational data

Notes on the calculation on the amount of water to be harvested: the rational method

The rational method was developed by UNEP, 2009b. It needs these inputs:

- the average annual rainfall for the selected location, disclosed per appropriated time step (.e.g. months)
- the size of the area of the collecting area, e.g. a roof
- type of roof or collecting surface and the run-off coefficient.

The rational method calculates the rainwater supply as:

Supply (Litres per time step) = rainfall (mm/time step) x roof area (m^2) x run-off coefficients

If the roof area is angled, a projection to the horizontal surface should be done to correctly estimate the amount of rain falling on the roof. To calculate this projection, the following expression can be used:

Roof surface area (m^2) = roof length (m) x roof width (m) x sin (angle)

The run-off coefficient is the amount of water that drains free of the surface relative to the amount falling on the surface. A run-off coefficient of 0.8 means that 80 % of the total water fallen onto a surface drains, while the remaining 20 % stays on the surface.

Several run-off coefficients for several catchment surfaces are shown in Table 3.24 and Table 3.89.

Table 3.89: Run-off coefficients for several catchment types

Type of catchment	Coefficient
Tiles	0.8-0.9
Corrugated metal sheets	0.7-0.9
Concrete	0.6-0.8
Brick pavement	0.5-0.6
Soil in slopes less than 10 %	0.1-0.3
Rocky natural catchments	0.2-0.5
More examples are shown in Table 3.24	

A worked example is shown in Table 3.90

Table 3.90: Example of rainwater supply calculation

Mean annual rainfall	1500 mm/yr
Roof Angle	70°
Roof area	10m x 8 m x sin(70°) = 75 m^2
Run-off coefficient	0.8
Supply	**1500 mm/yr x 75 m^2 x 0.8 = 90 000 litres**

Run-off collection system design

Rainwater collection and reuse is a simple process. The necessary components can be easily installed in a new building at relatively low expense, but are more difficult to retrofit in an existing building. Extensive plumbing modifications are required to separate the water supply network into two systems supplying: (i) kitchen taps, bathroom taps and showers supplied by 100 % potable water from the mains supply; (ii) toilet cisterns, urinals and laundry facilities supplied with rainwater or potable water depending on availability. Where rainwater is available in sufficient quality and quantity, it may also be used in showers.

A typical rainwater reuse system comprises the following components.

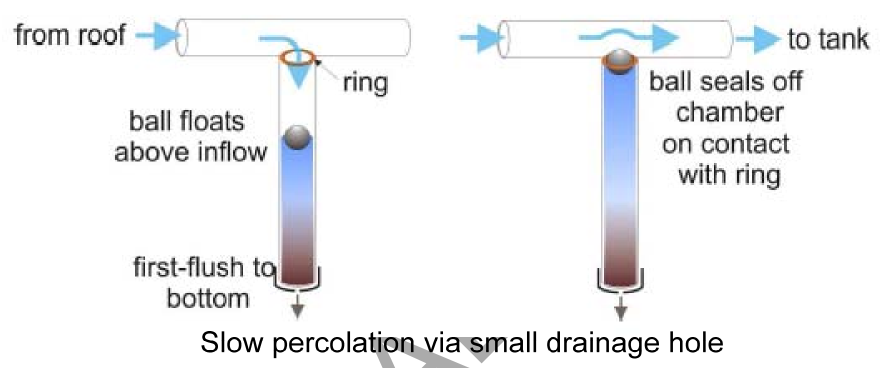
- A standard roof or surface run-off water collection system operating under gravity and diverted into a storage tank, fitted with a debris screen and filter.
- A storage tank with water-level detector, ideally situated underground, into which rainwater is diverted from standard rainwater collection pipes.
- A control unit that sends either mains water or stored rainwater either directly to the distribution system under pressure, or to a header tank.
- A separate pipe distribution system feeding relevant fittings (urinals, cisterns, etc.) with water supplied either directly under mains/tank-pump pressure or from a header tank.
- (Possibly) A header tank with float-operated inlet valves from pumped rainwater and from the mains water supply, and an outlet valve into the building water supply system.

The calculation of the water storage capacity should be calculated according to the weather and climate variability observed. For instance, Madrid rainfall is not different from those in Stockholm or Frankfurt. In Madrid, average precipitation calculated according to the example of Table 3.90, 26 000 litres could be recovered, while in Stockholm 31 000 would be recovered and 33000 in Frankfurt for the same roof.

There are various methods of tank sizing, some of which may be area specific. One guideline is that the tank should be large enough to hold 18 days of average demand, or five per cent of annual yield, whichever is lower (Peacock irrigation, 2011). Another guideline is that the tank should be able to store sufficient water to supply average demand over the longest dry periods (statistically defined from 30-year climatic data). Strong seasonality in rainfall, in particular the occurrence of long dry periods, may require larger capacity than the 5 % method. The seasonality of rainfall patterns should be assessed, and tanks may be sized according to the aforementioned dry-period supply rule. The British Standard code of practice for rainwater harvesting systems (BSI, 2009) recommends a modelling approach to tank sizing that considers temporal variations in demand and yield, using at least three years of data. Occasional overflows are a useful way to clean debris from the tank and maintain water quality. Tanks may also be sized for storm water control to reduce the risk of flooding, in which case statistical data on storm events should be used to specify 'oversized' tanks.

Rainwater system installation

Rainwater collectors such as guttering should be regularly inspected and kept clean of debris, including leaves. Wire mesh screens may be fitted to gutters to prevent debris entering the system, and it is recommended to fit a filter to the inflow of the rainwater collection tank. These typically contain a fine wire mesh of e.g. 0.35 mm, may contain additional micro-filtration layers, and can be self-cleaning (by periodically applying high-pressure water over the mesh surface to a separate outlet for debris). A first-flush diverter may be fitted to reduce the concentration of pollutants in the collected rainwater (Figure 3.56).

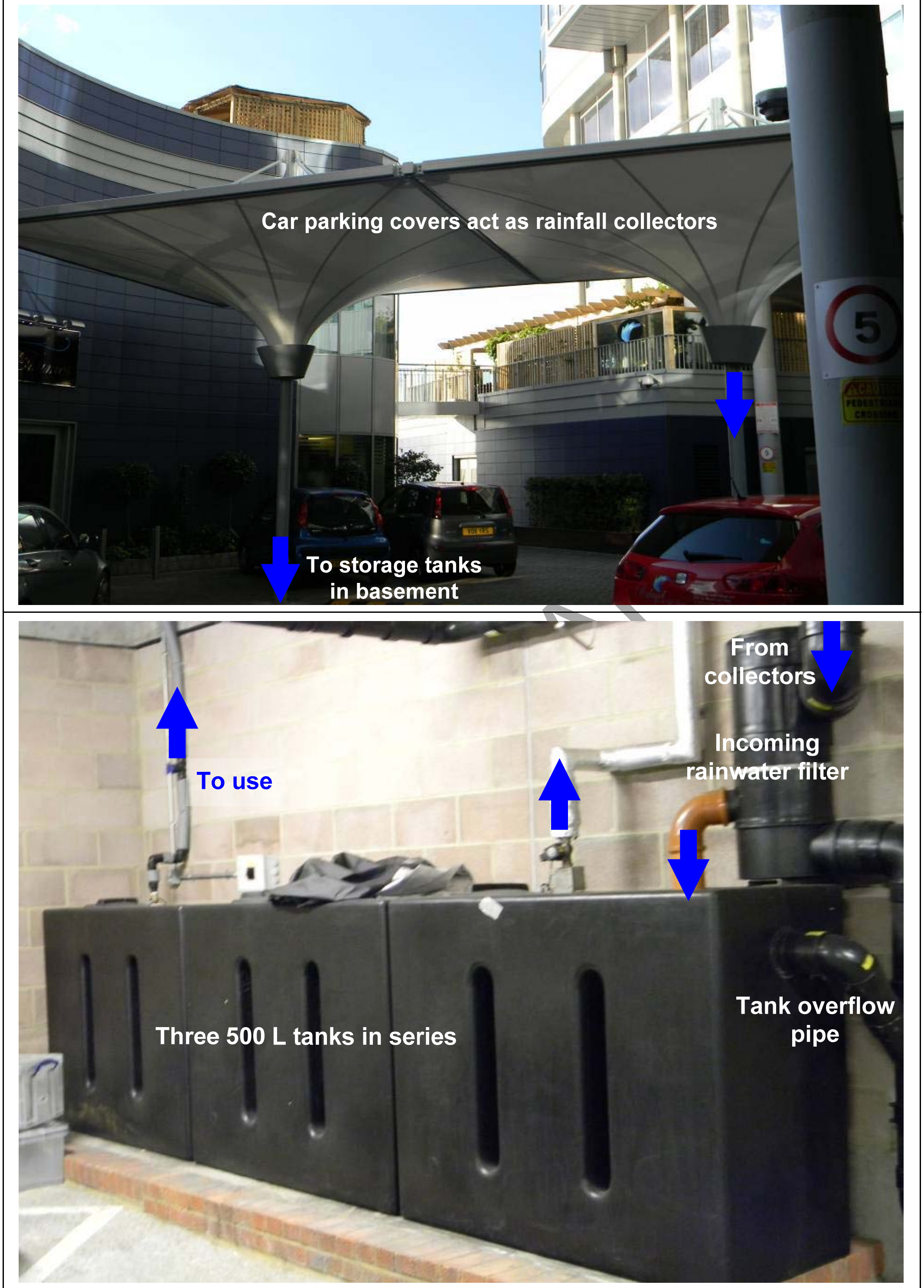


Source: UNEP (2009b).

Figure 3.56: Float-ball mechanism to divert first flush run-off water

Prefabricated rainwater storage tanks are commercially available in sizes of up to 7 m^3 for underground types and 10 m^3 for above-ground types (Bicknell, 2009). It is possible to buy tanks built in two pieces that are joined together during installation – these can be particularly useful where space on-site is restricted for installation. Where large storage capacity is specified at the building design phase, purpose-built concrete tanks may be constructed. Alternatively, multiple pre-fabricated tanks may be installed in series (see Table 3.91).

Table 3.91: An example of a small rainfall collection (above) and storage (below) system, from the Rafayel Hotel in London



Tanks should be installed underground or in unheated basement areas where the temperature remains stable and relatively low throughout the year. Buried tanks with an ambient temperature not exceeding 12 ºC are ideal because they restrict biological activity that can otherwise be associated with water discolouration, and potential health risks (Bicknell, 2009). BSI (2009) recommend a floating extraction point at 100 mm to 150 mm below the water surface, or alternatively a fixed extraction point at 150 mm above the base of the tank. Overflow pipes should be at least equal in capacity to inflow pipes, protected from backflow and vermin, and, where possible, connected to a soak-away drain.

It is highly recommended to install a metre to measure rainwater use. This will facilitate the identification of problems, and enable calculation of potable water savings. This system will usually be incorporated into the control system that controls pumps and regulates the back-up (potable) water supply. The system may also be integrated into a centralised building management system.

Pipework should be clearly identifiable as supplying rainwater, and differentiated from pipework supplying only potable water. Pipework may be identified by markings inserted during manufacture, or attached labels. It is recommended that labels be attached at 0.5 m intervals along the pipe, and on the outside of insulation where this is present (BSI, 2009). Similarly, labels and signs should be visible at all points of use stating 'non-potable water'. Frequent inspection of the system and tank water can identify water quality problems, combined with occasional dip testing of water in the storage tank or cistern.

Run-off water quality

Contaminants in roof run-off water include organic matter, inert solids, faecal deposits from animals and birds, trace amounts of metals and complex organic compounds. Concentrations vary depending on roof material, antecedent dry period and surrounding environmental conditions (e.g. proximity motorways or industrial areas). Leaching of heavy metals such as copper, zinc and lead can present a problem where these materials are extensively used in roof construction. However, a study of roof run-off quality in Hamburg, Germany, found that copper, lead and zinc concentrations were well within World Health Organisation drinking standards (Villarreal and Dixon, 2005). The quality of roof run-off (Table 3.92) is acceptable for domestic uses, especially following basic filtration. It is possible but usually not necessary to fit a device to rainwater collection systems that diverts the first flush of run-off water during rain events, containing the highest concentrations of contaminants, to normal drainage.

Table 3.92: Water quality parameters for 'fresh' and stored roof run-off water

	pH	BOD	COD	TOC	TS	SS	Turbidity
		mg/l					NTU
Roof run-off	5.2 – 7.9	7 – 24	44 – 120	6 – 13	10 – 56	60 – 379	3 – 281
Stored run-off	6 – 8.2	3	6 – 151	–	33 – 421	0 – 19	1 – 23

Source: Villarreal and Dixon (2005).

Run-off water from some surfaces such as car parks can contain relatively high levels of contaminants such as hydrocarbons and heavy metals from vehicles, and will not be suitable for use indoors. Run-off water should be tested before deciding to install a recovery system. Where water is not suitable for indoor use, it may be suitable for irrigation following installation of a first-flush diverter and appropriate filtration.

Grey water recovery

Grey water recovery requires the installation of separate waste water collection systems for: (i) showers, basins, washing machines, kitchen appliances, swimming pools (grey water); and (ii) toilets (black water). In fact, separate grey water collection may be restricted to room showers and basins, in order to avoid more heavily soiled water, excluding kitchen basins, water from washing machines or dish washers.

In its most basic form, grey water recycling requires:

- installation of a separate waste water collection system for grey water and blackwater
- basic screening to remove debris
- installation of large grey water storage tanks (as described above for rainwater harvesting)
- connection to an irrigation system.

It is easy to incorporate a basic heat-exchange process into grey water collection systems, to heat fresh water entering the heating system. Use for indoor activities such as toilet flushing requires installation of a separate supply system as described for rainwater recycling (above).

In Spain, the hotel NH Campo de Gibraltar, in Algeciras, installed an integrated treatment for grey water. Waste water is collected separately from basins and showers, treated, and recirculated for toilet flushing, reducing potable water consumption by 20 %. The main driving force for this specific example was water price, which is quite high in that region. The sequence of steps is elaborated with reference to photos in Table 3.93.

Table 3.93: Sequence of steps in grey water recycling implemented at NH Campo de Gibraltar hotel

	**1. Grey water diversion** An electrovalve controls flow of separated grey water into the treatment tank depending on remaining capacity. If full, grey water is diverted to the sewer.
	**2. Grey water filtering** A flow sensor located after the electrovalve activates a dosing system to add hypochlorite to grey water entering the treatment room for recovery. Following hypochlorite dosing, water is filtered through a mesh screen to remove debris such as hair. This screen is manually cleaned, requiring 15 minutes per day. Debris is collected in a standard waste bin and sent for disposal. Filtered water is left to settle in a sedimentation tank. Sludge from the sedimentation tank is collected every 15 – 30 days by a tanker.
	**3. Intermediate Storage** Filtered, settled grey water is directed to a series of three intermediate tanks.

 	**4. Treatment** Final storage tanks are filled under flushing demand. To fill this tanks with the filtered grey water, there are two intermediate treatment stages: a carbon filter (picture below) to remove pollutants and UV-disinfection (picture above)
	**5. Distribution** Stored grey water is pumped to toilet cisterns throughout the hotel through a clearly labelled grey water pipe network.

Required grey water quality

The composition of grey water is influenced by user behaviour. Usually, grey water contains low concentration of nutrients, even below the regulatory requirements for effluent discharge of municipal waste water treatment plants. Nolde, 1999, detected a high concentration of total and faecal coliforms, which is related mainly to seasonal periods of user behaviour. So, design should consider behavioural aspects in order to obtain best performance also for health issues. As an example of the characterisation of grey water, Nolde, 1999, reports the quality observed in two buildings (Table 3.94). Building 1 treatment plant is designed for 70 people and the second is a small grey water treatment appliance designed for a two-person house.

Table 3.94: Different untreated grey water qualities measured in two sample buildings

Parameter	Unit	Bath and shower (building 1)	Bath, shower and washing machine with baby diapers (building 1)	Shower (building 2)
TOC	mg /L	–	–	26 – 95
COD	mg /L	100 – 200	250 – 430	113 – 633
BOD_7	mg /L	50 – 100	150 – 250	70 – 300
N	mg /L	5 – 10	-	-
P	mg /L	0.2 – 0.6	-	-
Faecal coliforms	counts/ml	0.1 – 10	$10^4 – 10^6$	0.1 – 10
Total coliforms	counts /ml	$10^2 – 10^3$	$10^4 – 10^6$	$10 – 10^3$
Total counts	counts /ml	$10^5 – 10^6$	$10^6 – 10^7$	$10^5 – 10^6$

Source: Nolde, 1999.

It is evident that safe reuse of grey water is a priority and several measures should be taken into account to reuse water at buildings (CRC, 2002) make the following recommendations for the safe reuse of grey water that minimises potential human health risks:

- kitchen grey water should not be included as it is highly polluted, putrescible and contains many undesirable compounds
- grey water should not include waste water from kitchen sinks, dishwashers, garbage disposal units, laundry water from soiled nappies or wash water from the bathing of domestic animals
- removal of hair, lint, etc. via strainer or filter is necessary to ensure systems do not clog
- blockages and build-up of slime may be avoided by using pressurised systems
- storage of grey water is undesirable due to the potential for the growth of pathogenic micro-organisms, mosquito breeding and odour generation
- sub-surface reuse is the preferred method of irrigation as surface irrigation is prone to ponding, run-off and aerosols
- reuse of toilet flushing should not be considered as it requires a high degree of treatment to ensure no health risks, toilet staining or biodegradation in cistern.

Applicability

The installation of rainwater and grey water recycling systems is applicable to all new buildings. Retrofitting such systems to existing buildings is expensive and impractical unless the building is undergoing extensive renovation. Building ownership is also an issue for the renovation of buildings with these systems.

Technically, the application of rainwater harvesting is not dependent on the climate. Nevertheless, the economic feasibility is highly dependant on the climate.

Economics

As a general rule, the costs of equipment of water recycling facilities are high and the payback period is longer than for other water efficiency measures. Two rainwater harvesting systems are assessed by Domènech and Saurí, 2011, in Barcelona. They assessed two systems, one for a single family house with three residents and another for 42 residents in a multi-family building. The cost of the equipment is shown in Table 3.95. For those installations, they calculated the payback time according to several water price scenarios, with different tank sizes and discount rates and final water use. Results showed really long payback times, being longer than 40 years for the single house and usually longer than 20 years for multi-family buildings.

Table 3.95: Investment costs of rainwater harvesting for new buildings

Item	Single family building (EUR)	Multi-family building (EUR)
5 m^3 tank	2 900	
10 m^3 tank	4 500	
15 m^3 tank	6 500	
20 m^3 tank	7 700	
30 m^3 tank	10 100	
40 m^3 tank	12 500	
50 m^3 tank	12 600	
Installation	700	-
Pump (garden)	750	750
Pump (toilet/laundry)	750	2 000
Piping	300	1200
Filter	400	400
Maintenance EUR/year	50	300
Cost of electricity, EUR/kWh	0.1	

Therefore, the absence of reasonable payback times can make these systems not economically attractive to designers to save water. Governments may provide financial incentives for the installation of water recycling systems, such as grants or tax rebates. In the UK, the Enhanced Capital Allowance scheme allows businesses to offset installation costs for water recycling systems against tax in the year of installation.

The same happens with grey water recycling systems. Long payback periods are also foreseen, although achievable savings are higher and predictability of behaviour is better. So, according to Friedler and Hadari, 2006, 15 years or less payback times in optimised systems are possible when the size of the building, i.e. the number of apartments, is high enough. There is a strong dependence on water cost and waste water treatment fee for the economic feasibility of the system.

Driving force for implementation

The two primary objectives for implementing water recycling schemes are to: (i) reduce water consumption; (ii) reduce waste water volume. Increasingly, national regulations are encouraging the installation of water recycling systems and provide financial incentives for their installation.

Also, some building rating schemes, such as BREEAM, award points to water conservation measures including water recycling.

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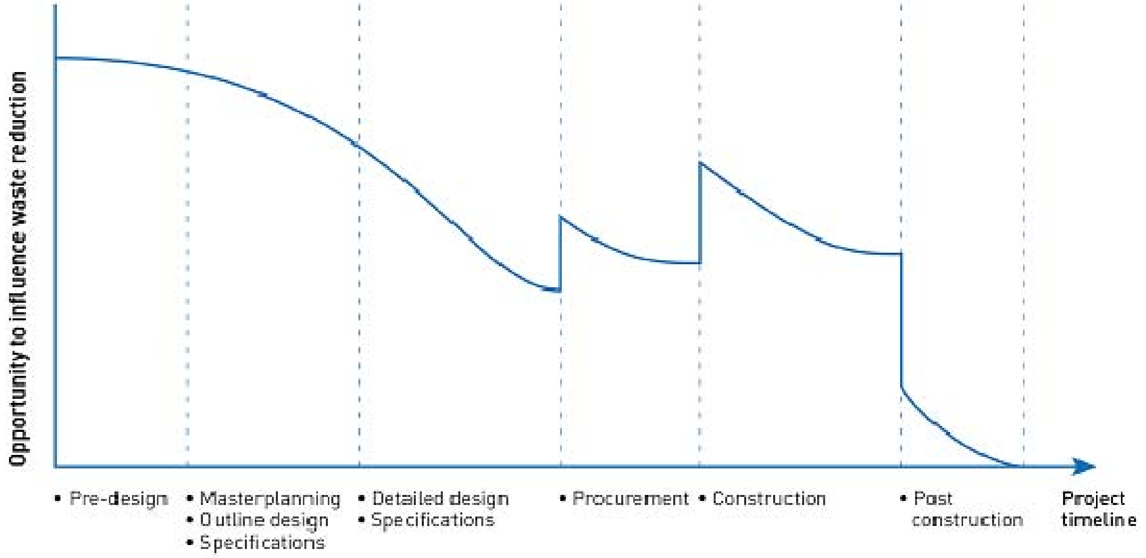
3.4.7 Designing out waste

Designing out waste is a tool, defined as such by the Waste and Resources Action Programme of the UK (WRAP), implemented at the design phase to minimise waste in the whole life cycle of a building. It considers design options suitable to reduce waste in every stage: construction, refurbishment and demolition or deconstruction.

Nevertheless, effective waste minimisation before construction or use phases, actually generating wastes, is not only dependent on the design phase. A good building project inception should be able to identify the main options to reduce waste. WRAP, 2012, considers waste minimisation options during these stages:

- Communication between different teams (e.g. contractor, designer, developer, subcontractors, etc.). Strategies for waste minimisation should be communicated from the very beginning of the project inception and targets should be established in the early stages. Environmental issues during team meetings should always be considered in the agenda.
- Designing out waste means the use of efficient design and planning to reduce the quantity of waste. This section of the document is dedicated to techniques preventing waste during construction and deconstruction.
- Procurement: an optimal material-need calculation is needed in order to avoid excess materials which can be wasted.
- Logistics: efficient logistics to move and to order materials at proper times would be required in order to optimise storage and distribution.

Figure 3.57 shows how these stages integrate in the overall development of a building project: the main opportunities are in the pre-design and design phase, while procurement and logistics during construction are also relevant. Communication best practices should be considered over the whole duration, from building inception to post construction and signing off.



Source: WRAP, 2012

Figure 3.57: Opportunity curve of waste minimisation opportunities during the project life cycle

3.4.7.1 Preventing waste during the design phase

Description

In the building life cycle, wastes are generated from demolition material (of the previous construction on site), damage of materials, off-cuts, design changes, temporary works materials, contamination of clean materials, packaging, etc. Excavated materials and soils can be considered also as wastes if they are polluted or they have to be managed as wastes. According to Osmani et al., 2008, a total of 33 % of waste generation in a construction site is the responsibility of designers' failure to implement waste prevention measures during the design phase. In Table 3.96, the origin and causes of wastes are described and Table 3.97 shows design opportunities identified by WRAP to reduce waste. The identification of opportunities for waste prevention and its implementation are the main scope of this description and are considered as a best practice for building design.

Table 3.96: Origin and causes of waste in a construction site

Origin of waste	**Causes of waste**
Contractual	Errors or incompleteness in contract documents
Design	Changes, complexity, lack of experience of designer, errors, poor coordination
Procurement	Over-ordering, order errors, supplier errors
Transportation	Damages
On-site management planning	Lack of waste management plans, inappropriate planning, delays, lack of material control, lack of supervision
Material storage	Inappropriate storage
Material handling	On-site transportation, inadequate handling
Site operation	Negligence, malfunctions, errors, etc.
Residual	Off-cuts, over-preparation, packaging

Source: Osmani et al., 2008

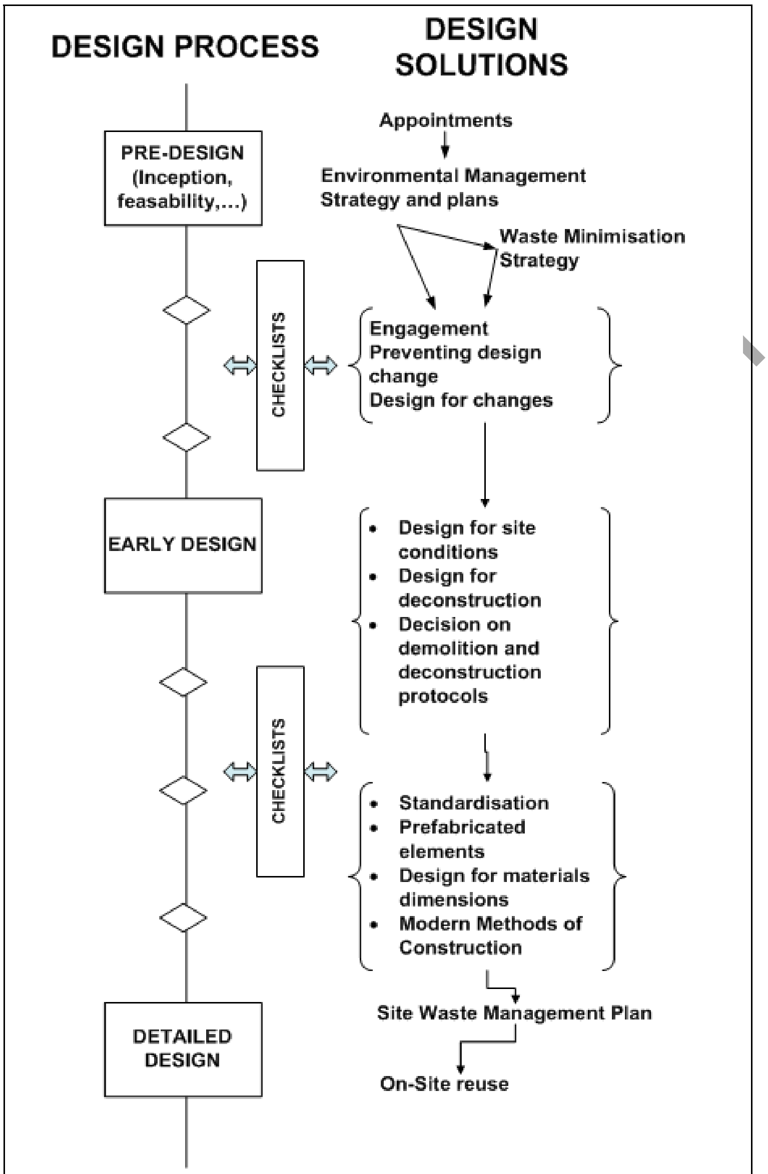
Table 3.97: Waste prevention options in design phase

Origin of waste	**Opportunity to reduce waste through design**
Demolition	Reuse existing structure and design to facilitate building deconstruction at maximum recovery rates
Materials from demolition of previous building	Reuse and recycle materials as aggregates, setting out target for material reuse and recycle on site
Temporary site	Choice of appropriate construction method. Take advantage of existing piling or foundation
Excavated material	Correct foundation depths and earthworks in order to get a zero cut and fill balance
Design change	Be flexible and adaptative in design. Accept changes with environmental benefit during pre-construction, construction and refurbishment. Freeze design and avoid last minute changes, which may increase the amount of material losses
Design inception	Use environmental criteria to define targets on the performance of the building, regarding waste
Design decisions	Use prefabricated elements and standardised design to avoid off-cuts
Off-cuts	Simplify building form to reduce site cutting and use manufacturer dimensions for specific elements
Over-ordering	Produce good estimates of materials requirements. Revise periodically estimation methodology
Damaged materials	Choose material which logistics may be optimised (e.g. just in time delivery)

Source: Adapted from WRAP, 2012

Figure 3.58 shows how the design process can integrate some opportunities (so-called design solutions) identified in the previous table.

One of the most important issues in the designing out waste technique is to identify how changes will be managed. Design freezes are needed in order to fix decisions at milestones, as last minute changes are responsible for a significant amount of waste generation. At the same time, some waste minimisation opportunities are identified during construction processes, so some flexibility on materials selection should be given (e.g. by minimising the range of materials or by defining minimum technical requirements).



Source: WRAP, 2012

Figure 3.58: Design process and solutions: opportunities and steps to reduce waste

In addition to the conclusions from WRAP, Osmani et al., 2008, adopted a more comprehensive view of the designing out waste problem. Four main issues were detected: design issues (as described above), construction techniques, building materials specifications and education. The inclusion of contractual clauses by the client and standardisation of design seems to be essential to reduce the amount of waste. Regarding materials, architects are often reluctant to specify materials with a low environmental impact due to a lack of knowledge about them, the non existence of standards or because of their properties. Education and awareness, on the other hand, seem to produce huge benefits, when all stakeholders are aware of the problem and of the solutions. Here, the flow of information and dissemination of best practices requires commitment from all parts.

Achieved environmental and health benefits

Designing out waste has a strong effect on waste generation during construction. Mainly, it establishes a framework focused on waste prevention and minimisation and puts the waste question on the agenda, so the benefit can be quite intangible for some building projects. Some designing out waste proposed techniques, as modern methods of construction, have huge impacts on waste generation during construction, as off-cuts and concrete handling is avoided. Waste reduction potential of modern methods of construction generate up to 90 % less waste at construction sites, although waste is localised at construction elements manufacturer's site. Table 3.98 shows some examples on waste reduction potential.

Table 3.98: Waste reduction potential of modern methods of construction

Modern method of construction (MMC)	Waste reduction potential
Volumetric building system	70-90 %
Framing systems	40-70 %
Pods	40-50 %
Panel systems	20-60 %
Other MMC	30-60 %

Source: WRAP, 2012

In addition, the impact of design on the decision for setting up waste strategies and plans is also significant. A benchmark for waste diverted from landfill is proposed to be 95 % (see 5.6.2.1)

Appropriate environmental indicators

To control the impact of designing out waste techniques on the environmental performance the main indicator is the amount of waste generated on site. It can be measured in a mass or volume basis. Density is quite variable, so volume seems to be a good unit to control waste management on site, as the manager can easily check the movement of waste containers. Nevertheless, the environmental impact and, thus, the materials efficiency of construction costs should be controlled using a mass basis. Apparent density for several construction and demolition wastes categories is shown below (Table 3.99).

The amount of generated wasted should be controlled per category according to best environmental management practices for monitoring (see 5.6.1.2). The use of relative or specific units (per built m^2 or per mill EUR project value) is usually performed by companies to assess their efficiency on waste generation. Nevertheless, only companies making very homogenous buildings (e.g. a specialised company which only builds schools of a similar size) are able to set benchmarks on this type of indicators. Usually, building construction generates from 100 to 180 kg of wastes per m^2. Demolition or deconstruction projects generate about 1000 to 1500 kg of wastes per m^2 and buildings projects with demolition and construction phases would generate an intermediate amount of wastes according to the mentioned values.

The impact of designing out waste should be controlled by the difference between generated waste compared to the amount of waste generated by a conventional design, estimated according to a robust methodology (see Section 5.6.2.1) and to common indicators, which may depend on contractor practices. The US Green Building Council proposes an indicator for construction waste reduction defined as the quantity of materials diverted from the waste stream divided by total potential waste quantity (GBC –Hardiman, T., 2010).

Table 3.99: Construction and demolition waste apparent density per category

Waste	Category	Apparent density, t/m^3
17 01 Concrete, bricks, tiles, ceramics, and gypsum-based materials	17 01 01 Concrete	1.50
	17 01 02 Bricks	1.25
	17 01 03 Tiles and ceramics	1.25
	17 01 04 Gypsum-based construction materials	1.00
	17 01 05 Asbestos-based construction materials	n.a.
17 02 Wood, glass and plastic	17 02 01 Wood	1.10
	17 02 02 Glass	1.00
	17 02 03 Plastic	0.60
17 03 Asphalt, tar and tarred products	17 03 01 Asphalt containing tar	1.00
	17 03 02 Asphalt not containing tar	
	17 03 03 Tar and tar products	
17 04 Metals (including their alloys)	17 04 01 Copper, bronze, brass	1.50
	17 04 05 Iron and steel	2.10
	17 04 07 Mixed metals	1.50
	17 04 08 Cables	1.50
17 05 Soil and dredging spoil	17 05 03* Soil and stones containing dangerous substances	1.62
	17 05 04 Soil and stones other than those mentioned in 17 05 03	
	17 05 05* Dredging spoil containing dangerous substances	
	17 05 06 Dredging spoil other than those mentioned in 17 05 05	
17 06 Insulation materials	17 06 01* Insulation materials containing asbestos	n.a.
	17 06 02 Other insulation materials	
17 07 Mixed construction and demolition waste	17 07 02* Mixed construction and demolition waste or separated fractions containing dangerous substances	1.25
	17 07 03 Mixed construction and demolition waste other than those mentioned in 17 07 02	

Source: Adapted from CYPE, 2012

Cross-media effects

No cross-media effects on the environment are foreseen on the application of best environmental management practices about designing out waste. The use of modern methods of construction, e.g. precasting, produces less waste, although wastes are generated in the manufacturing plant. According to Baldwin et al., 2009, total generated wastes are 90 % less than casting on site. However, improved logistics would be needed to ensure construction efficiency.

Operational data

Implementation of design principles

For design teams, RIBA published a guideline to help designers identify options for waste reduction (WRAP and RIBA, 2012) based on the five principles of designing out waste (section 3.3.1.4):

- Design for reuse and recovery
- Design for off-site construction
- Design for materials optimisation
- Design for waste efficient procurement
- Design for deconstruction.

RIBA defined five stages, A to E, where to apply designing out waste principles. First stages are more related to appraisal (A) and strategy definition (B). At these stages, the strategy brief is defined and the five principles are adopted and resource efficiency objectives are established. Stage C is the development of the design. Many opportunities come at this stage. Stage D is the finalisation of the design and when many decisions are taken, so detailed proposals are done. Stage E is the technical design of the decisions made in previous stages. In the quoted reference, RIBA provides a full list of key actions that could come into an effective waste reduction, producing significant cots savings.

Architects lack of engagement is a main problem for the implementation of designing out waste techniques. Osmani et al., 2008, conducted a research on the attitudes of architects regarding waste. According to the received answers, it can be concluded that architects and designers do not consider waste minimisation as a priority and they do not even know well the origin of wastes during construction. Also, client involvement and education and training on waste minimisation are key aspects. Many design changes are caused by clients, which may vary orders even during construction, generating a significant amount of waste. ISO 14001 certified architectural firms are not more involved in effective waste minimisation than others. Most architects are not even able to identify that design iss a potential source of waste prevention during construction, directly or indirectly.

Precasting

The precasting of building structure elements allow a reduction in situ casting methods, allowing a less labour intense activity and much less waste on site (Baldwin et al., 2009). Quality of the element is more homogeneous and controllable; there is less dependence on site conditions and weather. Production costs may be higher than cast in situ techniques, but a significant reduction of construction site working time is achieved. At the same time, some limitations on the application of precast elements are identified. For instance, for small buildings it may not be feasible. Some quality certification should be applied off-site, which can constitute a problem for site management. In main urban areas, the low available room for big elements may turn precast elements not applicable to a building. Also, increased logistics efficiency may be required, as the use of pre-manufactured elements is quite different to conventional construction methods.

Precast and prefabricated structural elements can be more expensive than in situ precasting. However, less manpower is needed (about 30 %, according to Baldwin et al., 2009). Less waste are generated, not only because of less cuts on site, but also because of less packaging materials, formwork, pastering stone, sand, steel or timber. At least, 30 % of concrete and 45 % steel materials savings can be achieved. Cost differences may be quite different and may produce differences up to 3 – 5 % of total costs.

Modern methods of construction (MMC)

Under this term, WRAP refers to MMC rather than off-site manufacturing, as new methods may comprise also manufacturing on site. According to WRAP, 2007, key types of MMC and their potential use are shown in Table 3.100.

Table 3.100: Key types of modern construction methods (MMC)

Type of MMC	**Short description**	**Used in**	**Potential use in**
Volumetric modular	Off-site manufacturing of three dimensional modules. Roof and external insulation, roof tiling, brick and block work, etc.	SLA, R, E,H, L, O	
Timber frame	Frames for substitution of concrete	SLA, R , H, L, O	E
Pre-cast panels	Part of panelised building systems, as staircases, roofing, basement, etc.	SLA, R, E, L, O	H, (O)
Steel frame	Substitution of concrete	R	H, L, O
SIPS/SIRPS	Structural insulated panels and prefabricated roof systems	R	H, L
Composite panels	Usually of steel, but also in other materials, displace the use of assembled walls on site	R, E, H, L, O	SLA,
Pre-cast cladding	High value products, usually for symbolic buildings	R, E, H, L, O	
LSF systems	Light steel frame for building façade	SLA, E, R, H, L, O	(H)
Pods	Services integrating building services (plumbery, electricity, etc.) E.g prefabricated kitchen and bathroom pods	SLA, R, E, H, L, O	
Pre-cast structural	To substitute e.g. in situ flooring	SLA, R, E,H, L, O	
Insulating concrete formwork	Formwork for in situ concrete that acts as insulation	R, L	
Tunnel form	It is an efficient on-site manufacturing using off-site techniques. It consists of a formwork that allows contractors to mould on site the external wall, floor slabs and party walls elements simultaneously	SLA	(SLA), R
N.B. SLA: Single living accommodation, R: Residential; E: Education; H: Healthcare, L: Leisure, O: Others (retailer, airport, industry, etc.			

Source: AMA Research as quoted by WRAP, 2007

The influence of construction processes on waste generation is huge. WRAP, 2007, analysed the opportunities for reducing waste through the substitution of traditional methods with MMC (see Table 3.101).

Table 3.101: Identified opportunities to reduce waste per category and per construction method

	Packaging waste							Material waste							
MMC	Wood Pallets	Shrink wrap	Cardboard	Metal tins	Plastic tubs and similar	Plastic bags	Paper	Timber	Concrete	Plasterboard	Panel board products	Sheet or roll insulation	Bricks, tiles	Cement, mortar or plaster	Building services products
Volumetric modular	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
Timber frame	🟩	🟩	🟦	🟦	🟦	🟦	🟧	🟩	🟦	🟩	🟧	🟦	🟩	🟧	n.a.
Pre-cast panels	🟩	🟩	🟧	🟦	🟦	🟦	🟧	🟩	🟧	🟧	▨	🟩	🟩	🟩	n.a.
Steel frame	🟩	🟩	🟧	🟦	🟦	🟦	🟧	🟩	🟩	▨	🟦	🟩	🟧	🟩	n.a.
SIPS/SIRPS	🟩	🟩	🟧	🟦	🟦	🟦	🟧	🟩	🟧	▨	🟩	🟧	🟩	🟩	n.a.
Composite panels	🟧	🟧	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	🟩	n.a.	n.a.	n.a.
Pre-cast cladding	🟩	🟩	🟧	n.a.	n.a.	n.a.	▨	🟩	n.a.	n.a.	n.a.	🟧	🟧	n.a.	n.a.
LSF systems - open	🟩	🟩	🟧	▨	🟧	🟧	n.a.	🟩	▨	n.a.	🟩	🟦	🟩	🟩	n.a.
LSF systems - closed	🟩	🟩	🟩	▨	🟧	🟧	▨	🟩	▨	n.a.	🟩	🟩	🟩	🟩	n.a.
Pods	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟦	🟦	🟧	▨	🟦	🟧	🟧	🟧
Pre-cast structural	▨	▨	n.a.	n.a.	n.a.	n.a.	n.a.	🟩	🟩	n.a.	n.a.	n.a.	n.a.	🟩	n.a.
Insulating concrete formwork	🟧	🟧	n.a.	n.a.	n.a.	n.a.	n.a.	🟧	🟧	▨	▨	🟧	▨	🟩	n.a.
Tunnel form	🟩	🟩	n.a.	n.a.	n.a.	n.a.	n.a.	🟩	🟩	🟦	🟧	n.a.	🟩	🟩	n.a.

N.B. 🟩 Significant reduction 🟦 Limited reduction
🟧 Moderate reduction ▨ No reduction

Source: AMA Research as quoted by WRAP, 2007

Case study

Middlehaven Hotel can be considered one of the best examples in the application of designing out waste concepts (WRAP, 2008). The good results achieved on this construction case are mainly due to the client's involvement in the environmental performance objectives of the whole site during the full life cycle of the building. For instance, biodiversity objectives are considered by minimising the land impact and minimising the amount of soil to be excavated, imported or exported. A waste management strategy was considered from the early stages (during inception phase). Also, communication with all stakeholders in the hotel construction was essential to achieve all the waste management objectives. The main results are shown in Table 3.102.

Table 3.102: Summary of options for costs savings for the Middlehaven Hotel development

Waste minimisation option	Waste savings	Cost of waste materials savings	Waste disposal cost saving
Use of bathroom pods	90 tonnes	15 500	13 200
Volumetric pods	660 tonnes	Unknown	50 000
Pre-cast walls and slabs	700 tonnes	86 825	52 000
Pre-cast columns	36 tonnes	5 290	2 700
Foundations	2 310 tonnes	0	280 000
Total savings	**3 140 tonnes (75 % total savings)**	**107 600**	**350 000**

Applicability

No restrictions on the applicability of designing out waste are foreseen. Some modern methods of construction may not be possible because of the lack of facilities and manufacturing sites or due to insufficient capacity of existing ones. Among the factors identified by WRAP, 2007, for the application of modern methods of construction to prevent waste, some key variables are detected:

- The extent of MMC national markets
- Capacity of industry to meet potential demand
- Uses of traditional construction
- Size of existing end users
- Design trends (e.g. existence of repetitive designs with cellular accommodations)
- Comparative costs
- Economies of scale for construction
- Availability of space for manoeuvrability, storage, accessibility, etc
- Skilled labour

Economics

Table 3.103 shows some examples of the application of construction techniques with low waste generation rates, as prefabricated elements or modular elements. As observed, construction may require less costs (because of time and resources allocation) and less resources consumption may be achieved (so material efficiency is increased).

Table 3.103: Examples of costs savings from reducing waste in design

Building Project	Project value	Construction costs-savings, EUR	Waste disposal costs savings, EUR	Costs savings for materials efficiency, EUR	Total savings, EUR
Colchester and Chelmsford Courts (prefabricated concrete stairwells)	EUR 34 mill	20 470	1 035	14 490	35 995
Quenshill Court (Prefabricated bathroom pods)	EUR 7,8 mill	90 620	3 450	4 945	99 015
Southgate College , modular classroom	EUR 23 mill	60 145	10 465	4 485	75 095
Southgate College , precast concrete columns	EUR 23 mill	46 805	690	23 575	71 070
Tate Modern 2, material reuse for landscaping	EUR 136 mill	89 700	12 880	8 510	111 090
Tate Modern 2, Fair-faced finish internal walls	EUR 136 mill	56 810	460	115	57 385

Source: WRAP, 2009

Driving force for implementation

Key drivers for the implementation may be regulations, as is the case for England and Spain, where site waste management plans are mandatory. Nevertheless, the construction and building design economics could be favoured for saving materials and the reduction of waste. Environmental performance will be increased, less transport would be needed and less CO_2 would be emitted. Reducing the amount of waste can also prepare constructors and designers for future regulations and standards on landfills, waste management and aggregates.

Reference organisations

WRAP is the UK Waste Resources Action Programme. A lot of information can be obtained from their comprehensive knowledge database. WRAP commitment to resource efficiency and waste prevention is divided into seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient
- Recycling organic waste and recovering energy
- Increasing the reuse and recycling of priority products.

RIBA is the Royal Institute of British Architects. They play a role in the communication and education of designers on waste prevention and on the use of recycled material. More information can be found on their webpage, www.architecture.com

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3.4.7.2 Design for Deconstruction (DfD)

Description

Waste from the demolition of constructions can be reduced by increasing the rates of reuse and recycling of building materials and components. Material reuse considerations do not just start when a building reaches the end of its life; improving material reuse should start when a building is designed. Many construction parts most sent to landfill have a reuse value or can be recycled. One obstacle to reuse is that most buildings were not designed for disassembly at the time of their construction. The most important decisions facilitating later deconstruction are made in the first stages of a building's life cycle, i.e. its design and construction stage. Key issues for deconstruction are an easy disassembly of construction elements, and the planning for possible reuses of construction elements or the whole construction (adaptability). Deconstruction and reuse can be significantly facilitated by appropriate assembling (separable joints) techniques that prevent them from being damaged as far as possible. For implementing these rather recent concepts, several challenges still exist: a lack of information and skills, or a large enough market for deconstructed products, existing buildings not designed for dismantling (inaccessible joints, composite materials, etc.), legal obstacles like the allocation of risk and responsibility when using 'second-hand' components, and health hazards (asbestos) (Hurley and Hobbs, 2005).

According to practitioners, the following building characteristics can simplify the dismantling, reducing the time and expense of salvaging the building materials (Webster and Costello, 2005):

- Transparency: Building systems should be visible and easy to identify.
- Regularity: Building systems and materials should be similar throughout the building and laid out in regular patterns.
- Simplicity: Building systems and interconnections should be simple to understand, with a limited number of different material types and component sizes.
- Limited number of components: It is often easier to dismantle structures that are composed of a smaller number of larger members (resistance to damage, removed more quickly).
- Easily separable materials: Materials should be easily separable into reusable components (mechanical fasteners preferable to adhesives, composite materials difficult).

The following general measures are useful for supporting DfD (Hurley and Hobbs, 2005; Scheibengraf and Reisinger, 2006; Shell et al., 2006):

- Making building components easier and faster to remove: in this way it is also easier to adapt or change the building to meet evolving functions over its lifetime, the concept has been called Life Cycle building. Extending the useful life of an entire building is the highest form of salvage and reuse.
- Provide access to building utilities and infrastructure (such as telecom, electrical, and mechanical systems), which are some of the most frequent components needing maintenance or upgrades.
- Record drawings, exposed assemblies, and photographs of utilities before they are concealed behind drywall or ceilings. A deconstruction plan based on the construction process should document the DfD concepts included in the building. Documentation of the building (labelled materials, location plans, instructions for deconstruction), as well as of its changes over its lifetime, is very relevant for decisions in the future in regard to both the form of disassembly and the form of recycling.
- Maximise reuse value of parts at deconstruction: using elements that can be cleaned, maintained and serviced in order to maximise the remaining lifetime in a component when it is removed by deconstruction.
- Designing for reuse of parts after deconstruction: ensure that the element can be removed from the building with as little damage as possible. There is also a distinct connection between design for deconstruction and design for constructability (simplify the construction process, e.g. by prefabrication, modularisation, and simplification of connections and building systems).

- Modular construction and pre-fabricated wall and floor units: their use means that it is both practical and economically feasible to either re-site an existing building or use the components in a new building. Design for deconstruction, however, is not solely an issue for the designers of buildings.
- Flexibility of whole buildings: buildings and rooms should be planned in a way that allows future changes of the buildings purpose, like dividing one large apartment into two small ones (or combining two small ones to one larger), use of standardised elements and square rooms, non-structural walls that can be moved, etc.
- Designing for recycling after deconstruction: the process of deconstruction can significantly increase the likelihood of materials being clean and separable and, hence, better suited to recycling.
- Avoid contamination: for example the use of safe products for fire protection may mean that removal and disposal of potentially hazardous materials make deconstruction uneconomic.

Achieved environmental benefits
See Section 7.3

Appropriate environmental indicators
As the environmental benefit of DfD is only achieved at the time of deconstruction of a building, giving quantitative indicators for these is difficult. The long lifespan of buildings makes it difficult to predict which materials will have salvage value and what technologies will be available to extract materials at the end of the building's life.

For several issues percentages could be calculated (share of separable connections, share of recyclable parts), but without knowing the real future results. In any case it should be checked, that the design recommendations given in 'Operational data' are implemented wherever applicable in a construction project.

Any indication of the amount of wastes or the percentage of material reused and recycled at the end-of-life of the building would measure the performance of the technique, but the time gap between the technique and its benefit is huge.

Cross-media effects
None

Operational data

In the following paragraphs, some recycling and reusing opportunities and barriers of specific building materials are described.

Masonry Bricks. In the past, when masonry buildings were built with solid walls and lime, mortar was used to hold the bricks or stones together, and it was rather easily possible to deconstruct and reuse the building materials. Used brick is one of the most popular materials available in today's salvaged material marketplace. Salvaged brick has a warm and comfortable appearance that is difficult to recreate in mass-produced modern brick. Deconstruction of newer buildings is more difficult, due to the use of more stable Portland cement mortars (and glues or other modern building materials) and cavity walls with block work and wall ties.

Among the barriers for masonry reuse is that the cost of time it takes to take down bricks by hand and stack and clean them for reuse can be enormous. For traditional bricks, tiles and slates there is a market. Cement mortar of modern buildings cannot be cleaned off so bricks can only be recycled as aggregate (Hurley and Hobbs, 2005)

Some of the main issues for DfD of masonry bricks are (Webster and Costello, 2005):

- Avoid Portland cement mortars. No cost-effective technology is currently available to separate the mortar from the brick.

- Consider using lime mortars. Lime mortars have been used for hundreds of years and are regaining popularity, especially for historical renovation projects. Use in new construction should be investigated. Lime mortars generally have adequate strength for use in veneer and bearing wall applications. Durability, water-resistance, and maintenance need to be addressed.
- Avoid using grouted reinforcement.
- Investigate using mechanical fasteners to secure brick masonry in place of mortar.

Concrete. Precast concrete offers greater reuse potential than cast-in-place concrete. Precast often comes in standard sizes and with standard amounts of reinforcement. Precast members are often joined together using mechanical fasteners. One problem is that cast-in-place topping slabs are often placed over precast floor members (Webster and Costello, 2005).

Of the key precast concrete products, masonry blocks, paving slabs and roof tiles all offer excellent opportunities for deconstruction and reuse, as they require no alteration to their design, have no fixtures, fittings or joints and therefore are easily dismantled and reused (they just need an economic market for their reuse). It is possible to recover and reuse flooring units, depending on the type of fixing and jointing used, if an in-situ joint is used then the potential is low. The lack of an economic gain is the main barrier at the present time for the deconstruction of concrete products, besides dimensional (most structures are one-off bespoke designs), physical, or practical barriers. Most commercial concrete buildings are cast in-situ concrete frames and therefore need to be destructively demolished. The concrete elements are therefore unlikely to be reused in their original form, and at best could be crushed down and the steel and crushed concrete recycled (Hurley and Hobbs, 2005).

Some of the main issues for DfD of concrete parts are (Webster and Costello, 2005):

- Avoid cast-in-place members.
- Fasten precast members together with removable, durable, mechanical fasteners. Stainless steel is a good material choice for fasteners. Allow for thermal movement at connections so members do not become severely cracked.
- Develop new systems for connecting together precast plank and tees to replace topping slabs. Removable materials such as plywood on sleepers may be used to provide a smooth sub-floor. In parking garages the precast joints may be left exposed.
- Indelibly label each member. The label should include concrete strength and member reinforcement.
- Consider eliminating basements and below-grade construction where possible. Foundation walls and deep footings are unlikely to be salvageable. Precast slabs-ongrade, precast foundation walls, and shallow precast footings have a greater likelihood of salvage.

Many products can never be reused in their original form and can only be recycled as aggregate, such as (Hurley and Hobbs, 2005):

- foundation units & piles (virtually impossible to remove from the ground)
- pipes and associated products (as above)
- bridge beams & gantries (dimensional, safety/risk and jointing problems)
- frames, beams & columns (as above)

Other physical barriers include (depending upon the type of concrete product):

  - pre- and post-tensioning beam/floors- dangerous to de-stress
  - joints often mortared or glued or tied together with reinforcement
  - block work is usually mortared together (nowadays cement mortars), which therefore requires cleaning
  - concrete ages naturally due to carbonation, weathering, colour change, cracking and chemical effects (such as sulphate attack, alkali-silica reaction and delayed ettringite formation)
  - reinforcements corrosion can occur

  - coatings (either cosmetic or protective) can deteriorate due to ageing, weathering and mishandling

Timber. There are several cases, in which timber can be directly reused. If not, alternatives are the production of wood chips or direct thermal use. Timber components can easily be adapted during construction, for instance by notching and drilling joists for services, but these types of modification turn a generic joist of uniform section into a joist that is tailored specifically for the building it is installed in. Similarly nails, screws and other types of fixing locally damage the timber rendering it in some cases unsuitable for reuse when that component is deconstructed. The suitability for deconstruction of timber products is also determined by the ease with which they can be removed. This often depends on the type and number of connectors used in the construction. Nails and staples for instance are more labour intensive to remove (there are however special handheld denailers([20])), cause more damage to the timber and require a greater number to achieve a sufficiently strong connection. The use of bolts, dowels, screws or pressed metal plate connectors greatly improves the deconstructability of components.

There are many timber products used in buildings that if deconstructed could be reused in new builds or renovations with little modification required. For example, large timber beams, railway sleepers (if not contaminated by preservatives), timber doors, flooring and windows are all currently reused to some degree through the salvage industry. The common link between these products is the high quality of timber or high value of the product which ensure profitability for relatively low volumes of re-sale. Technologies and techniques for deconstructing timber structures, structural elements and joinery still need to be improved (Hurley and Hobbs, 2005).

Some of the main issues for DfD of timber parts are (Webster and Costello, 2005):

- Use screws and bolts instead of nails. New connection techniques are required that lessen wood damage. Industry-standard bolting patterns would be helpful.
- Use robust moisture management techniques to protect wood from decay and insect damage.
- Use timber-frame construction instead of dimension lumber. Avoid fragile members such as engineered wood I-joists.
- Keep services (plumbing, electrical, HVAC) separate from structure.
- Label members with species and grades.
- Consider panelised construction, particularly at roofs, to permit final deconstruction on the ground.
- Avoid adhesives, such as when fastening floor sheathing to joists.
- Use wood preservatives not hindering later reuse.

Steel. It is already common practice not to reclaim, but to recover and recycle steel materials even where they are used with other construction materials such as concrete. For key steel products, beam sections and column sections can be reused where it is economically viable to remove the members without causing significant damage to the connected ends. Concerning direct reuse of steel elements, meeting the requirements for the new application may be an issue. This relates to methods for verifying performance in terms of load carrying capacity and durability. For steel elements, as long as they have not been highly stressed (inelastically) and do not show any visible signs of plastic deformation they are capable of being reused even for structural applications.

There are health and safety implications in working close to connections between beams and columns. Corrosion of existing structural sections may also provide a significant barrier to reuse. On the one hand in terms of strength and stability and on the other hand in terms of an aesthetically pleasing finish, reuse of parts might prove uneconomic (Hurley and Hobbs, 2005).

([20]) For example handheld denailer Nail kicker v20, Price one-driver kit, about EUR 400

Some of the main issues for DfD of steel parts are (Webster and Costello, 2005):

- Use bolted connections. Explore using clamped friction connections.
- Avoid conventional composite floor systems using welded studs and cast-in-place concrete. New systems using bolted or clamped fasteners and precast elements need to be developed.
- Use precast decks.
- Use common shapes and avoid short filler pieces.
- Use regular spacing.
- Mark steel grades and shape designations on members.
- Seek alternatives to spray-on fire-proofing. Although spray-on fireproofing no longer contains asbestos, it is difficult to remove from steel framing and hinders refabrication.

Applicability

In general, the basic principles of DfD can be applied to all new construction projects. Although many of the listed DfD principles are most relevant in the design phase of a building, not all address the same stakeholders. Table 3.104 shows the relevance of DfD aspects for different groups of stakeholders

Table 3.104: Relevance of design principles for different project players

Design Principles	Owners	Architect	Engineer	General Contractor	Specialty Subcontractor	Fabricator Manufacturer	Supplier
Design for prefabrication, preassembly and modular construction		high	high	medium	high	high	
Simplify and standardise connection details		medium	high	medium	high	high	
Simplify and separate building systems		high	high	medium	medium		
Consider worker safety during deconstruction		medium	medium	high	high	medium	medium
Minimise building components and materials		high	medium	medium	medium	medium	medium
Select fittings, fasteners, adhesives and sealants that allow for quicker disassembly and facilitate the removal of reusable materials		medium	high	medium	high	high	high
Design to accommodate deconstruction logistics		high	high	medium	medium		
Reduce building complexity	medium	high	medium		medium		
Design to reusable materials	medium	high	medium	medium	medium	medium	medium
Design for flexibility and adaptability	high	high	medium				

Source: Adapted from Pulaski et al., 2004

Economics

The use of rather high quality materials for durability and separable joints instead of cheaper gluing or nailing increases investment, however later economic benefits from longevity, flexibility for building use and reclaiming of parts are expected. See Section 7.3

Driving force for implementation

The reduction of deconstruction waste is important as legislation will increase construction materials recycling rates and stops landfilling of waste. Reducing the amount of waste can also prepare constructors and designers for future regulations and standards on landfills, waste management and aggregates

Reference organisations

International Council for Research and Innovation in Building and Construction, Task Group 39 on Deconstruction, http://www.cibworld.nl

WRAP is the UK Waste Resources Action Programme. A lot of information can be obtained from their comprehensive knowledge database. WRAP commitment to resource efficiency and waste prevention is divided into seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient
- Recycling organic waste and recovering energy
- Increasing the reuse and recycling of priority products.

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4 CONSTRUCTION PRODUCTS

4.1 Scope

This chapter provides information on existing labels and on environmental criteria concerning several environmentally friendly aspects of construction products selection: the exclusion of certain substances and the improvement of the environmental footprint of construction works through the use of selection criteria. Materials efficiency through better design, less waste generation and enhanced material management at construction sites is described in other parts of this document.

The document describes best practices going beyond current requirements. For instance, the work being done on the harmonisation of indoor air quality criteria for Europe is considered, although the description of best environmental management practices rely on the proactive selection of environmental solutions rather than on policy approaches at Member States.

4.2 Introduction

4.2.1 Verification of the environmental performance of building materials

At a European level, the basic requirements for construction works (i.e. buildings and any other civil engineering construction) are defined in Regulation 305/2011 of 9 March 2011 laying down harmonised conditions for the marketing of construction products. These basic requirements should be employed for the determination of harmonised conditions of construction products. In general, construction products and their separate parts should be fit for their intended use, taking into account several conditions throughout the life cycle of the works. From the environmental point of view, the most important points related to the performance are:

- hygiene, health and environment: construction works should not have an exceedingly high impact over their entire life cycle, on environment quality or on the climate during their construction use and demolition. Special attention has to be paid to the dangerous substances or radiation realising to air, groundwater and other waterways, discharge of waste or polluted water, etc.,
- protection and noise
- energy performance during all life cycle stages, and
- sustainable use of natural resources: construction products should ensure reuse and recyclability of construction works, their materials and parts after demolition, durability of the construction works and the use of environmentally compatible raw and secondary materials in the construction works.

With regardsto the life cycle environmental performance of a building, most of the environmental impact is due to the energy consumption of the building, with a small part coming from the embodied energy of construction materials. Other environmental categories impacts may be quite low compared to the long lifetime of buildings (Mötzl and Fellner, 2011). A special effort should thus be made for the environmental assessment, going beyond just life cycle measurements of the building as a whole.

In this regard, the role of ecolabels to verify the environmental performance of construction products is relevant, as they can provide reliable information to be checked against pre-established criteria. These criteria may even be used in tendering procedures (EC, 2008) for construction products, given the following conditions:

- requirements for the label are based on scientific information
- the label is adopted with the consensus of stakeholders (government bodies, consumers, manufacturers, distributors and environmental organisations)

- all the information concerning environmental performance is accessible to all interested parties.

To understand the role of ecolabels, it is recommended to follow the definitions of International Standards Organisations definition under ISO 14024 for type I environmental labelling for ecological trademarks and ecologos. Key criteria are the reliability of information, the transparency of the administrative procedures of the scheme and the existence of a formal process of consultation with stakeholders. According to the ISO definitions, there are three types of eco-labelling:

- Type I labels. This is the most useful for establishing environmental criteria for products. Products are labelled based on the environmental impact of these life cycles. This is assessed by an independent body and monitored according to a certification process.
- Type II labels. These are environmental claims made for products by their manufacturers and/or suppliers. No third party verification is usually done and these do not use pre-determined criteria.
- Type III labels. These are informative labels, giving the more relevant life cycle information about a product. A score is given by a third party verifier. So, the result from type III labels can be used to make comparisons and to establish rankings or help choose the most environmentally friendly. A type III label does not identify a product having an improved environmental performance. Environmental Product Declarations are a type III label.

Type I and Type III labels may be very useful for the selection of environmentally friendly products. Both provide independently verified information on the environmental characteristics of products. However, only type I ecolabels can reflect products with an enhanced environmental performance. Type III labels, such as EPD, do not indicate minimum performance standards, and bearing a type III label does not provide direct indication on environmental performance (EC, 2008)

Usually, best practices on materials selection have a large number of parameters to be controlled. In Section 4.3.1, some indications on ecolabels and environmental criteria are given.

In general, three recommendations can be made to improve the environmental performance of materials:

- reduce the load of materials by optimal design, avoiding excessive materials consumption
- exclude hazardous substances
- use type I label awarded products or establish benchmarks of excellence in the performance of a product's life cycle.

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4.2.2 Finishings, facilities, interior fitting

Herein, some background information on the performance of finishings, building facilities and the indoor environment is given.

Indoor air quality

According to some studies, European citizens spend over 90 % of their time inside buildings. Health and comfort-related problems and illnesses occur in more than 40 % of these enclosed spaces (ECTP, 2007). These issues related to the quality of the indoor environment also lead to a reduced efficiency at workplaces, which has direct effects on many economic sectors. The main parameters for health and comfort of people in enclosed spaces are manifold:

- indoor air quality (incl. smell)
- room temperature and humidity
- volumetric open air current and wind speed
- lighting and noise immission
- perceived aesthetics (materials colour, etc.).

Whereas immissions in the outside air are regulated, fewer regulations for indoor air quality exist. An exception are working areas, in which air pollution arises from technical production processes, which are regulated by provisions of industrial law. Pollutants from different sources are often present in interior rooms, carried by the outside air or from sources within buildings. Table 4.1 gives an overview of possible indoor air pollutants, which may be caused by building products and equipment.

Table 4.1: Common indoor air pollutants and their sources

Substance	Source (building products and equipment)
Dust	Abrasion of floors, insulating materials, processing of building products
Carbon monoxide	Defective or poorly ventilated heating equipment
Radon	Subsoil
Formaldehyde (HCHO)	Wooden materials (fibre boards), acid-hardening varnishes
Volatile organic compounds including • alkanes • aromatic compounds • aldehydes (HCHO), ketones • ester • alcohols • terpenes • glycols • chlorinated/brominated/fluorate hydrocarbons	Products containing solvents, such as paint and varnishes, floor adhesives, carpets especially the so-called ‘biocolors’ wooden materials Paint stripper, flame retardants (electronics)
Softening agents	PVC-floors, PVC-wallpapers
Biocides	Wood preservative
Polycyclic aromatic hydrocarbons (PAH)	Screed topping, tar-based floor adhesives

Source: adapted from BBSR, 2009

Assessment scales are available for only a few of the numerous substances that can cause indoor air pollution. Table 4.2 lists guideline values (data from 1999) and provides orientation for the assessment of indoor air pollutants.

Table 4.2: Guideline values for the maximum levels of indoor air pollutants (proposed by the Indoor Air Hygiene Commission IRK/AOLG1 in 1999)

Substance	Immediate measures to be taken (mg/m^3)	Target value for remedial works (mg/m^3)	Source
Toluene	3	0.3	Sagunski, H.: Guideline Values for Indoor Air; Toluene. Federal Health Department Bulletin 39 (1996) 416 – 42
Nitrogen dioxide	0.35 (1/2 h) 0.06 (1 week)	-	Englert, N.: Guideline Values for Indoor Air: Nitrogen Dioxide.Federal Health Department Bulletin 41 (1998) 9 – 12
Carbon monoxide	60 (1/2) 15 (8 h)	6 (1/2) 1.5 (8 h)	Englert, N.: Guideline Values for Indoor Air: Carbon Monoxide. Federal Health Department Bulletin 40 (1997) 425 - 428
Pentachlorophenol	1 µg/m^3	0.1 µg/m^3	Federal Department of Environment and Natural Resources: Guideline Values for Indoor Air. Pentachlorophenol. Federal Health Department Bulletin 40 (1997) 234 - 236
Dichloromethane	2 (24 h)	0.2	Witten, J.; Sagunski, H. and Wildeboer, B.: Guideline Values for Indoor Air. Dichloromethane. Federal Health Department Bulletin 40 (1997) 278 - 284
Styrene	0.3	0.03	Sagunski, H.: Guideline Values for Indoor Air: Styrol. Federal Health Department Bulletin 41 (1998) 392 - 398
Mercury (metallic Hg-vapour)	0.35 µg/m^3	0.035 µg/m^3	Link, B.: Guideline Values for Indoor Air: Mercury. Federal Health Department Bulletin. Health Research - Health Protection 42 (1999) 168 - 174

N.B. *Source*: adapted from BBSR, 2009

Other recommended limit values for indoor air (BBSR, 2009):

- TVOC (Total Volatile Organic Compounds), (Seifert, 1999):
  - 10 – 25 mg/m^3 temporarily
  - 1 – 3 mg/m^3 longer stay
  - 0.2 – 0.3 mg/m^3 long-term average.
- Formaldehyde: In 1977 the German Federal Department of Health (BGA) recommended a value of 0.1 ppm (0.12 mg/m^3) for interior rooms. This value is reflected in the regulation on the prohibition of chemicals dated 14.10.1993 as the equilibrium concentration in the air of a test room; the regulation refers here to coated and non-coated wooden materials (chipboard, tabletop, veneerboard and fibreboard).
- Carbon dioxide (CO_2): The amount of CO_2 should not exceed 0.15 %. It is recommended as a hygienic guideline value for indoor air (for seated or light activity in rooms with ventilation and air-conditioning systems).
- Polychlorinated Biphenyles (PCB): Values recommended by the German Federal Department of Health (BGA) in 1990:
  - Indoor air concentrations of < 300 ng/m^3 are considered to be tolerable long-term levels.
  - Where indoor air concentrations between 300 ng/m^3 and 3000 ng/m^3 occur, the sources have to be traced and where reasonable these are to be removed or at least attempts are to be made to reduce the level of PCB concentrations to a target value of 300 ng/m^3.
  - Where PCB-concentrations > 3000 ng/m^3 occur, control analyses have to be carried out immediately.

Volatile organic compounds (VOCs) are organic chemical compounds that can have negative impacts on the environment and human health. They are traditionally used as solvents in paints and glues, also to some extent such solvents are also released to indoor air from (new) products such as carpets or furniture. Off-gassing may continue for months or even years even though the paint or other product has dried.

A primary goal in the creation of healthy buildings is to generally reduce the overall amount of VOCs. Tipically, they are not acutely toxic but have chronic effects. Exposure to VOCs can worsen asthma symptoms and cause nose, skin and eye irritation, headaches, nausea, and respiratory problems. Concerning their sources, neurotoxic toluene often comes from polyurethane foam insulation, with other potentially carcinogenic and respiratory-irritant VOCs coming from paints, glues, finishes and carpets; formaldehyde is often found in pressed-wood products and wood finishes; and finally phthalates, which have been linked to reproductive problems, obesity and asthma, can be emitted from polyvinyl chloride (PVC) pipes and floor tiles. Since many people today spend most of their time within buildings at home or in an office, long-term exposure to VOCs in the indoor environment can contribute to sick building syndrome, in particular if air is not sufficiently exchanged, e.g. as a result of improved air-tightness.

Poor indoor air quality can also be caused by biological contaminants, such as mould that grows as a result of moisture infiltration, due to e.g. inadequate ventilation, poor design and maintenance, and other factors.

Dust, another major source of air pollution inside homes, can be reduced by installing permanent front door walk-off mats and by using hard surface flooring materials such as natural linoleum, bamboo, wood or wood alternatives, or concrete and regular wet-cleaning.

Concerning issues of indoor air pollutants, different priority of clean air can be considered depending on the use of the building: the highest priority for clean indoor air exists in residential buildings (including industrial or commercial buildings refurbished as loft apartments). The most sensitive groups (pregnant women, small children) may stay in these buildings for up to 24 hours per day. Second priority buildings for clean indoor air are other buildings with permanent occupancy suh as hospitals, nursing homes, and schools with daytime occupancy. Lowest priority for air indoor quality issues are office buildings and other buildings with limited part time occupancy (CRTE, 2009).

Paints

Paints are liquid or liquefiable compositions, which are applied to surfaces in a thin layer for their protection and for decorative reasons. After the solvent has dried, a solid film remains on the surfaces. Volatile organic compounds (VOCs) are organic chemical compounds traditionally used as solvents. Once applied, they aid the paint in rapidly drying from a liquid to a solid by evaporating (off-gassing). The ‘clean’ smell of new conventional paint is vapours being released from the solvents. They are especially problematic for indoor air quality, as due to the more or less quick (often several weeks to several months) off-gassing of VOC from buildings or interior fitting, indoor pollutants concentration can reach high levels.

Many different kinds of paints exist; in Section 4.3.1.2 an overview of the main types used in construction is given. The type of paint has to be adapted to the specific application characteristics (interior/exterior, surface, wear, etc.), but in many cases environmentally friendly options are more available than conventional. Selecting products with a generally accepted ecolabel may be recommended regarding indoor air quality, as these paints are checked for hazardous ingredients and low VOC content.

Wood Preservatives

Wood preservation includes all measures that ensure the long life of wood and wood products, generally by increasing their durability and resistance from being destroyed by insects or fungus. Apart from structural wood preservation measures, there are a number of different (chemical) preservatives and processes that can extend the life of wood, timber, wood structures or engineered wood. Concerning the exterior use of wood products, several design decisions can help avoid permanent moisture of wood parts (e.g., leaving air space for ventilation). For wood parts in buildings that are already affected by insects, thermal treatment (heating the room/attic to 80 -100 °C) are an environmentally friendly option.

Wood product applications are divided into different risk classes (for example German DIN 68800-3), with several naturally durable woods (e.g., black locust) being suited for quite high risk classes without chemical treatment (Table 4.3).

Table 4.3: Risk categories of timber following DIN 68800-3

Wood risk category	Conditions of use	Type of threat
0	interior construction part, always dry	-
1	construction parts, dry, relative air humidity up to 70 %	Insects
2	interior construction part, relative air humidity at times over 70 %, condensate and exterior construction parts without intimidate weather stress	Insects and fungi
3	exterior construction parts with weather stress	Insects, fungi and leaching
4	timber construction parts in constant earth or fresh water contact	Insects, fungi, leaching and soft rot

Source: Adapted from CRTE, 2009

As most chemical wood preservation products contain substances with possible negative health effects, wood products intended for interior use (wall panels, floor covering, and furniture) shall not be treated at all with these products, especially in case of residential or other permanent occupancy buildings. It can be said that all chemicals for wood preservation have some negative environmental impacts (e.g. emission of VOC, hazardous salts that can be washed out, biocides that are slowly released to the environment), so their use shall be limited as much as possible, (with few exception with a technical justification) and several general measures should be respected:

- Wood shall only be utilised for construction when it is fully dry; protection against moisture during the use phase is advised.
- The risk class of the wood to be protected has to be determined beforehand.
- Some substances such as chromates shall be avoided.
- Skin contact shall be avoided during application, spraying is not recommended.
- The used products shall be documented, to support later deconstruction and recycling.
- Organic products shall not be used for interior application.

Adhesives

In general, the adhesives used in construction activities can be divided into several types: dispersion, adhesives, (wheat) paste, solvent-based adhesives, polyurethane adhesives and epoxy resin adhesives. The differences between dispersion adhesives and solvent-based adhesives are espcially significant from a environmental and health point of view. Wheat past is an old adhesive with special application areas, polyurethane and epoxy resin adhesives are new adhesives also for special applications. Table 4.4 summarises the major characteristics of these groups of adhesives.

Table 4.4: Properties off different types of glues

	Dispersion glue	(Wheat) paste	Solvent-based glue	Polyurethane glue	Epoxy glue
Hardening mechanism	physical			chemical	
Binding agent	various	starch/cellulose	various	polyurethane	epoxide
Binding type	cold binding				
Form of delivery	one-part adhesive			one or multi-part adhesive	multi-part adhesive
Mechanical properties	basically plastomer			plastomer, duromer and elastomer	
Application in construction	universal	breathable wallpapers	increased demands	increased demands	special applications

***Source*: CRTE, 2009**

The choice of a suitable adhesive depends on the material (e.g. floor covering) to be glued to a surface and the surface itself, as well as on the expected load or wear of the connection and on specific local conditions. The composition and, thus, the environmental impacts of glues can vary quite widely.

A classification of adhesives for floor coverings in three emission classes has been done by the German Association of Adhesive Industry 'Industrieverband Klebstoffe e.V.' using the EMICODE label (cf. 0) (EMICODE, 2010)

The emission class is determined by the summed TVOC emission, so medium and low volatility compounds can be measured. These slowly evaporating compounds are the main determinants for the long-term emission characteristics and indoor air pollution.

In the selection of adhesives, some recommendations are given:

- Prefer mechanical fixing to adhesive bonding (loose laying with double-sided adhesive tape, afloat laying with gluing just on the sides or mechanical fixation with nails, bolts)
- Prefer dispersion adhesives
- Emission classes should be considered and low classes should be chosen
- Use low-VOC products (70 g/L or less) in place of standard adhesives and caulks for all interior applications, such as the installation of flooring, countertops, trim, wall coverings, panelling and tub/shower enclosures.

Other interior finishing materials

Cleaning efforts and environmental impacts can be reduced by use of smooth surfaces and largely uniform materials. The use of glass materials often leads to higher cleaning efforts and thus environmental impacts.

Wallpapers have a strong environmental impact during production (e.g. preference for recycled paper products). The content of pollutants, such as heavy metals or formaldehyde, is high. Choosing products bearing a recognised ecolabel is recommended for assuring quality and sustainability of the product (recyclability, absence of problematic chemicals, etc.).

Generally, wood products performance can be certified by several certification schemes, such as that the Forest Stewardship Council (FSC) or other generally recognised organisations in order to assure its sustainable production and tropical woods should be avoided. The FSC certifies that the wood in a product has been responsibly produced. Key FSC principles include the protection of forest watersheds, soil and indigenous species; restricted chemicals use and limits on genetic engineering; giving local populations influence over forestry operations; and upholding fair-labour policies.

High quality dimensional lumber in long lengths can often be salvaged from old buildings. Using this reclaimed/recycled wood (FSC certification or source relevant here too) is an environmentally friendly option for souricng non-structural parts saving natural resources. Generally, wood products (including furniture) treated with natural materials or made from untreated wood is recommended for environmental and health reasons.

The use of different kinds of engineered wood (also called composite wood) can increased performance parameters of wood products and reduce wood consumption. These include a range of derivative wood products which are manufactured by binding together the strands, particles, fibres, or veneers of wood, together with adhesives, to form composite materials. For example, finger-jointed materials are resource-efficient engineered materials, which are straighter and more stable than solid-sawn studs. They are manufactured from short pieces of clear wood glued together to create a finished material. Elements from this material are straighter and more stable than conventional clear wood, and use wood more efficiently, as solid sawn studs may have weak spots and may twist and warp.

Rapidly renewable trim materials such as straw-based MDF and bamboo plywood or laminate are durable alternatives to wood-based MDF and solid wood for interior trim, and reduce pressure on harvest forests. Bamboo is as durable as most hardwoods.

However, for all composite materials, the used glues and chemicals should be friendly to the environment and human health. Especially, formaldehyde glues (made of urea and phenol), often used as a binder in home-building products, should be reduced in interior finishes. A classification system for wood products concerning formaldehyde emissions exist (EN 13896: class E1: < 0.1 ppm, class E2: < 1 ppm (boards of this class may not be sold in Germany), class E3: < 2.3 ppm (boards of this class, i.e. > 1 ppm may not be sold in Europe).

For furniture that requires cushioning, foamed material is not the best option, as foam emits off-gases over time. For beds, sofas etc., the recommended options are cotton padding, latex, or kapok or furniture designed ergonomically to reduce the need for foam. Buying furnishings assembled with toxic epoxies, stains, paints and varnishes or fabrics (perfluorated hydrocarbons) should in general be avoided.

Floor Covering

Floor coverings can be classified according to different characteristics, e.g. application area (residential, office or industrial buildings), resource type (mineral, renewable, fossil), chemical composition (organic, inorganic) and product conditions (textile, elastic, hard). The important properties of floor coverings are density, hardness and fire classification, as well as noise and thermal conductivity. Table 4.5 shows different wear classes for floor coverings.

Table 4.5: Wear classes for floor coverings

Application area	**Residential**			**Commercial**				**Industry**		
Wear	**moderate**	**normal**	**high**	**moderate**	**normal**	**high**	**Very high**	**moderate**	**normal**	**high**
Wear class	**21**	**22**	**23**	**31**	**32**	**33**	**34**	**41**	**42**	**43**

***Source*: CRTE, 2009**

Environmental performance indicators, as well as more details (application, operational data…) about different types of floor covering are given in Table 4.18.

General recommendations for selecting floor coverings (EC, 2010. CRTE, 2009) are to:

- Prefer domestic (European) woods. Select wood from sustainably managed forests (e.g. FSC).
- Choose floor coverings according to the wear class for the particular application. Use durable, low maintenance products.
- Use solvent-free or low-solvent adhesives (see chapter adhesives).
- Prefer mechanical fixing to adhesive bonding (loose laying with double-sided adhesive tape, afloat laying with gluing just on the sides or mechanical fixation with nails, bolts).
- Plan laying in such a way that a destruction-free reopening and reuse is possible.
- Apply surface treatment as far as possible already at the factory level since the factory is better equipped to collect the emissions.
- For elastic floor coverings, a high traceable product quality should be ensured, which should normally lead to low emissions during the utilisation phase.
- Clean and care of floor coverings during the utilisation phase can produce emissions; environment-friendly processes should be applied here.

The EMICODE label (EMICODE, 2010) gives some guidelines for selecting textile floor covering installation material, these include:

- The flooring installation product should meet all the legal requirements, especially regarding to chemicals content and specifications.
- The flooring installation product should be solvent free (occupational health).
- Carcinogenic, mutagenic, reprotoxic substances, as well as those substances under suspicion to cause such defects, are not permitted to be used in the manufacturing of the flooring installation product.

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4.3 Best environmental management practice in the selection of construction products

4.3.1 Building materials

4.3.1.1 Selection of environmentally friendly products

General guidelines

This description does not follow the conventional standard description scheme, as it is providing basic information on environmentally friendly selection of materials as best practice. Examples from other sectors may be used here: front-runners from the retail sector (EC, 2011) are able to implement several best practices such as:

- Integrate supply chain sustainability into business strategy and operations.
- Assess core product supply chains to identify priority products, suppliers and improvement options.
- Identify effective product supply chain improvement mechanisms.
- Choice editing and green procurement of priority product groups based on third party certification.
- Enforce environmental requirements for suppliers of priority product groups.
- Drive supplier performance improvement through benchmarking and best practice dissemination.
- Collaborative research and development to drive widespread supply chain improvement and innovation.
- Promote front-runner ecological products.

The business approach taken by retailers is, of course, different, but techniques to be applied can be quite similar. The application of best environmental management practices to the supply chain should not only involve choosing products with an Ecolabel. Best practitioners in the construction sector should be able to prioritise product groups according to their environmental footprint, to work with suppliers and identify improvement options, to establish green procurement mechanisms and to participate in research projects to develop innovations with environmental improvement options.

Main barrier for the application of best practices aimed at reducing the environmental impact of construction works through more environmentally friendly products is the complexity of the decision making for materials procurement. Since the main responsibility lies with the project developer, material selection is usually performed by designers. It is usual that a certain degree of freedom is given to contractors. Common practice is primarily based on budgetary restrictions, making the uptake of environmentally friendly measures in the supply chain difficult.

A materials resource efficiency best practice in construction has two variables that designers, construction companies, clients and relevant stakeholders (WRAP and RIBA, 2012) will have to take into account:

- Material selection. Here, resource efficiency should be achieved by applying the following concepts (in priority order)
    - Use local construction and demolition waste
    - Use materials with high recycled content
    - Use renewable materials from sustainable sources
    - Specify materials from sustainable sources
- Waste management, achieved by applying the following concepts (priority order):
    - Prevent waste
    - Minimise waste (reuse-and seggregate)

  - Return surplus materials
  - Recycle
  - Recover heat content

Concepts related to waste management is already covered in several sections of this document (i.e. sections 3.4.7, 5.6.2.1, 5.6.2.2, 5.6.2.3, 5.6.2.4 and chapter 7)

These two aspects of resource efficiency are covered by many building environmental assessment methodologies. Usually, a bigger significance of waste management is given to the construction phase, although most of the schemes also provide relevance to designing out, preventing measures and materials efficiency.

When assessing the environmental performance of construction materials, it should be considered best environmental management practice to minimise the environmental impact of construction products according to a priority scale for several categories. These materials categories can correspond to different product families, as it is usually done in product labels or for building components selection.

Materials families bearing existing ecolabels include (non exhaustive list):

- Concrete
- Mortar
- Cement
- Bricks
- Paints
- Varnished
- Adhesives
- Wood
- Tiles
- Plasters
- Insulation
- Linoleum,

There are several prioritisation methodologies for materials. In general, total environmental impact should be the main criterion, which is related to the total mass used and the specific impact taking into account results from life cycle assessment. Also, economic criteria can be used to establish priorities, e.g. choosing those ecolabeled products with a low impact on final costs.

Some examples of labels for construction products are shown within this chapter. These labels would help in choosing environmentally friendly products. In some European regions there is a lack of labels to identify environmentally friendly products. Also, the low ratio between the price and weight of the main mineral based construction products make transport costs relatively important. The lack of accessibility to proven, third party verified, environmentally friendly products is a main barrier for constructors to improve their supply chain. The environmentally friendliness of used materials needs, in these cases, a proactive approach from developers, clients or contractors, to use environmental criteria can be used in the selection of materials. An example of a set of environmental criteria for concrete construction blocks, proposed by NaturePlus, is shown in Table 4.6. A proactive approach could identify easily achievable environmental improvements in the supply chain of construction products, and should seek for third party verification of criteria. In fact, transport distances involve a significant associated level of greenhouse gases emissions, which can set a maximum distance for deliver or its application would need extra compensation measures. Also, recycled content can be easily checked and proven with supply chain stakeholders.

Table 4.6: Description of some Nature Plus requirements for concrete blocks and elements

Category	**Description**
Functional suitability	Check the technical feasibility of the product according to standarised building block elements. Also, an increase of acoustic insulation should be achieved.
Composition, Forbidden Substances, Substance Restrictions	Polymer and hydrophobic additives should be less than 5 %. Also, organic carbon and absorbable organic halogen compounds will be tested according to the criteria of section 3. No specific criteria is established for recycled content.
Raw material sourcing and manufacturing	Standards are set for the manufacturing process: dust particle emissions, sulphur oxides, carbon monoxide and nitrogen oxide contents. Hazardous materials are forbidden (if cement content is higher than 5 %) and cement has been produced according to energy efficiency standards. For instance, the consumption of non renewable energy source of the life cycle of cement should not be higher than 1900 MJ per m^3
Usage	Heat capacity of concrete should be less than 1.50 kJ/kgK if it is planned for heat storage. It should not contain chromate or increased radioactivity levels. Also, mortar to be used with blocks should fulfil several criteria on the content of volatile organic compounds, some additives are forbidden.
Recycling and disposal	It should fulfil the requirements to be disposed or recycled as inert material
Laboratory tests	Limits according to standarised testing methods (DIN/ISO) are established for metals, eluate, organic compounds content, radioactivity, and for the quality of thin-bed mortar (VOCS).

N.B. *Source*: Nature Plus, 2011

Another suitable approach is to use comprehensive assessment methods based on life cycle measurements on the environmental performance of building elements. For instance, the British Code for Sustainable Homes establishes a scoring system for different elements of a building (CSH, 2010):

- Roof
- External walls
- Internal walls (including separating walls)
- Upper and ground floors (including separating floors)
- Windows.

Here, a score of 15 points, maximum, is awarded to the environmental performance of products, which is weighed according to the mass balance of each element. The performance of used products is taken from the Green Guide calculator of BRE. This database provide a ranking, A+ to E according to a weighing methodology (BRE, 2007), taking into account the full environmental footprint of the element.

The score for materials performance can be used to drive improvements in materials supply. Nevertheless, the use of comprehensive assessment dilutes the effect of best environmental management practice. Table 4.7 shows the total credit balance, the weighing factor for the BREEAM assessment and the approximate weighed value of each credit (CSH, 2010). Materials credit (accounting for responsible sourcing and environmental friendliness) is weighted as 0.3 of final score, while energy and CO_2 emissions account for 1.17. So, materials improvement should be driven by specific commitments on the use of labels or criteria.

Table 4.7: Credits per category and the approximate value of each category credit in the final score.

Category	Total Credit	Weighing factor (% points contribution)	Approximate weighed value of each credit
Energy and CO_2 emissions	31	0.364	1.17
Water	6	0.09	1.5
Materials	**24**	**0.072**	**0.3**
Surface Water Run-off	4	0.022	0.55
Waste	8	0.064	0.8
Pollution	4	0.028	0.7
Health and Well-being	12	0.14	1.17
Management	9	0.1	1.11
Ecology	9	0.12	1.33

Source: BRE, 2007

Other comprehensive assessment methods use combinations of a scoring system and the use of ecolabels to drive improvement of the environmental performances of materials. The LEED Home (USGBC, 2010) approach, for instance, seems more convenient since this system:

- establishes minimum requirements for waste factor of materials (establishing materials efficiency as a rule)
- awards designing out waste practices, as the use of prefabricated elements
- establishes minimum requirements for ISO 14024 type I labels, as FSC
- awards the use of recycled and/or reclaimed products (although the threshold value seems low, 25 %)
- establishes VOC contents to minimum achievable values
- requires construction management planning to avoid waste
- takes diversion from landfill of construction waste as a criterion for materials (with a benchmark of excellence in 88 %).

The proactive goal of environmental improvement also includes that excavated natural materials from quarries can also be labelled or selected according to their environmental performance. Quarries for limestone, sand, gravel and other materials have usually a large impact on the surroudings, especially on local biodiversity. So, for natural extracted material, special attention should be given to the reclamation and/or compensation measures that would produce a net gain on biodiversity. Table 4.8 shows several examples provided for this document.

Table 4.8: Biodiversity reclamation activities in exhausted quarries

Example	Location	Description of recovery practices
Limestone quarry reclamation	Brno, Czech Republic	Habitat creation (use of steppe plants from surroundings, coverage of waste, creation of water-holes, etc.)
Grange Top quarry, bat cave	Ketton, UK	Artificial bat cave: use of old stone mine next to working area, with collaboration of quarry managers. Temperature profiles and bat activity monitored since construction
Gravel pit restoration	Durmersheim, Germany	Activity management by quarry managers, improving habitats and monitoring. Measures since the extraction was stopped: removal of soil for the creation of succession areas, measures against the spreading of invasives species, repressing the succession of some species.
Quarries restoration	Several	Creation of nesting aids for the peregrine falcon in quarries
Mixed deciduous forests	Schelklingen, Germany	Restoration of mixed deciduous forest by sowing
Sand, gravel pits	Several	Creation of natural and artificial nesting aids for birds in gravel pits

N.B. *Source*: Hammerl, 2011

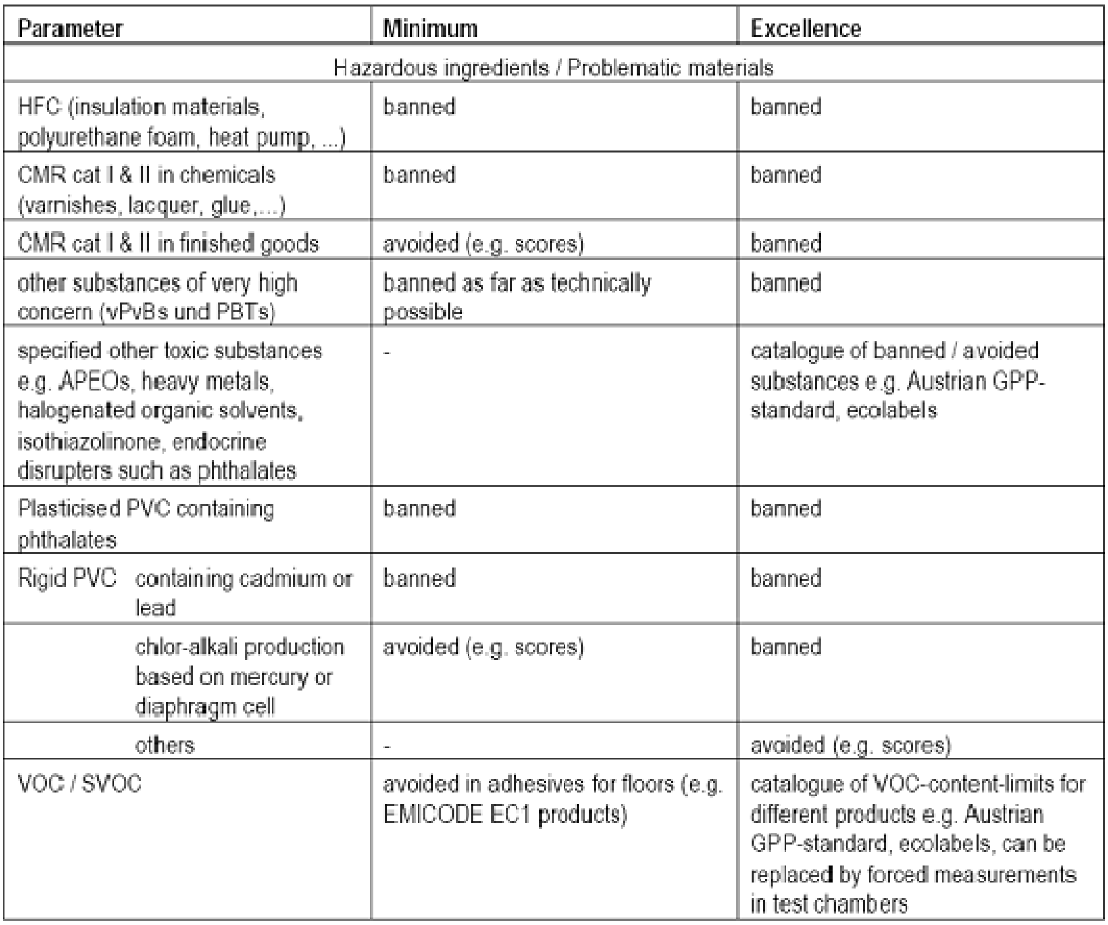
Environmental criteria in labels seek for best indoor air quality, which is very important for indoor finishing products (floor covering, paints, treated wood, boards, etc.). Mötzl and Fellner, 2011, reviewed the environmental criteria for chemical products in building materials and indoor air. Special care should be taken with several product families with regards to indoor air quality:

- Wood panels
- Timber structures
- Resilient, textile and laminated floor coverings
- Wood flooring
- Flooring adhesives
- Decorative paints and varinishes
- Wall-coverings (wall papers)
- Adhesive
- Sealings
- Bitumen coatings and adhesives.

These categories correspond to the main materials to be considered in the improvement of indoor air quality. There is harmonisation of the testing of volatile organic compounds, VOC, and mandatory labelling exists in Germany (AgBB) and France (AFFSET), but, still, it is not possible to prescribe low emissions products.

Below, Table 4.9 and Table 4.10 are taken from Mötzl and Fellner, 2011 and show some recommendations concerning the use of chemicals and some indications on the evaluation of the emissions from building materials.

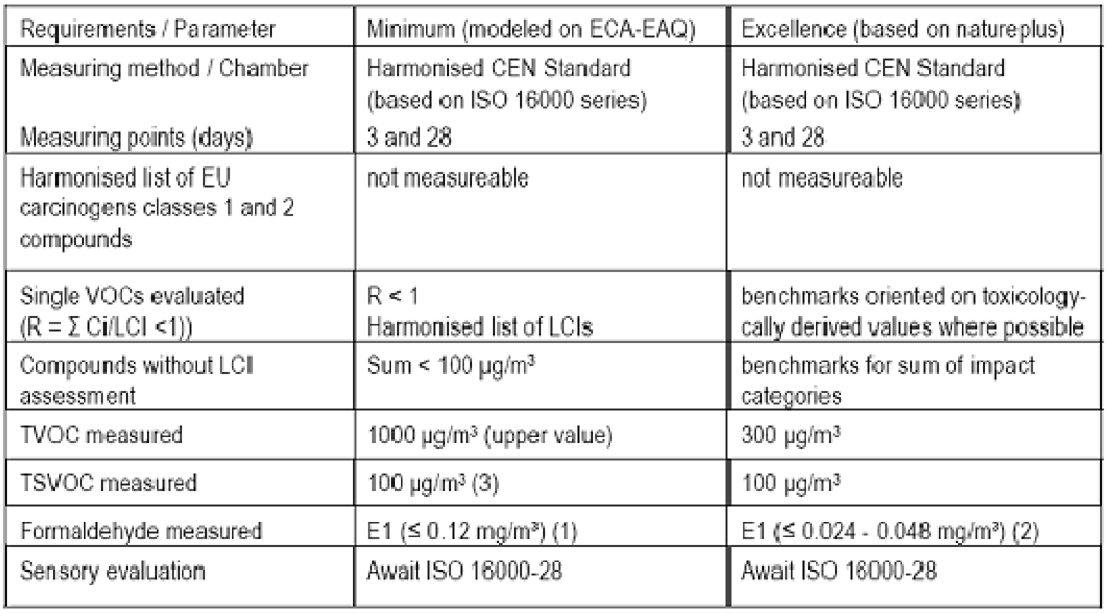
Table 4.9: Recommendations of the authors concerning the use of chemicals in building materials



Parameter	Minimum	Excellence
Hazardous ingredients / Problematic materials		
HFC (insulation materials, polyurethane foam, heat pump, ...)	banned	banned
CMR cat I & II in chemicals (varnishes, lacquer, glue,...)	banned	banned
CMR cat I & II in finished goods	avoided (e.g. scores)	banned
other substances of very high concern (vPvBs und PBTs)	banned as far as technically possible	banned
specified other toxic substances e.g. APEOs, heavy metals, halogenated organic solvents, isothiazolinone, endocrine disrupters such as phthalates	-	catalogue of banned / avoided substances e.g. Austrian GPP-standard, ecolabels
Plasticised PVC containing phthalates	banned	banned
Rigid PVC containing cadmium or lead	banned	banned
chlor-alkali production based on mercury or diaphragm cell	avoided (e.g. scores)	banned
others	-	avoided (e.g. scores)
VOC / SVOC	avoided in adhesives for floors (e.g. EMICODE EC1 products)	catalogue of VOC-content-limits for different products e.g. Austrian GPP-standard, ecolabels, can be replaced by forced measurements in test chambers

N.B.: *Source*: Mötzl and Fellner, 2011

Table 4.10: Evaluation scheme for the emissions from building materials



Requirements / Parameter	Minimum (modeled on ECA-EAQ)	Excellence (based on natureplus)
Measuring method / Chamber Measuring points (days)	Harmonised CEN Standard (based on ISO 16000 series) 3 and 28	Harmonised CEN Standard (based on ISO 16000 series) 3 and 28
Harmonised list of EU carcinogens classes 1 and 2 compounds	not measureable	not measureable
Single VOCs evaluated (R = Σ Ci/LCI <1))	R < 1 Harmonised list of LCIs	benchmarks oriented on toxicology-cally derived values where possible
Compounds without LCI assessment	Sum < 100 µg/m³	benchmarks for sum of impact categories
TVOC measured	1000 µg/m³ (upper value)	300 µg/m³
TSVOC measured	100 µg/m³ (3)	100 µg/m³
Formaldehyde measured	E1 (≤ 0.12 mg/m³) (1)	E1 (≤ 0.024 - 0.048 mg/m³) (2)
Sensory evaluation	Await ISO 16000-28	Await ISO 16000-28

N.B.: *Source*: Mötzl and Fellner, 2011

Use of products bearing an Ecolabel

For many consumer products, so-called ecolabels are awarded by different organisations. These products include many building products and especially those sold directly to consumers. As these consumer products include many interior finishing products, ecolabels are especially relevant here (but only if available to all other sectors of the construction industry).

Generally, it is considered best environmental management practice to establish a selection procedure giving preference to construction products having a generally recognised international or national ecolabel. An ecolabel is a voluntary labelling system for consumer products, that is given to help avoid negative environmental effects. These labels were created to help manufacturers, retailers and service providers gain recognition for good standards, while helping purchasers identify products which are less harmful to the environment.

Independency of the label from product manufacturer should be assured. Also, best practitioners are those able to prioritise materials selection using a scientific basis, creating selection and procurement procedures able to minimise the environmental impact of construction products.

Some examples of ecolabels relevant for the Construction sector are shown below:

EU Ecolabel

The EU Ecolabel aims to help consumers and public procurers to easily identify ‘green’ products. The voluntary scheme recognises environmentally sound goods and services by awarding them a distinctive and easily recognisable symbol of environmental quality – the Flower symbol. The EU Ecolabel was established to encourage businesses to market products and services that meet high standards of performance and environmental quality, and covers 26 types of products and services, with further groups being continuously added. EU Ecolabel criteria are based on scientific information agreed at a European level following consultation between a panel of experts and stakeholders representing industry, consumer groups and environmental NGOs. Criteria consider environmental concerns such as energy consumption, toxic substances, recyclability and waste prevention.

Product groups covered by this label relevant for the construction sector are for example:

- Paints and varnishes
- Floor coverings (wooden, textile, hard)
- Light bulbs
- Heat pumps
- Under development: lighting, refrigeration, buildings.

Natureplus

The natureplus label is an international label of quality for sustainable building and interior finishing products, tested for health, environmental-friendliness and functionality. The primary aim is to provide consumers as well as architects, tradesmen, building companies and all those involved in construction, with a reliable orientation aid towards sustainable products i.e. environmentally-friendly and not posing any health risks, for instance oil and varnish of renewable raw materials, low-emission wall paints etc.

Only those products which are comprised of a minimum of 85 % renewable raw materials or mineral based materials which are almost unlimited in their availability are considered for certification. These materials have a proven positive influence upon the interior room climate. At the same time the synthetic components are strictly regulated and reduced to the minimum level that is technically possible. On one hand, harmful emissions can be avoided and on the other, the use of fossil fuels and consumption of limited natural resources can be minimised. The origins of the raw materials are carefully checked.

Product groups covered by this label relevant for the construction sector are for example:

- Insulating materials from renewable or mineral raw materials
- Insulation compound systems

- Floor coverings of wood and timber products
- Linoleum floor coverings.

Forest Stewardship Council, FSC
FSC is an independent, non-governmental, not-for-profit organisation established to promote the responsible management of the world's forests.

FSC provides internationally recognised certification and labelling of forest products. This offers customers around the world the ability to choose products from socially and environmentally responsible forestry. Its criteria include:

- Prohibit conversion of forests or any other natural habitat
- Respect of international workers rights
- Respect of Human Rights with particular attention to indigenous peoples
- Prohibit the use of hazardous chemicals
- No corruption – follow all applicable laws
- Identification and appropriate management of areas that need special protection (e.g. cultural or sacred sites, habitat of endangered animals or plants).

Product groups covered by this label relevant for the construction sector are for example:

- Wood floor covering
- Construction elements made of wood
- Wood furniture.

Programme for the Endorsement of Forest Certification PEFC
The Programme for the Endorsement of Forest Certification is an international non-profit, non-governmental organisation dedicated to promoting Sustainable Forest Management (SFM) through independent third-party certification. It is based on international decisions of the follow-up conference of the environmental conference of Rio (1992). The criteria and indicators were adopted by 37 nations in the Pan European process at ministerial conferences for the protection of the woods in Europe.

PEFC works throughout the entire forest supply chain to promote good practice in the forest and to ensure that timber and non-timber forest products are produced with respect for the highest ecological, social and ethical standards. Thanks to its eco-label, it is claimed, that customers and consumers are able to identify products from sustainably managed forests. However, standards are not as high as for the FSC label and social issues or the use of wood with harmful consequences to natural forests are criticised by some parties([21]).

Product groups covered by this label relevant for the construction sector are for example:

- Wood floor covering
- Construction elements made of wood
- Wood furniture.

The Blue Angel
The Blue Angel (applied in Germany) is the first and oldest environment-related label for products and services in the world. It considers itself as an instrument of environmental policy designed to assess the positive environmental features of products and services on a voluntary basis. The criteria for awarding this label include environment and health related issues and LCA criteria (depending on the product category).

Product groups covered by this label relevant for the construction sector are, for example, (overall, there are a total of 10 000 products in 80 categories):

- Paints and varnishes
- Wallpapers

([21]) http://www.oroverde.de/regenwald-wissen/tropenholz/zertifizierung-von-tropenholz.html

- Floor covering
- Furniture
- Flushing tanks
- Building insulation materials
- Solar collectors
- Wood pellet heaters.

The Nordic Swan

The Nordic Swan Label is an environmental label introduced by the Nordic Council of Ministers in 1989. Norway and Sweden were members of the eco-labelling scheme from the very beginning, Finland joined in 1990 and Iceland in 1991.

The Swan assesses the environmental impact of the product carrying the label. The Swan labelling helps private consumers and professional purchasers to make environmentally friendly product choices and encourages manufacturers to develop more environmentally friendly products. When criteria for a new product group are developed, the impact on the environment throughout its life cycle is taken into consideration. In order to select the product groups, which are most suitable for eco-labelling, their relevance, potential and controllability are investigated. The Swan also sets criteria with regards to quality and performance.

RAL Institute certification mark

RAL is an institute representing industry associations, manufacturers and suppliers. RAL is most famous for its RAL colour space system. Besides this, the RAL Institute awards at the request of specific associations different labels (certification mark / quality seal), but according to its own criteria or in cooperation with government agencies. RAL labels are mainly of interest in those fields of application, where no standards or official guidelines exists but where there is an interest in quality assessment. For the construction sector, its quality seals assess processes (e.g. demolishing), building components and complete constructions (e.g. low-energy houses).

Umweltzeichen

The Austrian Umweltzeichen ‘environmental sign’ is awarded to products and services which fulfil high standards with regard to their achievement in the area of environment protection and quality.

Product groups covered by this label relevant for the construction sector are for example:

- Floor covering
- Furniture
- Wood construction materials
- Paints and varnishes
- Insulation materials
- Wood furniture.

GEV-Emicode

A group of German manufacturers of flooring installation products founded the ‘Gemeinschaft Emissionskontrollierter Verlegewerkstoffe e.V.’ (GEV), or translated ‘Association for the Control of Emissions in Products for Flooring Installation’. Its main purpose is to supply information regarding the emission characteristics of these materials, thereby offering guidance to planners, consumers and craftsmen when choosing suitable products that will protect the consumer as well as the environment. The Emicode sign divides the checked products according to the measured emissions into three classes: EC 1 = very low-emission, EC 2 = low-emission, EC 3 = not low-emission (but still some restrictions on solvents).

Product groups covered by this label relevant for the construction sector are for example:

- Liquid products (primer and moisture barriers)

- Mineral products with mainly inorganic binding material
- Paste products and such with a high content of organic binding material
- Ready for use products that do not need any chemical or physical drying
- Joint-sealants on dispersion or reactive resin basis

Further labels for environmentally friendly (building) products:

- 'Dena Efficient Homes' (Deutsche Energie-Agentur - the German Energy Agency, http://www.zukunft-haus.info): Dena's energy standard that requires the energy consumption of the refurbished building to be 30 % less than that of a comparable new building has become a fixed component of the German CO_2-Building Rehabilitation Programme of the Federal Promotional Bank (KfW Förderbank).
- 'Quality checked passive house' (Passive House Institute, Germany, http://www.passiv.de/): Certification for passive houses and components for these.
- 'Toxproof Zertifikat' (TÜV Technischer Überwachungs-Verein, Technical Inspection Association, Germany, http://www.tuev.com/): TÜVs are German organisations that work to validate the safety of products of all kinds to protect humans and the environment against hazards. Concerning construction, the toxproof certificate assesses pollutants as well as dust and germs for prefabricated houses, but also for individually built houses and ventilation systems.
- 'Health passport' of The Sentinel-Haus Institute (Germany, http://www.sentinel-haus.eu/en/): The institute offers support to building contractors and planners for quality assurance in healthy living environments with regards to both solid and timber construction methods. It compares quality of the indoor air with contractually stipulated target values (among others chemical and biological contaminants, electro-smog, radon).

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4.3.1.2 Choosing environmentally friendly paints

Description

Paints are liquid or liquefiable compositions which are applied to surfaces in a thin layer for their protection and for decorative purposes. After the solvent has dried, a solid film remains on the surfaces. Many different kinds of paints exist; Table 4.11 gives an overview of the main types used in construction. The type of paint has to be adapted to the specific application characteristics (interior/exterior, surface, wear, etc.), but in many cases several more environmentally friendly options are available than conventional paints that have rather high environmental and health impacts.

Some conventional paints have negative environmental and health impacts, mainly due to the content of volatile organic compounds (VOCs) used as solvents, other hazardous ingredients (like heavy metal salts) and due to their synthetic nature. It is therefore important to select the most environmentally and health friendly product suited to the application. Available techniques in this area are the use of low-VOC paints and of paints from natural materials.

VOCs are organic chemical compounds that can have negative impacts on the environment and human health. They are especially problematic for indoor air quality, as due to the more or less quick off gassing of VOC from buildings or interior fitting, indoor concentrations can reach high levels. Concerning interior finishing, VOC are mainly used as solvents in paints, glues, etc. To some extent such solvents are also released to indoor air from (new) products like carpets or furniture.

Fortunately, the building products industry is responding to these indoor pollution problems by developing safer products, including low-VOC paints, cleaners and adhesives and replacing problematic ones (e.g. chlororganic) by others. These products are now commonly available from most major suppliers at costs comparable to conventional products. The following techniques are described in the following section :

- Use low-VOC or zero-VOC paints and wood finishes: Several types of lower VOC or no VOC paints exist. Of the traditional interior paints, latex or water-based paints have lower amounts of VOCs than oil-based paints. In general, flat finish paints often contain fewer VOC than glossy finish paints, while white or pale paints have less VOCs than brightly coloured or dark paints. Although lower in VOC content, most of them (even those paints labelled as 'no VOC ') generally release some VOCs into the air, especially if solvents are only substituted by less volatile (more slowly evaporating) ones that do not count as VOC.
- Use paints and wood finishes from natural materials

Paints that are completely free of man-made chemicals are the least polluting and harmful option. 'Natural' paints are composed of natural materials, such as natural rubber, milk casein, plant oils and resins (linseed, citrus oils, pine-derived turpenes), natural minerals such as clay, chalk and talcum, plant pigments, lime, and chalk. Although they are made from natural ingredients, some oil-based natural paints may still emit 'natural' VOCs from ingredients such as turpenes or citrus oil (often seen as a rather pleasant fragrance). Water-based natural paints normally give off almost no smell([22]).

Achieved environmental and benefits

The benefits of selecting the most environmentally friendly type of paint suited for the given application are mainly, that the following negative impacts (mainly VOC emissions, toxic compounds and use of non-renewable ingredients) of some conventional paints are avoided.

Concerning the environmental aspects, VOCs have negative effects on plant growth and contribute to photochemical pollution. This means they contribute to the formation of ground

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([22]) Cf. www.buildgreennow.org

level ozone; in sunlight, some organic solvents used in paint can react with nitrous oxides in the atmosphere to form smog.

Concerning the health aspects, VOCs are typically not acutely toxic but have chronic effects. The 'clean' smell of new conventional paint is vapours being released from the solvents. These include less harmful substances like alcohols, but also benzene, formaldehyde, kerosene, ammonia, toluene and xylene, some of which are known carcinogens and neurotoxins. While VOCs vary greatly in their safety, ranging from those that are highly toxic to those with no known adverse health effects, most VOCs found in paints unfortunately fall into the former category. The more VOCs a paint contains, the stronger the odour, during application but also during a large time afterwards for slowly off-gassing substances:

- Lead, a highly toxic metal once used in paint, is another environmental health hazard especially to children and pregnant women, as lead poisoning can lead to learning disabilities, memory loss, aggression and other behaviour problems. Further harmful heavy metals (cobalt, chrome, etc.) used as pigments in paints should also be avoided. Other pollutants to be avoided in paints are for example plasticisers and preservatives.
- Also of concern in paints and primers is the addition of biocides. Biocides include pesticides, poisonous heavy metals, and other preservatives that prevent paints from spoiling. Some biocides may off-gas just as VOCs do, and can cause reactions in chemically sensitive people.

The main environmental criteria for paints in construction indicators are (see also Table 4.11 several environmental aspects of paints):

- VOC concentration: For maximum VOC contents allowed by European legislation see Table 4.15.
- Absence of hazardous substances (lead, toluene, etc)
- No or little interference of coating product with later recycling options of the base material
- Share of natural or recycled raw materials in the product.

Concerning health and comfort issues, the following parameters are relevant in addition to the above mentioned (see also Table 4.11):

- Breathability of the coated surface (especially for walls)
- Steam permeability of the coated surface (especially for walls).

Biocides (pesticides and preservatives) are often added to water based paints and should be in very low levels (0.01 to 0.025 % can be effective in preventing spoilage and not adverse to health) or not at all present, e.g. for indoor use in non-critical applications. For low- or no-VOC paints, clean-up does not require toxic solvents that release additional VOC pollutants.

Appropriate environmental indicators

Compliance with product related indoor air quality standards and certification schemes provide indication concerning major health and environmental concerns.

Cross-media effects

No data available

Operational data

- Use low-VOC or zero-VOC paints: Low and zero-VOC paints reduce emissions of VOCs, a major indoor air pollutant.
- Use low-VOC or zero-VOC wood finishes: Low-VOC finishes, such as waterborne urethane and acrylic, are lower in toxic compounds compared to conventional oil-based finishes while providing similar durability.
- Use paints and wood finishes from natural materials:

- Solvents: In these paints, water is used as the main solvent. Besides, essential oils from plants are used, as well a plant-based surfactants.
- Pigments and dyes: Traditional chemical pigments are often toxic and their production leads to high amounts of chemical waste. Alternatives are very light-resistant natural mineral pigments (like umbra, English red, ochre, chalkstone) and colourings from plants (reseda, madder, indigo). The colour range of natural paints is generally more limited than for synthetic paints.
- Additives: Most kinds of paints contain numerous additives like siccatives, emulsifiers, UV-absorbers, thickeners and biocides (the latter especially for water-based paints). For natural paints, these additives are mainly natural, too, like borax, amine soaps, gypsum, lecithin, and milk or wheat flour.
- Some ‘natural’ paints may still emit ‘natural’ VOCs from ingredients like turpenes or citrus oil. ‘Milk-based’ paints, on the other hand, emit no natural or man-made VOCs, but are not well suited for damp areas (for example kitchens, bathrooms), take a long time to dry, and require more frequent repainting.

The complete declaration of all used ingredients is important for selecting natural paints and is usually available from many producers(23).

In Table 4.11, a summary of the characteristics of the main types of paints is given. However sometimes different fields of application are suited for different paints.

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(23) For example the detailed list of ingredients for their ‘Agalia’ plant-based paints and the composition of each of these products from ‘BEECK`sche Farbwerke (www.beeck.de)’ can be found at http://www.metaefficient.com/paint/agalia-plant-based-paints.html.

Table 4.11: Characteristics of selected paints (part I)

	Glue bound dispersions	Emulsion paints, solvent – based	Emulsion paints, solvent-free	Natural resin colour, solvent-based	Natural resin colour, solvent-free	Polyurethane resin, solvent-based	Polyurethane resin, water dilutable	Epoxy resin dispersion	Epoxy resin, solvent-based
Ingredients	fillers and pigments (52 – 56 %), water (30 – 45 %), solvents (1 – 18 %), additives (0.1 – 0.3 % preserving agents)	fillers and pigments (35 – 55 %), water (30 – 40 %), synthetic resin solvents (5 – 25 %), additives (0.5 – 5 %), preserving agents and stabilising agents), solvents (1 – 3 %)	fillers and pigments (50 – 60 %), water (35 – 45 %), synthetic resin stabilising agents (1 – 6 %), additives (0.5 – 2 %, preserving agents and stabilising agents)	fillers and pigments (40 – 50 %), water (40 – 50 %), natural resin adhesive agent (5 – 15 %), solvents (1 – 7 %), additives (1 %, preserving agents)	fillers and pigments (40 – 55 %), water (35 – 50 %), natural resin adhesive agent (5 – 10 %), additives (1 – 6 %, preserving agents)	fillers (25 – 45 %), solvents (25 – 40 %), adhesive agents (25 – 35 %), additives (1 – 4 %)	water (35 – 40 %), adhesive agents (25 – 35 %), fillers/ pigments (20 – 30 %), solvents (4 – 8 %), additives (1 – 2 %)	water (35 – 45 %), fillers/ pigments (20 – 40 %), adhesive agents (23 – 27 %), solvents (0 – 5 %), additives (1 – 4 %, surfactants, rust-inhibiting agent, anti-foaming agent, thickener)	fillers/pigments (25 – 45 %), adhesive agents (25 – 40 %), solvents (25 – 35 %), additives (2 – 3 %)
Energy input in MJ/m^2	1 – 3	12 – 13	6.5 – 9	3.5 – 5.5	2.5 – 4.5	38 – 41	20 – 25	No data available	No data available
Water vapour resistance factor	80 – 100	200 – 5 000	100 – 2 000	< 100	< 100	25 000 – 35 000	25 000 – 35 000	10 000 – 40 000	10 000 – 40 000
Application area	mineral interior surfaces in the interior with little wear, wallpaper, plasterboard	heavy wear walls and facades, floors (base coat necessary for plasterboard and other porous materials)	mineral interior wall and ceiling surfaces and wallpapers with little wear, (base coat necessary for plasterboard and other porous materials)	mineral interior wall and ceiling surfaces and wallpapers with little wear, (base coat necessary for plasterboard and other porous materials)	mineral interior wall and ceiling surfaces and wallpapers with little wear, (base coat necessary for plasterboard and other porous materials)	wood, metal and concrete heavy wear interior surfaces	wood, metal and concrete in heavily stressed interior	wood, metal and concrete heavy wear interior surfaces	wood, metal and concrete heavy wear interior surfaces
Median expected useful life	15 (interior painting)	15 (interior painting) 20 (exterior	15 (interior painting)	No data available	No data available	18 (interior painting) 8 (exterior	18 (interior painting) 8 (exterior	18 (interior painting) 8 (exterior	18 (interior painting) 8 (exterior

	Glue bound dispersions	Emulsion paints, solvent – based	Emulsion paints, solvent-free	Natural resin colour, solvent-based	Natural resin colour, solvent-free	Polyurethane resin, solvent-based	Polyurethane resin, water dilutable	Epoxy resin dispersion	Epoxy resin, solvent-based
		painting)				painting)	painting)	painting)	painting)
Maintenance	can be cleaned and over coated	can be cleaned and over coated, complete removal only with high efforts	can be cleaned and over coated, complete removal only with high efforts	can be cleaned and over coated, complete removal only with high efforts	can be cleaned and over coated, complete removal only with high efforts	complete removal only with high efforts, new over coating problematic	complete removal only with high efforts, new over coating problematic	complete removal only with high efforts, new over coating problematic	complete removal only with high efforts, new over coating problematic
Indoor climate	+ breathable + antistatic - mould-prone if moist	- not breathable - water vapour resistant - electric static	- not breathable - water vapour resistant - electric static	+ breathable + steam permeable + antistatic	+ breathable + steam permeable + antistatic	- not breathable - water vapour resistant - electric static	- not breathable - water vapour resistant - electric static	- not breathable - water vapour resistant - electric static	- not breathable - water vapour resistant - electric static
Recyclability	Treated construction parts are affected in their recyclability								

Source: CRTE, 2009

Table 4.12: Characteristics of selected paints (part 2)

	Lime paints	Silicate paint (1 component)	Silicate paint (2 components)	Silicone resin colours	Polymer resin colours	Dispersion varnishes	Alkyd resin varnishes	Oil and natural resin varnishes
Ingredients	water (45 – 55 %), fillers and pigments (25 – 35 %), binding agents (15 – 25 %), additives (0.5 – 1,5 %)	fillers and pigments (43 – 51 %), water (39 – 47 %), binding agents (8 – 13 %), additives (0.2 – 1.5 %, stabilization agents), solvents (0 – 1.7 %)	fillers and pigments (65 – 75 %), water (20 – 30 %), binding agents (5 – 10 %)	fillers and pigments (35 – 55 %), water (35 – 50 %), binding agents (8 – 12 %), solvents (0 – 3 %), additives (0.5 – 2 % preservatives, stabilization agents)	fillers and pigments (40 – 55 %), solvents (30 – 40 %), binding agents (8 – 18 % synthetic resins), additives (1.5 – 8 %, diluents)	water (30 – 40 %), fillers and pigments (20 – 35 %), synthetic resin additive agents (20 – 30 %), solvents (3 – 8 %), additives (1 – 6 %, preservatives, stabilization agents)	fillers/ pigments (30 – 45 %), binding agents (25 – 40 %) solvents (25 – 30 %), additives (1 – 3 %, drying agents)	fillers/ pigments (30 – 65 %), natural resin binding agents (10 – 65 %), solvents (0 – 35 %), additives (0.5 – 4 %)
Energy input in MJ/m2	1 – 2	9 – 11	4 – 5	8 – 12	15 – 20	11 – 14	20 – 24	9 – 20
Water vapour resistance factor	< 100	60 – 800	40 – 150	50 – 600	100 – 1 500	1 500 – 10 000	12 000 – 25 000	1 000 – 5 000
Application area	mineral and lime surfaces in the interior with little wear	facades in the interior and exterior with mineral surfaces	facades in the interior and exterior with mineral surfaces	facades in the interior and exterior with mineral surfaces, for gypsum and highly porous surfaces a silicone resin base coat is necessary, not appropriate for reinforced concrete	mineral facades, steel surfaces in the exterior, mineral surfaces in the interior	Heavy wear surfaces in the interior, timber and derived timber products in the interior and exterior (base coat necessary for gypsum boards, highly porous or loose mineral surfaces, timber, metal)	timber and metal protection in the interior and exterior	timber in the interior and exterior
Median expected useful life	15 (interior coating) 7 (exterior coating)	15 (interior coating) 20 (exterior coating)	20 (interior coating) 15 (exterior coating)	8 (exterior coating)	8 (exterior coating)	18 (interior coating) 20 (interior coating)	18 (interior coating) 8 (exterior coating)	18 (interior coating) 8 (exterior coating)
Maintenance	brushing, washing and new over coating, (but not with film-	brushing, washing and new over coating, (but not with film-	brushing, washing and new over coating, (but not with film-	cleaning by high pressure and coating with silicon resin, complete	refurbishing limited, complete removal only with high efforts	can be washed, sanded and over coated, complete removal only	can be sanded and over coated (with synthetic or natural resins), complete	Can be over coated

	Lime paints	Silicate paint (1 component)	Silicate paint (2 components)	Silicone resin colours	Polymer resin colours	Dispersion varnishes	Alkyd resin varnishes	Oil and natural resin varnishes
	forming colour)	forming colour)	forming colour)	removal only with high efforts		with high efforts	removal only with high efforts	
atmospheric environment	+ breathable + odour-absorbing + moisture-regulating + disinfectant + mildew-abrasive (alkalinity) + antistatic	+ antistatic - only limited breathable - partly steam-permeable	+ breathable + steam-permeable + antistatic + mildew-sensitive (if no organic additives)	+ breathable	- not breathable - electric static	- not breathable - water vapour resistant - electric static	- not breathable - water vapour resistant - electric static	- not breathable - steam-permeable
recyclability	treated construction parts can recycled without quality reduction	treated construction parts can affected in their recyclability	treated construction parts are not affected in their recyclability.	treated construction parts are affected in their recyclability	treated construction parts are affected in their recyclability	treated construction parts are affected in their recyclability	treated construction parts are affected in their recyclability	treated construction parts are affected in their recyclability

Table 4.13: Characteristics of selected paints (part 3)

	Clear coat, water based	Natural resin clear coat, solvent based	Synthetic resin clear coats, solvent based	Glazes, water based	Natural resin glazes, Solvent based	Synthetic resin glazes, solvent based
Ingredients	water (50 – 70 %), adhesive agents (25 – 40 %), solvents (2 – 8 %), additives (2 – 5 %)	solvents (45 – 65 %), adhesive agents (30 – 45 %), additives (1 – 10 %, matting agents and drying agents)	solvents (40 – 85 %), binding agents (15 – 60 %), additives (0.5 – 4 %)	water (55 – 75 %), binding agents (15 – 30 %), solvents (1 – 8 %), fillers and pigments (1 – 5 %), additives (0.5 – 4 %, drying agents, etc)	solvents (55 – 80 %), binding agents (15 – 25 %), additives (1,5 – 7 %), fillers and pigments (0 – 12 %)	solvents (60 – 75 %), binding agents (20 – 35 %), additives (1 – 3 %, drying agents), fillers/pigments (0 – 5 %)
Energy input in MJ/m^2	4.5 – 8	1.5 – 4,5	14 – 22	7 – 11	13 – 16	22 – 25
Water vapour resistance factor	25 000 – 35 000	no data available	12 000 – 14 000	12 000 – 23 000	no data available	12 000 – 23 000
Application area	wood-protection in the interior	wood-protection in the interior	wood and metal protection in the interior	wood protection in the interior and exterior	wood protection in the interior and exterior	wood protection in the interior and exterior
Median expected useful life	18 (interior) 8 (exterior)	18 (interior) 8 (exterior)	18 (interior) 8 (exterior)	12 (interior) 15 (exterior)	12 (interior) 15 (exterior)	12 (interior) 15 (exterior)
Maintenance	can be cleaned, sanded and over coated, complete removal only with high efforts	can be, sanded and over coated, complete removal only with high efforts	can be cleaned, sanded and over coated, complete removal only with high efforts	can be brushed, sanded and over coated, complete removal is not necessary needed	can be brushed, sanded and over coated, complete removal is not necessary needed	can be brushed, sanded and over coated, complete removal is not necessary needed
Indoor climate	- not breathable - water vapour resistant - electro-static	No data available	- not breathable - water vapour resistant - electro-static	+ breathable - water vapour resistant	+ breathable + steam-permeable + antistatic	- not breathable - water vapour resistant
Recyclability	treated construction parts can affected in their recyclability					

Applicability

- Use low-VOC or zero-VOC paints and wood finishes: Low-VOC or zero-VOC paint: Paint with low- or zero-VOC content is available from most major manufacturers and is applied like conventional paint. Water-based coatings often require a more thorough preparation of the surface (for example complete removal of fat).
- Low-VOC wood finishes: Low-VOC wood finishes can be used in most applications where oil-based finishes are typically used. If oil-based wood finishes must be used, they should be applied off-site or left to off-gas for three to four weeks prior to occupancy.
- Use paints and wood finishes from natural materials: Concerning application, there are basically no large differences to conventional paints. Equipment has to be corrosion-resistant. ‘Milk-based’ paints have limited usage (for example, not in kitchens, bathrooms, or other damp areas) and require more frequent repainting. Natural resins and oils often have smaller molecules allowing them to penetrate deeper for example into wood, allowing better water-protection and weather-resistance and avoiding chipping-off of coatings. The used natural oils and resins normally dry slower (one day) than conventional paint, which can delay the workflow. However, fast-drying conventional paints continue drying and oxidising more quickly than natural paints and are thus prone to embrittlement. For certain high-wear applications like highly-used flooring, natural paints cannot be as resistant as specialised synthetic compositions. However, in these cases oiling and waxing with natural products is an alternative, as instead of a scratch-resistant one-time coating, wear can be locally repaired, which is not possible for paints.

Economics

- Use low-VOC or zero-VOC paints and wood finishes: Low- and zero-VOC paints typically cost about the same as a manufacturer's premium line of paints([24]).
- Use paints and wood finishes from natural materials: Paints from natural raw materials are generally considered as expensive. This may often be the case regarding only the price per container (e.g. litre) of products. However the same amount will often cover a larger surface (sometimes two or three times the surface of conventional coatings). The useful lifetime and quality of natural paints is often at least as good as for conventional paint, the uniform weathering of these paints (no flaking off) and the easy refurbishing contribute to their positive economic characteristics.

A comparison of typical costs [€/m²] of conventional and natural coatings is given in Table 4.14.

([24]) http://www.toolbase.org/Technology-Inventory/Interior-Partitions-Ceilings/low-voc-paints

Table 4.14: Comparison of costs [EUR/m²] of different conventional and natural coatings (complete build-up including primer or pretreatment)

Product	Floor	Wood interior	Wood exterior	Walls interior (2 coatings)
Conventional sealing	4.10	-	-	-
Conventional hard wax oil	3.10			
Natural hard wax	2.80			
Natural floor wax 'aqua'	1.90			
Conventional wood glaze with label 'blue angel'	-	1.70		
Boiled linseed oil		0.50		
Natural hard wax		1.80		
Natural hard wax 'aqua'		1.50		
Conventional wood protection glazing		-	2.50	
Conventional permanent protection glazing			3.00	
Natural wood glazing 'classic'			3.00	
Natural wood glazing 'aqua'			4.20	
Conventional white wall paint (high quality)			-	1.00
Conventional white interior wall paint (cheap)				0.60
Natural lime paint				1.30
Natural wall paint				1.50

N.B. *Source*: FNR, 2010

Driving force for implementation

Increased end-user awareness of environmental and health issues have created demand and hence a wide availability of low-VOC and natural resource paints.

Also, the European 'Decopaint' Directive (2004/42/EC) limits the total content of VOCs in certain (conventional, i.e. not those considered low-VOC or VOC-free) paints and varnishes for reducing VOC emissions, as shown in Table 4.15. The next revision of this directive is planned for 2011, probably then including more product groups. Products must carry a label showing the type of product as given in the Directive, and the contents of VOC in g/l of the product in a ready to use condition.

Table 4.15: Maximum allowed VOC content of paints according to 2004/42/EC

	Product Subcategory	Type	Phase I (g/l) (from 1.1.2007)	Phase II (g/l) (from 1.1.2010)
1	Interior matt walls and ceilings (Gloss < 25@60°)	water based	75	30
		solvent based	400	30
2	Interior glossy walls and ceilings (Gloss > 25@60°)	water based	150	100
		solvent based	400	100
3	Exterior walls of mineral substrate	water based	75	40
		solvent based	450	430
4	Interior/exterior trim and cladding paints for wood and metal	water based	150	130
		solvent based	400	300
5	Interior/exterior trim varnishes and wood stains, including opaque wood stains	water based	150	130
		solvent based	500	400
6	Interior and exterior minimal build wood stains	water based	150	130
		solvent based	700	700
7	Primers	water based	50	30
		solvent based	450	350
8	Binding primers	water based	50	30
		solvent based	750	750
9	One-pack performance coatings	water based	140	140
		solvent based	600	500
10	Two-pack reactive performance coatings for specific end use such as floors	water based	140	140
		solvent based	550	500
11	Multi-coloured coatings	water based	150	100
		solvent based	400	100
12	Decorative effect coatings	water based	300	200
		solvent based	500	200

References

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4.3.1.3 Choosing certified wood and substituting tropical wood

Description

The Forest Stewardship Council (FSC) is an independent, not for profit, non-governmental organisation that provides standard setting, trademark assurance and accreditation services for companies and organisations interested in responsible forestry. It is recognised worldwide and only awarded if wood is produced without clear cutting, soil degradation or use of pesticides. Converting natural forests to plantations is not permitted for certified wood; among the relevant criteria are also social and health issues of local populations. FSC is committed to ensuring forests' survival for future generations. Less recommendable is wood from mixed sources (only partly FSC wood). Other existing wood labels are also not as meaningful. The PEFC (Programme for the endorsement of certification schemes) of the European Associations of wood owners and forest industries also aims to promote sustainability throughout the wood supply chain. However, it is not as strict concerning sustainability criteria as the FSC label and is criticised for allowing the use of natural woods in Scandinavia.

Avoiding tropical wood

Hardwood from tropical species is still largely used as a construction material for example in furniture and floor covering, mainly due to its durability and optical properties. However, due to negative environmental impacts of its production, those woods should be avoided; options for substituting different tropical woods by local woods are given in Table 4.16. The EU has adopted in June 2010 new legislation that will oblige wood importers and traders to know the source of any wood or forest products that they are buying and to ensure that it is legally compliant. The EU 'Illegal Timber Regulation' includes the prohibition of sale of illegal timber in the EU. The Regulation will enter into force from the beginning of 2013.

Using reclaimed/recycled wood

Reclaimed/recycled wood often has special aesthetical features making it suitable for substitution of new (tropical) wood in applications like furniture or floor covering. However, the origin of the wood should be checked to avoid supporting unsustainable sources.

Achieved environmental and health benefits

The achieved environmental benefit of using certified wood is to avoid the negative environmental impacts from its production. According to WWF, 2012, FSC was started with environmental goals in mind. FSC's environmental criteria recognise that forest management should:

- Conserve biological diversity and its values: water resources, soils, unique and fragile ecosytems and landscapes
- Maintain the ecological functions and integrity of the forest
- Protect threatened and endangered species and their habitats.

Some examples of environmental benefits are explained below:

Deforestation of rainforests

Tropical and temperate rainforests have been subjected to heavy logging and agricultural clearance throughout the 20th century with the area covered by rainforests around the world is shrinking. Globally, around 40 % of rainforests have been destroyed in the last 30 years. Even if nowadays trees are logged selectively in many regions, harvesting 5 - 10 % of all trees can damage or destroy 50 – 60 % of all trees per ha, thus the rainforest is no longer the same ecosystem, even with selective logging.

Problems with tropical wood from plantations

Only a small share of tropical wood originates from plantations (estimated 1 %), the origin of imported wood products in Europe is often not completely documented. Only rubberwood, teak and eucalyptus have so far been used in plantations on a larger scale. Even wood originating from these is problematic, as often high amounts of pesticides are used for protecting the trees and also for protecting the wood.

Illegal logging in other countries

Illegal logging is also a major issue for spruce and pine sold in European markets. According to WWF, 2010, a high percentage of wood-based products imported into the EU come from countries with illegal logging. Uncontrolled and illegal harvesting can contribute to damaging nature and local communities in these regions. For example, timber fencing is often made of larch, a rare species in the European part of Russia and often protected. Illegal and uncontrolled cutting of larch is a major issue. According to WWF, 2010, overall illegal logging rates have reached 27 per cent in the north-west of Russia and 50 per cent in the Russian far east. Bad practices put wildlife in Russia's boreal forests - such as the Siberian tiger and the Far Eastern leopard - at high risk.

Appropriate environmental indicators

The amount of products using accrediting compliance with environmental criteria of the FSC certification scheme (see Section. 4.1.1.1) provides an indication of major health and environmental concerns. The use of this indicator should be related to the total amount of used wood, e.g. as a percentage.

Cross-media effects

No data available.

Operational data

The selection of wood products with an FSC label does not lead to technical changes, but is a mere issue of procurement. Concerning the substitution of tropical woods with more sustainable alternatives, Table 4.16 gives an overview of traditional application areas for tropical woods and possible local substitution woods with similar properties.

Table 4.16: Tropical woods by application area and possible local substitutes

Application area	Tropical woods	Local substitution woods
Woods for bridges, water (dike construction, bulkheads, shoreline stabilisation)	Basralocus, Shorea laevis, Nauclea diderrichii, Azobe, Makassar Ebony, Camphor Tree	Oak, Larch, Black locust, Elm
Exterior facing (shingles, shutters, pergola)	Agba, Cedar, Tieghemella africana	Larch, Black locust, Thuja, Cedar
Chemically resistant wood (ship decks, seawater and chemical resistant bins)	Afromosia, Brazilian pine, Basralocus, Cedar, Cordia africana, Kahja, Padouk, Sipo, Teak	Oak, Holm oak, Black locust, Elm
Carpentry (windows, doors, stairs, furniture)	Afzelia, Agba, Brazilian pine, Cerejeira, Cordia africana, Framiré, Koto, Philippine mahogany, Limba, Tieghemella africana, Meranti, Movingui, Niangon, Sapelli, Sipo, Teak, Wengé	Douglas fir, Oak, Ash, Spruce, Pine, Larch, Read oak, Elm, Fir
DIY (ledges, planks)	Abachi, Faro, Limba, Muiratinga, Ramin	Pear, Birch, Alder, Spruce, Pine, Lime, Fir
Saunas	Abachi	Poplar
Table- and worktops	Bongossi, Doussie, Iroko, Teak, Wengé	Maple, Birch, Beech, Oak, Ash, Hornbeam
Furniture veneer	Abachi, Afzelia, Cerejeira, Framiré, Greenheart, Iroko, Limba, Tieghemella africana, Padouk, Ramin, Sapelli, Sipo, Teak, Wengé	Maple, Birch, Common beech, Douglas fir, Oak, Alder, Ash, Spruce, Pine, Larch, Cherry, Lime, Walnut, Poplar, Black Locust, Elm
Ground floor (parquet)	Kokrodua, Mersawa, Ozouga, Wengé	Beech, Oak, Ash, Pine, Larch, Black Locust, Elm
Outside section (park benches, fences, garden furniture)	Afzelia, Basralocus, Framiré, Greenheart, Iroko, Limba, Tieghemella africana, Teak	Hornbeam, Oak, Spruce, Pine, Black locust
Small goods (bread boards, brushes)	Teak, Framiré	Alder, Larch, Walnut
Carving, art	Bilinga, Cerejeira, Padouk, pockwood, Ramin, Sapelli, Sipo, Teak, Wengé	Maple, Birch, Hornbeam, Douglas fir, Read oak, Alder, Ash, Conker tree, Larch, Lime, Walnut, Black locust, Elm

N.B. *Source*: OroVerde, 2012

Applicability

The selection of sustainable wood products (FSC certified, no tropical woods) is recommended for all interior and exterior application in construction. Concerning options for substituting tropical woods, see Table 4.16.

Economics

No data available

Driving force for implementation

The trade of some woods is prohibited according to CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora, also known as the Washington Convention) and the European Commission Regulation (EC) No 2724/2000 of 30 November

2000 amending Council Regulation (EC) No 338/97 on the protection of species of wild fauna and flora.

Besides legislation, consumer awareness for problems of unsustainable deforestation is increasing, especially concerning tropical forests.

Reference organisations

The main organisations for the certification of wood are FSC and PEFC, which define themselves as:

- Forest Stewardship Concil, FSC, is an independent, non-governmental, not-for-profit organisation established to promote the responsible management of the world's forests.
- The Programme for the Endorsement of Forest Certification (PEFC) is an international non-profit, non-governmental organisation dedicated to promoting Sustainable Forest Management (SFM) through independent third-party certification.

Other helpful organisations to understand and uptaking certified wood schemes are:

- ESPEN AG is a company which purchases 100 % of FSC certified products.

- Precious Woods Europe is a company importing wood from the tropical forestry and timber industries which hase obtained comprehensive FSC certification for all of its value-adding chain It is one of the main importers of FSC certified wood.

References

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4.3.1.4 Choosing environmentally friendly materials for floor covering

Description

In the following section, some examples for floor covering materials with good environmental performances are presented (Alameda, 2005). These are the techniques considered to be best environmental management practices:

- Selection of certified (FSC or PEFC) or reclaimed flooring wood
- Use of rapidly renewable flooring materials
- Use of ceramic tiles with recycled-content
- Use of exposed concrete as finished floor
- Use of recycled-content carpets
- Use of thermally massive floors.

Achieved environmental and health benefits

Reclaimed flooring reduces new raw material consumption. Reclaimed wood, often aesthetically very attractive is rescued from landfill and given a second life. Other uses for reclaimed wood include furniture and wall panelling.

Rapidly renewable flooring materials can be attractive, durable, low-toxic and perform well and reduce pressure to harvest old-growth forests. Bamboo is as durable as most hardwoods, but is actually a grass and harvesting bamboo does not kill the plant. Also, bamboo stalks grow to maturity in just a few years, so the same plant may provide for many different floors. Cork flooring does not transmit sound easily, is comfortable under your feet, and is very healthy with low VOCs. Cork and linoleum are naturally fire and moisture resistant as well as sound absorbent.

Ceramic tiles with recycled content reduce the consumption of fresh raw materials and are a high-grade use for ceramic waste. Recycled ceramic tiles are generally not 100 % recycled but contain a substantial portion of recycled material, with the content varying in type and percentage, depending on the manufacturers. The recycled content can range from 20 % to 70 %, with the higher being obviously better. Some recycled-content ceramic tile is very dense, which significantly reduces the amount of moisture and stains that are absorbed into the tile, making it more durable and easier to maintain.

Using the slab as a finish floor eliminates the need to use other flooring materials and it is also durable and easy to clean. Exposed aggregate concrete is well suited for patios, driveways, walkways, in bands or fields, and many other flatwork applications.

Recycled-content carpets save resources and divert waste from landfills. Recycled carpets can be made from recycled polyethelene terephthalate (PET) or from recovered textile fibres. Old carpets, as well as plastic soda bottles (about 40 two-litre soda bottles are recycled per square yard of carpeting) and other textiles can be woven into new carpet fibres.

Increasing thermal mass will reduce peak heating and cooling energy use and will moderate indoor temperature swings, keeping the home more comfortable. This is especially helpful for passive cooling concepts.

Appropriate environmental indicators

Some usegul indicators for floor covering materials indicators are:

- The percentage of recycled materials content in floor coverings: Floor coverings ideally should contain at least to 95 per cent of renewable raw materials; the glue portion should be reduced as much as possible. Table 4.17 shows the typical composition of different floor covering products.

- Alternatively: The percentage of (fast growing) renewable materials (from certified sources especially for non-European woods) in floor coverings.
- Other performance indicators include
    - The absence of emissions or pollutants as in some floor coverings
    - Life cycle related issues, such as primary energy consumption and recyclability
    - Comfort issues and reduced heating (for warm flooring materials such as cork) and cooling (for exposed concrete and other thermally massive floor coverings) demand, low sound transmission, etc. (no values available).
- The document 'Wooden Floor Coverings EU Ecolabel Award Scheme User Manual' (EC, 2010) gives comprehensive information on additional aspects.

Concerning the available materials for floor covering, general data is presented in Table 4.17.

Table 4.17: Composition of floor covering materials

Product group	Renewable raw materials [%]	Fossil raw materials [%]	Mineral raw materials [%]
Wood floor covering	80 – 100	0 – 20	0
Laminate floor covering	80 – 85	15 – 20	0
Linoleum floor covering	65 – 75	< 1	25 – 35
Polyolefin floor covering	0	30 – 90	10 – 70
PVC floor covering	0	35 – 55	45 – 65
Rubber floor covering	0 – 10	20 – 55	45 – 70
Natural fibre floor covering	45 – 100	0 – 35	0 – 35
Synthetic fibre floor covering	0 – 5	55 – 100	0 – 35

N.B. *Source*: CRTE, 2009

Producing floor coverings mainly leads to environmental impacts through the use of more or less environmentally friendly raw materials (see Table 4.17 and Table 4.18). Further environmental impacts arise through the installation of floor coverings (cf. section adhesives) and through their cleaning and maintenance. In Table 4.18 and Table 4.19, the main types of floor coverings with their application areas, environmental and practical performance indicators are shown.

Table 4.18: Operational and environmental parameters of different floor coverings (part 1)

	Linoleum	Rubber floor covering	PVC floor covering	Polyolefin floor covering	Solid wood parquet
Ingredients	Linseed oil, wood resin, wood and cork dust, mineral fillers, additives (pigments), artificial resins	Natural and sysnthetic rubber, mineral fillers, additives (pigments), supporting material (cork, foams)	Polyvinyl chloride, fillers, additives (pigments), supporting material (jute, polyester fleece), surface treatment	Polyolefins, fillers, additives (pigments), surface treatmernt	Wood, binder, surface treatment (oil, wax, sealer)
Heat conductivity in W/(mK)	0.081 (cork linoleum) 0.12 (linoleum-composite coatings) 0.17 (linoleum)	0.23	0.23	0.23	0.20 (hardwood) 0.13 (softwood)
Application area	Residential, administration, commercial, no application in wet areas	Commercial and industrial	Residential, commercial, industrial	Residential, commercial, public	Residential, administration, commercial, public, avoid use in the wet area
Average useful life in years	20	20	20	no data	60 (hard wood), 8 (sealing and lacquer), 4 (impregnation, oil and wax)
Maintenance	avoid intense alkaline cleaning-agents, repairs possible	use pH-neutral cleaning agent	-	-	surface treatment must be exchanged regularly, by abrasion of the surface the surface can be renewed
Material specific information / contaminant loads	Decomposition products can be emitted (VOC), consider type of glue, oxidation of the linseed oil (formaldehyde & aldehydes), chloranisole	Decomposition products of the styrol-butadiene-structure can emit (nitrosamines - vulcanization accelerator, VOC, vinylcyclohexane - synthetic rubber, 4-phenyl-cyclohexane), consider type of glue	Plasticizers (phthalates), vinyl chloride, possibly formaldehyde or isocyanates from the glue or the sealer	Consider type of glue; possibly formaldehyde or isocyanates of the glue or the sealer	Consider type of glue; dependent on the surface treatment isocyanate, solvents, biozides, flame resistants or terpene loads possible

	Linoleum	Rubber floor covering	PVC floor covering	Polyolefin floor covering	Solid wood parquet
Indoor temperature	humidity regulating + breathable antistatic (in each case only without surface treatment)	No data available	not breathable water vapour resistant electrostatic	electrostatic not breathable	warm to the feet Unsealed wood parquet: breathable humidity regulating antistatic Sealed wood parquet: not breathable electrostatic
Recyclability	Cleaned coating reusable in principle or partially biodegradable, energy recovery	Cleaned old coatings can be added to different products theoretically (downcycling), energy recovery	Reuse of cleaned PVC as product raw material possible, energy recovery problematic	Material use of clean product theoretically possible, energy recovery	Dependent on the fastening systems a material further use is possible, energy recovery

Table 4.19: Operational and environmental parameters of different floor coverings (part 2)

	Laminate	Natural fibre carpet	Synthetic fibre carpet	Natural stone floor covering	Ceramic tiles and plates
Ingredients	Wood, paper, adhesive agent, additives	Wool (new sheep wool), other fibres (coco, sisal, jute), caoutchouc, jute, fillers (stone dusts), additives	Plastics (polyamide, polypropylene, polyester, Polyacrylics), caoutchouc, jute, fillers (stone dusts), additives	Stones	Quartz, feldspar, clay, kaolin, water
Density in kg/m³	850 – 1100	No data available	No data available	1600 (volcanic porous natural stones), 2600 (sediment stones – sand stone, coquina), 2800 (crystalline metamorphous stones – granite, basalt, marble)	2000 (ceramic and glass mosaic)
Heat conductivity in W/(mK)	No data available	No data available	No data available	0.55 (volcanic porous natural stones), 2.3 (sediment stone – and stone, coquina), 3.5 (crystalline, metamorphous stones - granite, basalt, marble)	1.2 (ceramic and glass mosaic)
Material-specific information /contaminant loads	Wood dust (fine dust mask), formaldehyde emissions dependent on the used glue (consider glue type) formaldehyde, isocyanates	Consider type of glue for Styrol-Butadien-Latex backs emissions occur from decomposition products, biocide (eulane)	Consider type of glue decomposition products can emit (VOC), diluents, flame retardants, isocyanates (dependent on the carpet back), biocides	Partly radioactive loads in volcanic stones (granite, basalt); no loads in sediment stones (sandstone, marble, coquina)	Dust emissions while cutting
Application area	Residential, administration and trade, avoid use in wet and humid surroundings	Residential and trade	Residential and trade	Interior and/or exterior floor covering	Interior and/or exterior floor covering
Average useful life in years	No data available	10	10	70 (soft natural stone), 100 (hard natural stone)	60 (ceramics)

	Laminate	Natural fibre carpet	Synthetic fibre carpet	Natural stone floor covering	Ceramic tiles and plates
Maintenance	Renovation only possible by change	No data available	Renovation nearly not possible, in most cases covering must be changed, are sensitive to dirt	No data available	Single tiles can be changed without problems
Indoor temperature	+ not cold in winter - electrostatic - not breathable (dependent on the surface treatment)	+ not cold in winter + humidity-regulating + antistatic + anti-noise	+ not cold in winter - not breathable	+ antistatic - cold in winter	+ antistatic - not breathable - cold in winter
Recyclability	Energy recovery	Energy recovery	Energy recovery	Reuse possible theoretically, further utilisation as gravel or filling	Accumulate normally as construction waste, intact tiles can be cleaned and further used

Cross-media effects

No data available

Operational data

Bamboo, cork and natural linoleum flooring are alternatives to hardwood flooring. Bamboo is a fast-growing grass that can be harvested in three to five years. Although bamboo is resource-efficient, there are indoor air quality concerns related to the urea-formaldehyde binders used in some products. While conscientious manufacturers would not treat their products with toxic chemicals, this has to be checked. Cork is harvested from the outer bark of the cork oak tree; the tree regenerates its bark within about 10 years. The operational benefits of cork include durability, rot-resistance and fire-resistance. *Cork* also has excellent sound absorption qualities, especially at a thickness of 6mm or greater. The manufacturing process produces almost no material waste. Cork products use urea melamine, phenol-formaldehyde and polyurethane as the typical binders, much less toxic than urea formaldehyde, a common binder in typical flooring. Cork is often treated with several coats of polyurethane, similar to hardwood flooring, to protect it from wear. *Natural linoleum* is manufactured primarily from renewable materials such as cork, wood flour and linseed oil.

Recycled-content ceramic tiles can contain up to 70 % recycled glass or other materials. Ceramic tile is an inert material used as a durable finish for floors, countertops, and walls. While somewhat energy intensive to produce, the environmental impacts are offset by ceramic tile’s longevity. Recycled-content ceramic tile provides additional environmental benefits; in addition to using up to 100 % waste glass, they are often more durable and moisture and stain resistant than their non-recycled counterparts.

For slab-on-grade construction, the concrete can be polished, scored with joints in various patterns, or stained with pigments to make an attractive finish floor. There is a variety of concrete colouring, staining, and finishing techniques (such as exposed aggregate concrete), which has made interior exposed concrete floors and surfaces an additional finish option. An exposed aggregate finish is obtained by placing concrete and then removing the outer 'skin' of cement paste to uncover decorative coarse aggregate (either batched into the concrete mix or seeded onto the surface).

Recycled-content carpet is made from recycled plastic bottles, recycled nylon/wool or recycled cotton. Recycled-content carpet is comparable in appearance, performance and price to conventional synthetic carpet. Recycled content carpet has a similar look, feel, and price as virgin fibre (typically polyester, nylon, and olefin) carpet. The backing used for recycled content carpet is the same as traditional carpets.

Some types of floors (concrete, cement or brick tile and other hard floors) have a high thermal mass. Thermal mass is a property that enables building materials to absorb, store, and later release significant amounts of heat. This delays and reduces heat transfer through a thermal mass building component, leading to three important results.

- Fewer spikes in the heating and cooling requirements, through moderated indoor temperature fluctuations.
- Less energy than a similar low mass building due to the reduced heat transfer through the massive elements.
- Thermal mass can shift energy demand to off-peak time periods when utility rates are lower. Since power plants are designed to provide power at peak loads, shifting the peak load can reduce the number of power plants required.

Applicability

- FSC-certified or reclaimed wood can be used without special limitations in place of conventional hardwood flooring.
- Bamboo flooring is a very hard, dimensionally stable and durable substitute for wood flooring that creates a beautiful and unique floor. *Cork* can also be used as underlay for

hard-surfaced flooring to reduce impact noise between rooms, which makes it a natural choice in a home where noise is a factor. Cork floors require somewhat more maintenance that other flooring options but also offer comfort benefits the others do not. Cork is anti-microbial and is resistant to mould and mildew, a well-maintained cork floor will last for decades. Coatings may increase hardness of surfaces.

- Recycled-content tiles can be used in a variety of settings, such as kitchens, bathrooms, fireplace surrounds, shower bases as well as other rooms in the home or workplace.
- Recycled-content carpets can be used in all applications where conventional carpet is specified. Recycled carpets usually comes with the same warranties for colourfastness, static control, and resistance to stain, crushing, and matting as virgin synthetic fibre carpets.
- Low-cost thermal mass includes using hard floor coverings such as tile and wood. Wood flooring over a concrete slab also provides reasonably good thermal mass. Thermal mass has the greatest benefit in climates with large daily temperature fluctuations above and below the balance point of the building. For these conditions, the mass can be cooled by natural ventilation during the night, and then be allowed to absorb heat during the warmer day. In heating-dominated climates, thermal mass can be used to effectively collect and store solar gains or to store heat provided by the mechanical system to allow it to operate at off-peak hours.

Economics

No data available.

Driving force for implementation

The reduction of the environmental footprint can produce economic benefits, through the lower costs of some materials and because of energy savings during building life cycle. Enhanced reputation and further legislation on indoor air quality requirements are also important driving forces.

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5 CONSTRUCTION AND REFURBISHMENT

5.1 Chapter structure

This chapter provides information to companies performing construction and refurbishment of buildings, roads and other civil works to improve their environmental performance. An introduction about the performance and the decision making process on environmental issues is given in Section 5.3, where a realistic picture of the potential of management systems is drawn. Some data on the environmental performance of the sector as a whole and the performance of construction sites is provided in section 5.4.1.

Background information about the impact of the main construction activities on the environment is provided in section 5.4. A list of the described practices is given in the techniques portfolio, Section 5.5, which is divided into management and site organisational practices (Section 5.6.1), and construction processes practices (Section 5.6.2).

5.2 Scope

In this section, the main environmental aspects to be covered by Chapter 5 are described and justified. The EMAS regulation and the ISO 14001 requirements establish that environmental aspects should be identified, and also which aspects are significant and should be taken into account when establishing, implementing and maintaining an environmental management system. According to Piñeiro and García-Pintos, 2009, two levels of environmental management are detected in construction companies: strategic management and construction site management. Although all site activities should be, at least, covered by the environmental policy of the company, defined at the strategic management level, some of them can be out of the scope of the construction site management. For instance, all the influence of the company to improve the environmental performance of the product should be defined at strategic management level. The environmental performance of the product is usually considered an indirect aspect, with much more influence in turnkey projects, where the design is made by an architect working with the construction company. The performance of the product (e.g. a building) is already covered in Chapter 3. Nevertheless, the performance of the product is really relevant for the pre-construction phase, where the most important environmental impacts of a construction can be predicted from project documents (Gangolells et al., 2009) and can increase the efficiency of the environmental management and reduce the overall environmental impact of the construction site. This process may be considered a best environmental management practice in the pre-construction phase, and hence it will be described in this chapter.

The environmental management at the strategic level should be in charge of the communication with the customer, the developer and to other stakeholders with decision-making powers or with a special interest in the environmental performance. Communication to the local community can be also made at the site level.

The environmental performance of materials is an issue that may be out of the control of constructors, since materials are defined at a project level and any change requiring extra costs or essential changes of the original design is up to the architect. Nevertheless, the construction company may have a relevant influence on this issue, as they are the real purchasers and may raise awareness and create efficient arguments from their perspective. This is the case for the reuse of materials, where constructors can optimise their own logistics to reduce materials consumption by using leftovers from one site for another site. This will have double benefits: reduced consumption and waste generation, apart from the reduction of transport needs. The use of recycled materials is usually not allowed because of legal aspects (such as recycled gravel in roofs), material properties or aesthetic reasons. Also, aggregates and other reusable materials (e.g. from pavement crushing) can be employed when they are considered fillings for non-functional parts of the building.

Due to the difficulty and the apparent impossibility of managing indirect aspects, the main environmental management systems in construction companies focus on operations during the construction phase, and hence the identified aspects are always related to the energy consumption, water consumption, effects on waterways, soil alteration, air emissions, incidents, accidents, noise, vibrations and training of workers.

Figure 5.1 gives an overview of the main environmental aspects of construction activity and the main links with different management strategies. This reference document is not providing any method for the assessment of the significance of environmental aspects, since it has to cover best practices for all aspects. According to several stakeholders consulted for the development of this document, best practice implementation at site level usually depends on workers awareness. Regardless of the significance, the repetition of environmental practice from one site to another seems to be the best way for laborers, foremans and managers to internalise environmental tasks as part of their normal job and not as extra tasks with repercussion on their productivity.

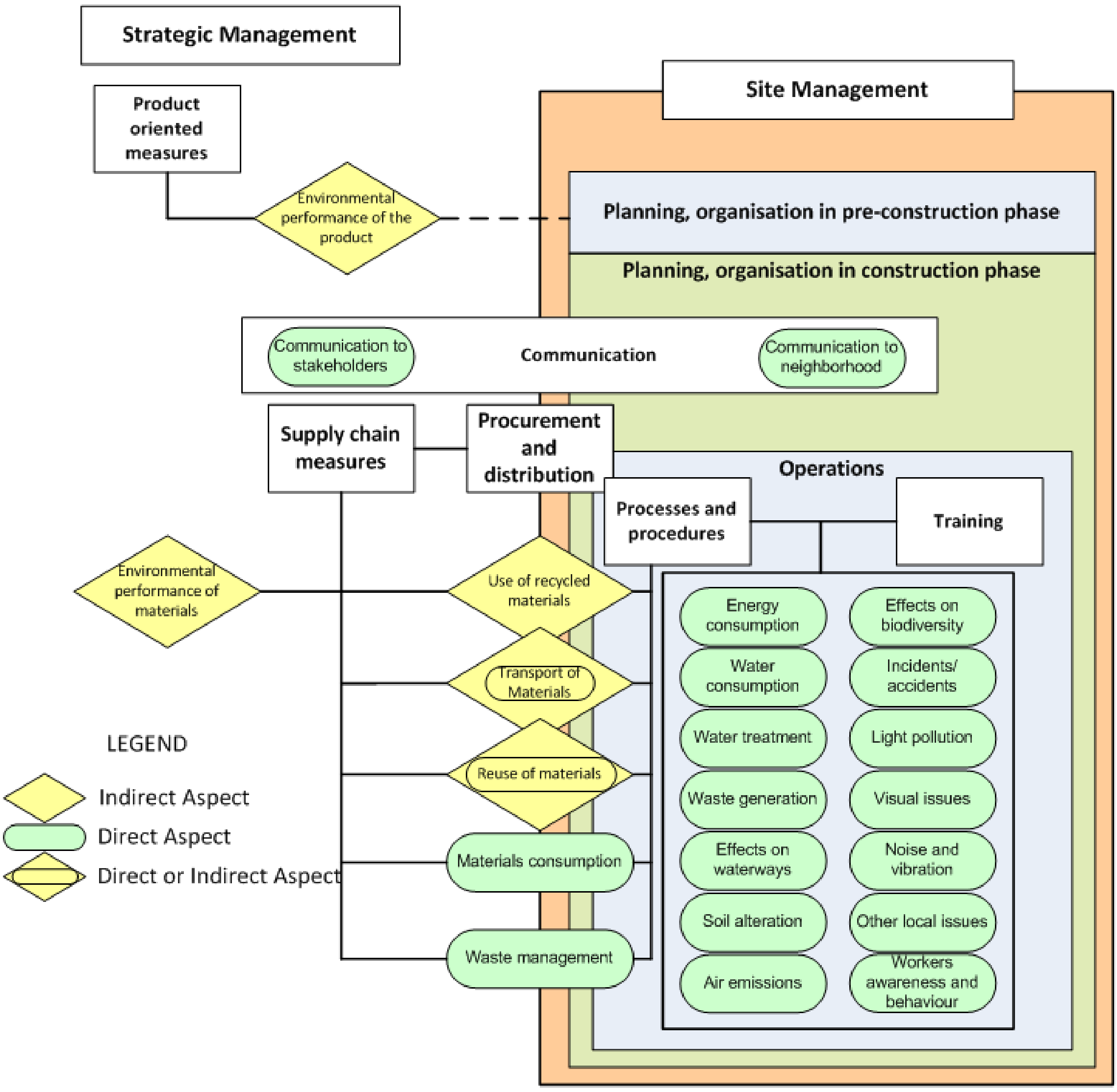

Figure 5.1: Identified environmental aspects and approximate links with company environmental management activities

In order to identify the subcategories of environmental aspects, several comprehensive documents were addressed:

- Gangolells et al., 2009, published a predictive methodology to identify relevant environmental aspects of construction activities at the planning stage. This methodology is a process oriented approach.
- *Fomento de Construcciones y Contratas* (FCC) published in 2009 an environmental declaration of the company activities. It is mainly focused on the environmental aspects of civil works and the list shown below highlights aspects considered significant in more than 10 % of sites.
- *Asociacion Española de Normalización y Certificación* (AENOR) published, in 2007, a guide for the implementation of ISO 14001:2004 in construction companies. In this publication, they publish a so-called ‘non-exhaustive’ list of environmental aspects.
- Jackson Civil Engineering is a civil works company based in UK. They publish their environmental statement under EMAS regulation in 2009 and they control every aspect with their links to all processes, so it is also a process-oriented approach.

Table 5.1 to Table 5.9, shown below, list the direct environmental aspects proposed under each publication. Although these publications are quite comprehensive regarding environmental aspects, they cover direct aspects. The construction sector is composed mainly by SMEs, so it is quite difficult for their environmental management systems to control and to manage indirect aspects. Also, the decision power of constructors is quite restricted and depends on the decisions made by other economic agents (public administrations, developers, designers, customers, etc.). Thus, frequently the focus is only made on the environmental aspects where the company has a direct control.

Table 5.1: Direct environmental aspects identified in several publications (Atmospheric emissions)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main significant environmental aspects (AENOR, 2007) - '*non-exhaustive list*'	All environmental aspects (Jackson Civil Engineering, 2008)
Atmospheric emissions			
Generation of greenhouse gas emissions due to construction machinery and vehicle movements.		Exhaust gases from combustions	Gas/fumes/smokes
Emission of VOCs and CFCs.		VOCs emissions	
	Dust emissions due to inert material and debris transport	Dust Emissions	Dust
	Dust generation in earthworks activities and stockpiles.		
	Dust emissions due to machinery circulation		
	Dust emissions due to demolitions		
		Night light emissions	
			Asbestos/fibres

Table 5.2: Direct environmental aspects identified in several publications (Water effluents)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Water effluents			
Dumping of water resulting from the execution of foundations and retaining walls. Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids. Dumping of sanitary water resulting from on-site sanitary conveniences.	Discharge of sanitary waste water	Discharge of process water (cleaning, excavations, etc.) Discharge of municipal waste water from sanitary conveniences	Discharge to Sewage Discharge of polluted water with fuel/oils Discharge to groundwater Discharge of solids/wastes/chemicals to water sewage

Table 5.3: Direct environmental aspects identified in several publications (Waste generation)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Waste generation			
Generation of excavated waste material during earthworks.			
Generation of municipal waste by on-site construction workers.	MSW generated during site cleaning and recovery operations.		Litter/waste
Generation of inert waste.	Generation of inert waste.(Debris)		Construction waste
Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	Generation of non hazardous waste (packaging and others)		
Generation of special (potentially dangerous) waste.	Generation of hazardous waste (empty packaging) Generation of hazardous waste (paints, solvents, etc)) Generation of hazardous waste: soil contaminated because of chemicals dumping, lubricants, fuels, etc.		Hazardous waste

Table 5.4: Direct environmental aspects identified in several publications (Soil alteration)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Soil alteration			
Land occupancy by the building, provisional on-site facilities and storage areas.			
Use of concrete release agent at the construction site.			
Use of cleaning agents or surface-treatment liquids at the construction site.			
Dumping derived from the use and maintenance of construction machinery.			Oils/fuels
Dumping of water resulting from the execution of foundations and retaining walls.			
Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.			
Dumping of sanitary water resulting from on-site sanitary conveniences.			
		Soil compaction	
		Soil pollution	
			Dust

Table 5.5: Direct environmental aspects identified in several publications (Resource Consumption)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Resource consumption			
Water consumption during the construction process.	Water consumption for dust dumping	Water consumption	Tap Water input
			River/borehole water input
Electricity consumption during the construction process.	Consumption of electricity	Electricity consumption	Electricity input
Fuel consumption during the construction process.	Fuel Consumption	Fossil fuel consumption	Diesel/petrol/oils input
Raw materials consumption during the construction process.		Raw materials consumption	Raw materials
			Manufactured goods input

Table 5.6: Direct environmental aspects identified in several publications (Transport)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Transport			
Increase in external road traffic due to construction site transport.			
Interference in external road traffic due to the construction site.	Interference of external road traffic due to construction site transport.	Interference on external traffic	Rights-of-way

Table 5.7: Direct environmental aspects identified in several publications (Local issues)

Main Environmental Aspect of Construction Sites (Gangolells, 2011)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Local issues			
Dust generation in activities with construction machinery and transport.	Dispersion of granular materials during transport		Dust
Dust generation in earthworks activities and stockpiles.			
Dust generation in activities with cutting operations.			
Operations that cause dirtiness at the construction site entrances.	Operations that cause dirtiness at the construction site entrances.	Dirtiness of surrounding pavement	Mud
Generation of noise and vibrations due to site activities.	Vibrations due to demolition		Noise
	Noise Generation due to earthworks		Vibration
Landscape alteration by the presence of singular elements (cranes).		Visual impacts	Visual Pollution
		Pavement occupation	
	Water bed and sea bottom ocupation	Water bed occupation and deviation (public domain)	
		Public maritim domain occupation	
			Archaeology

Table 5.8: Direct environmental aspects identified in several publications (Effects on biodiversity)

Main Environmental Aspect of Construction Sites (Gangolells, 2011)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Effects on biodiversity			
Operations with vegetation removal (site preparation). Operations with loss of edaphic soil (site preparation). Operations with high potential soil erosion (unprotected soils as a consequence of earthworks). Opening construction site entrances with soil compaction. Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.		Vegetation removal Animal biodiversity affectations	Agricultural land Natural habitats Protected habitats/species

Table 5.9: Direct environmental aspects identified in several publications (Incidents, accidents, emergencies, abnormal and wins)

Main Environmental Aspect of Construction Sites (Gangolells, 2009)	Main environmental aspects, considered significants in more than 10 % of the sites. (FCC, 2009)	Main environmental aspects (AENOR, 2007) - 'non-exhaustive list'	All environmental aspects (Jackson Civil Engineering, 2008)
Incidents, accidents and potential emergency situations			
Fires at areas for storing flammable and combustible substances. Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes). Breakage of receptacles with harmful substances. Storage tanks for dangerous products	Fires at areas for storing flammable and combustible substances. Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).		Fire Equipment failure Major spill Flood
Abnormal			
			Late working hours Relocating and moving of equipment Filling/refuelling
Wins			
			Habitat creation Training and education Recycling / reuse Sustainability promotion

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5.3 Introduction

Construction is defined as the action of creating a structure, e.g. a building, typically large, to provide a service to one or several users. The main focus of this document is the construction of a building, which, defined in the simplest way, is a structure with walls and roof (EPBD, 2010). So, a construction company can be seen as the building manufacturer, and NACE code F41 would fit. Nevertheless, this approach may be a rough simplification of a more complex business structure. A building may be regarded as a service (Taipale, 2011): the definition can change to the space, provided to the user, with a particular purpose. Many processes, businesses and actors are involved in this ‘service provision’:

- public administration
- designer
- project developer
- construction company (usually a contractor): can be composed of several companies in a joint initiative
- subcontractors
- services providers
- users
- maintenance organisation.

Construction activity is usually neglected or subtracted in life cycle assessments due to its low duration compared to the construction products lifespan and the impact from this building use during its lifespan.. Currently, this has led to a very particular situation regarding the construction sector, in that building use produces a significant environmental impact, but this building use is mainly influenced by the planning and design stages. Even in scientific studies, there is less attention paid to the construction phase and so fewer incentives for cleaner production in the construction activity are available, compared to other sectors. Figure 5.2 shows a conceptual chart of where the environmental impact is produced and where it can be influenced.

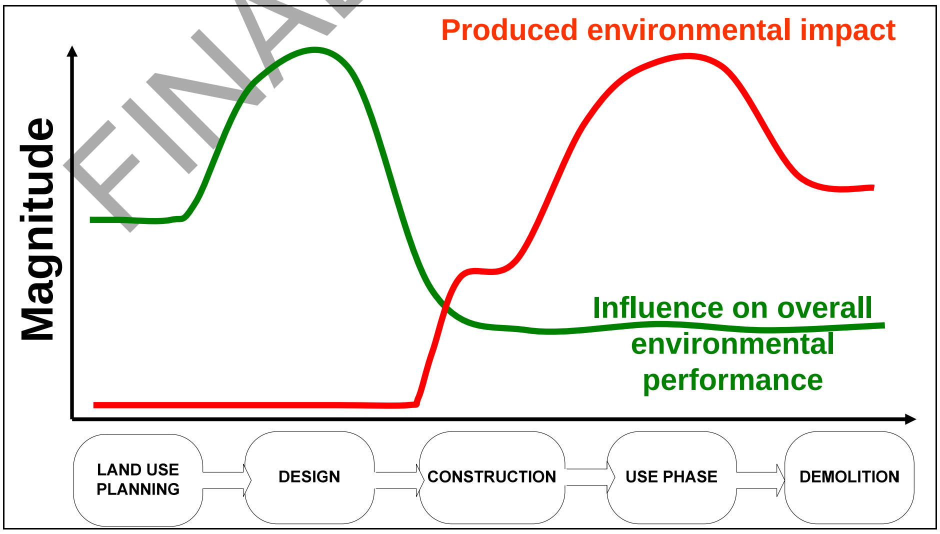


Figure 5.2: Environmental impact and influence on environmental performance of different actors in several construction stages

The decision-making process, which definitely influences the environmental performance, is also complex during the construction phase. The construction company is executing a designer's project, financed by the developer. Environmental decisions changing the design need to be approved by the designer (usually, an architect) and by the developer, who is responsible of covering the extra costs for it. The construction company manages the environmental performance of the site during the construction phase (waste management, materials recycling, dust, dirtiness, etc.), but the environmental responsibility lies with the project developer.

Decision-making schemes may differ among countries. In Spain, for building construction management, responsibilities are regulated through the national act 38/1999. In this act, all the roles and figures of responsibility are defined: developer, designer, constructor, site management direction (site management and execution management directors), suppliers, quality testing entities and laboratories, users and owners. The main environmental impact of the construction process is produced by the contractor, although the final responsibility belongs to the developer. Nevertheless, environmental management decisions that may increase costs are made by the site management director, who is usually hired by the developer. Unfortunately, environmental oriented decisions are usually based on costs. If extra costs have to be assumed, the developer will usually reject them or make the contractor assume them.

The Spanish Advisory Board for the Certification of Construction companies (CACEC, 2011) recommends taking into account several characteristics of the sector when dealing with environmental management:

- the wide geographical dispersion of construction sites: this would imply that environmental management on-site costs would increase due to staff allocation or to the assignment of environmental management tasks to production units.
- temporary sites: a construction company does not have a permanent site, as the company has to set up production site at the future location of the building or the civil construction project.
- heterogeneous activities: the design of products is usually not the same. Even the typology of products can be very different for civil works or buildings in the same company
- joint ventures: it is common practice for two or more companies to cooperate for the development of synergies, sharing capabilities, resources and knowledge in order to be more efficient in the development of a project.
- definition of projects by third parties: construction activity as such is not in charge of the design and its influence on the environmental performance of the product is rather limited.
- the business structure: is quite complex, with many economic agents involved. This situation makes it difficult to implement some practices. For instance, the high labour turnover makes environmental training needs more costly.

Against this background, three main priorities of environmental actions can be highlighted:

- Actions addressing the environmental performance of the construction activity. In many cases, the influence of the construction company in the performance of the final product is very small. Also, the degree of influence can be quite heterogeneous in the sector. Thus, many construction companies only manage their direct environmental aspects which have a significant impact and those indirect aspects that they can manage. For instance: materials supply chain, suppliers and contractors environmental practice, labourers transport and others. Environmental management systems in construction companies are usually implemented with different purposes:
    - Customer's requirement: environmental management of certain aspects is usually asked for in public tenders. Sometimes, certified an EMS is required or can be an advantage for competitiveness. As observed during site visits for the development of this document, improvement of competitiveness is one very important driver for the implementation of a certified EMS.
    - Regulation: there are no rules forcing companies to have a certified EMS. Nevertheless, it can be a very helpful tool to fulfil and control any legal aspects concerning the environmental performance of the company.
    - Other purposes are also important: i.e. showing the environmental commitment of the company seems to be very relevant, especially for companies dealing

with civil works, which will enhance their reputation and environmental credentials with the public and the public administration.

- Actions addressing the environmental performance of the final product (which may be considered an indirect aspect). In this case, the construction company may be in the same businesses group as the designer, real estate companies and other related activities. There, the group may be developing a turnkey project and the company may then have a stronger influence on the performance of the final product, as best design practices can be applied (see section 3). Nevertheless, many restrictions arise when evaluating the economic performance of the final product. For buildings, customers usually prefer to minimise the initial investment. The performance of the final product is an indirect aspect that can be slightly influenced by constructors. Sometimes, construction companies participate in 'lighthouse' projects dealing with environmental solutions: for instance, there are examples of zero energy buildings built by the initiative of the construction company. This is intended to show that they already have the capabilities, the will and the expertise to build environmentally-friendly products.
- Actions addressing redesign and project modifications due to environmental performance arguments. There are case studies where best management practice led to redesign and redrawing of the layout plan of projects at the construction site, sometimes even due to the construction company initiative, in order to improve the environmental performance of the construction process or of the construction product.

References

Ley 38/1999 de 5 de Noviembre de Ordenación de la Edificación (Act 38/1999 of 5th November on Building Construction Management)

CACEC, 2011. Personal Communication in the Construction TWG Kick-off meeting for the development of the Reference Document according to Article 46.1. of EMAS regulation 1221/2009. Brussels.

5.4 Background information

5.4.1 Environmental performance of the sector and the potential for improvement

In this section, some relevant data of the performance of the construction sector are shown. From the environmental point of view, the environmental impact of construction activity is usually neglected when calculating the life cycle performance of products, especially buildings. This simplification is due to the long lifetime of the building and due to the significant environmental impacts occuring during its use. This has led to a peculiar situation, where many research projects, ecolabelling schemes, policies, legislation, voluntary initiatives, etc. target the *construction product*, i.e. a building, to improve its environmental performance, but not much effort is directed towards improving the *construction process*.

The lack of incentives, the traditional behaviour of the sector, the lack of decision power of construction companies in a very complex business structure and the prevalence of economic criteria do not allow the sector as a whole to pursue persistently the best environmental performance, which itself depends mainly of individual initiatives.

Looking at the industry as a whole, Figure 5.3 (a) shows the amount of waste generated per capita in EU countries, giving an idea of the real impact of wastes generation in different countries. Except for Nordic countries, which have higher waste generation from mining and quarrying, construction activity is the main responsible for waste generation in the other countries. According to Figure 5.3 (b), two tonnes of construction waste are generated per capita, which is more than 50 % of the total amount of waste. Other industrial sectors, such as mining and quarrying, electricity and water supply and manufacturing of products generate about 1.7 tonnes of waste per capita. The services sector generate less than 400 kg per capita.

The intensity of waste generation is also high, as shown in Figure 5.3. This chart has strong links with the economic aspect of waste management. Mining and quarrying generate more than 1500 tonnes of waste per EUR million turnover. Construction activity generates more than 600 tonnes, electricity and water supply about 400 and the manufacturing industry about 60 tonnes. Incorrect management and treatment (costing about EUR 70 – 100 per tonne) can multiply waste management costs by a factor of 2 in the construction sector. Nevertheless, the figure of 600 tonnes per million EUR has to be taken into account with caution, as activities under the construction definition are really heterogeneous: demolition and earthworks in civil engineering activities produce much more wastes than building construction or other specialised activities.

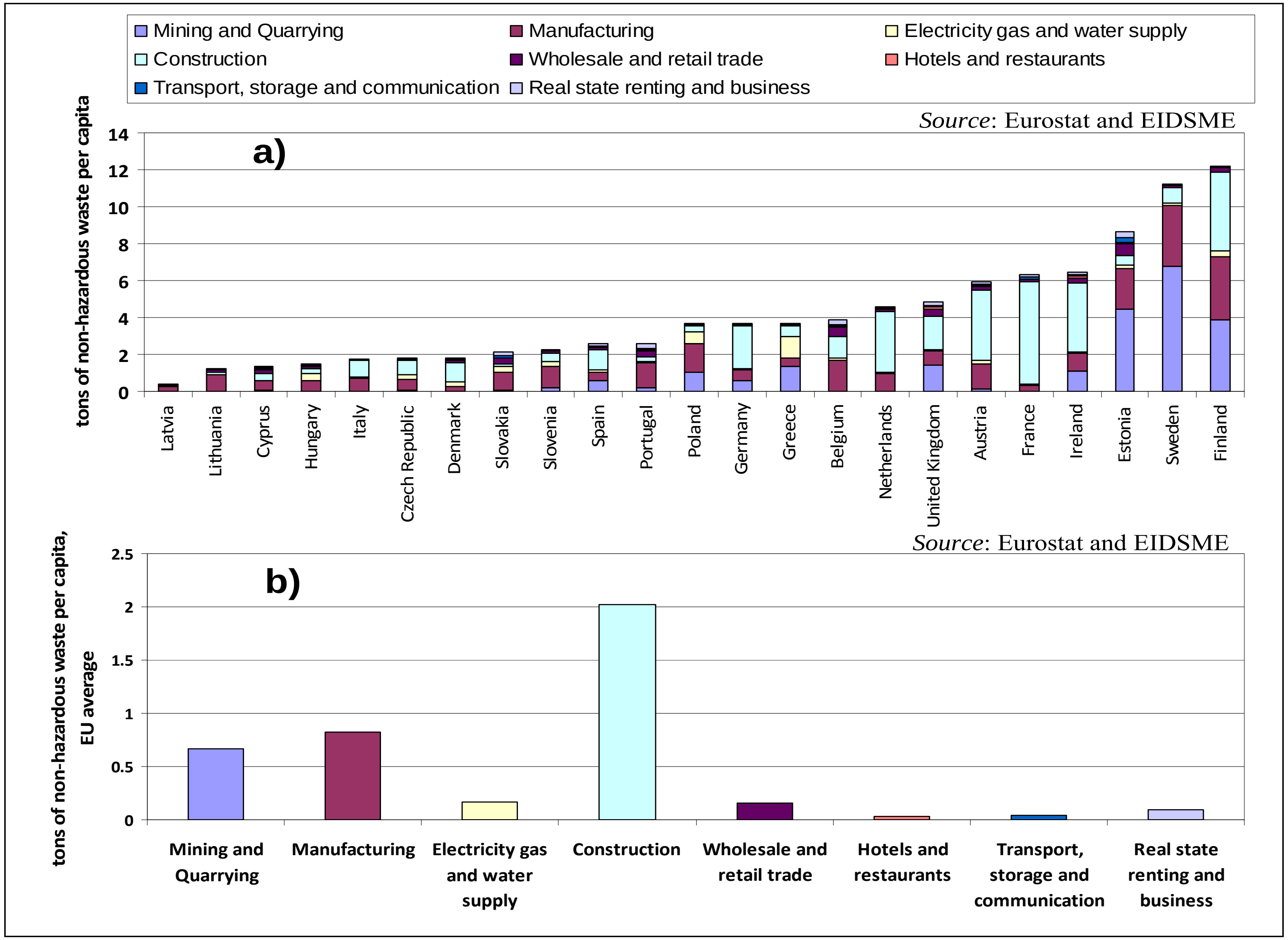
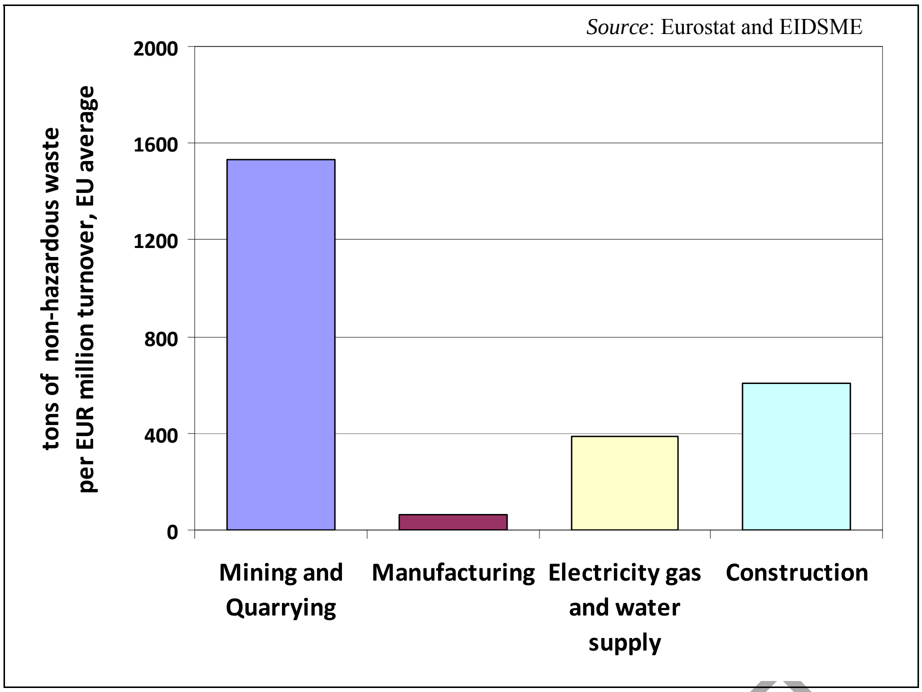


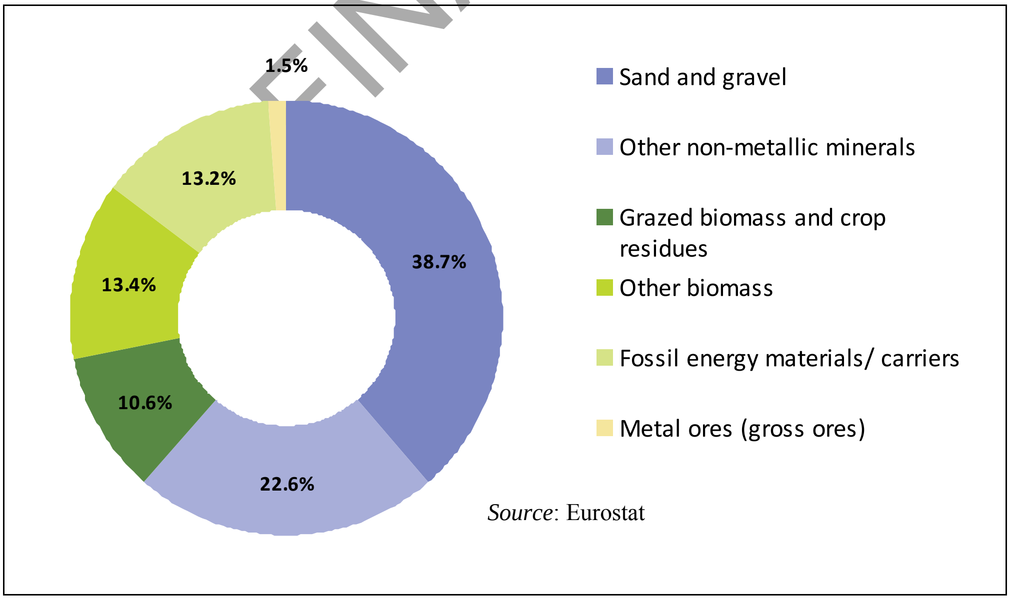
Figure 5.3: (a) Non-hazardous waste generated per capita in different sectors for 24 EU countries. (b) European average of non hazardous-waste generation per capita for different sectors



Source: Eurostat and EIDSME

Figure 5.3: Non-hazardous waste generation from industry and construction per EUR million turnover

In general, almost 40 % of the total materials extraction in Europe is sand and gravel (Figure 5.4.) So, it can be concluded that the impact of construction in natural resources is quite relevant. Germany, France, Italy and the United Kingdom extracted almost 60 % of sand and gravel in Europe during 2007, as shown in Figure 5.5. Nevertheless, the evolution of extraction shows that in 2007 these countries have extracted 10 % less than in 2000. Countries like Ireland, Spain, Sweden, Finland, Slovenia, etc. have had sharp increases of materials extraction. It is also noticeable that the main extractors per capita are Nordic countries and Cyprus.



Source: Eurostat

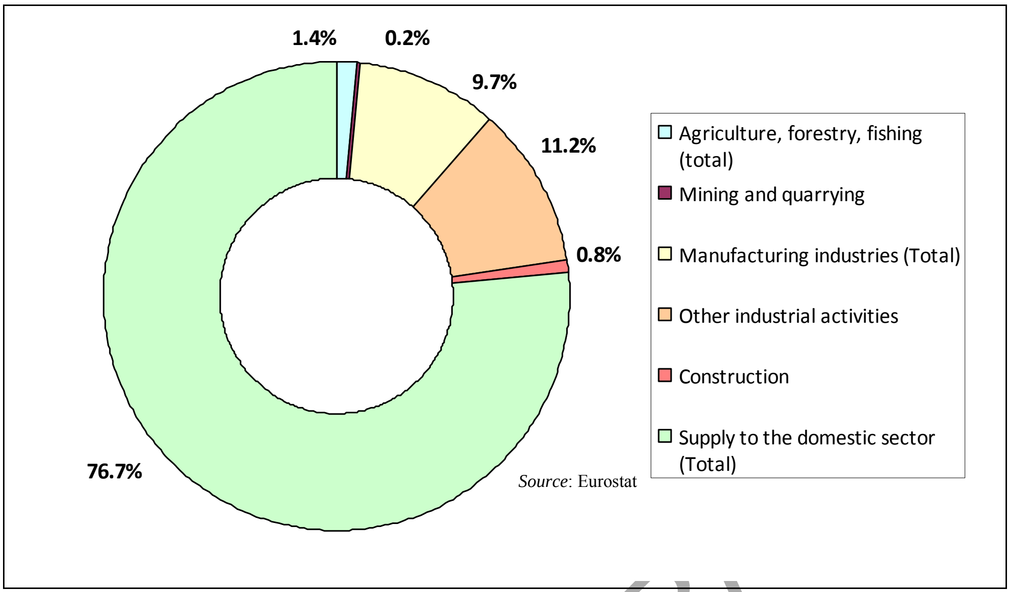
Figure 5.4: Breakdown of domestic materials extraction in Europe.

Source: Eurostat

Source: Eurostat

Figure 5.6: **(a) Sand and gravel extracted for several years in 23 EU countries. (b)Sand and gravel extractions per capita for several years in 23 EU countries.**

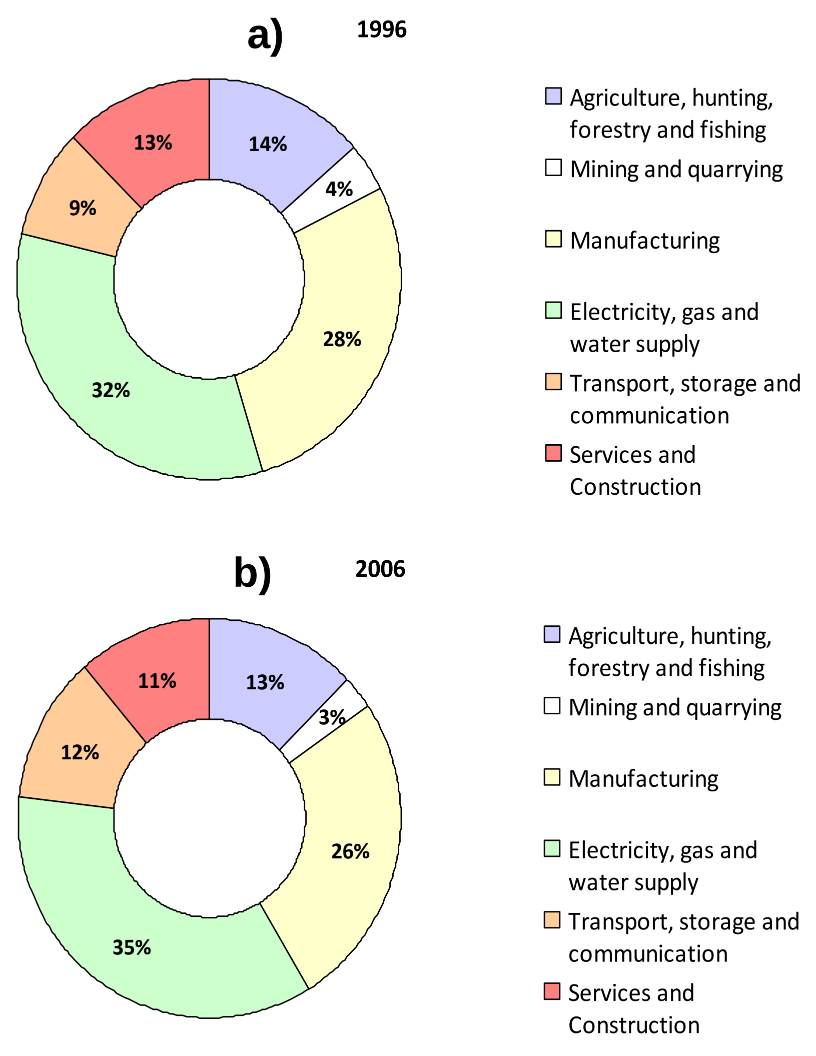
Water consumption is not relatively high for the construction sector. Figure 5.7 shows the breakdown for water consumption in Spain. As observed, water use in construction is not higher than 2 litres per capita per day, which is a low value if compared to household consumption, about 180 L per person and day. Regarding water, affectation to groundwater and waterways should be considered carefully. No statistics on the use and the impact on groundwater are shown.



Source: Eurostat

Figure 5.7: Breakdown of water consumption per sector in Spain.

Greenhouse gases emissions are produced in the construction sector due to the use of non-renewable energy sources, usually from the electricity grid or generated by the combustion of diesel to produce electricity or to work machinery. Nevertheless, greenhouse gases emissions arising from construction transport are much more relevant. Figure 5.8 shows the breakdown for greenhouse gases emissions in 1996 and in 2006. The relative contribution of services and construction has been reduced, while the contribution of transport and electricity has increased. The total carbon footprint of building construction is negligible compared to the carbon footprint of the service life of the building, where heating and electricity are the main causes of GHG emissions.



Source: Eurostat

Figure 5.8: Greenhouse gases generation breakdown for different sectors, except for domestic sector. Data for the EU 27.

Figure 5.9 shows the performance of a construction process of a non-residential building. In total, more than 260 tonnes of wastes are generated, including debris to be recycled, with a significant fraction assumable as municipal waste. For this site, moved earth is not considered as waste since it is used as raw material at the same or different sites. The consumption of water is low compared to the service year of a similar building. In terms of occupancy, the consumption of water during construction is about 16 L per final occupant per day (not per employee). Electricity consumption is also low compared to a service year, as it can be assumed around 6 kWh per m^2 and year(25). Nevertheless, part of the needed energy for the construction site comes from a diesel power generator, which consumes more than 15 kWh per m^2 yr. So, the primary energy performance of the site is about 30 kWh/m^2yr. Although it cannot be considered as relevant as energy consumption during a year of use (about 100 – 200 kWh/m^2yr), it neither can be considered negligible.

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(25) Year of construction phase, not of service life. The impact of construction per year of service life can be calculated by dividing these values by a factor of 15.

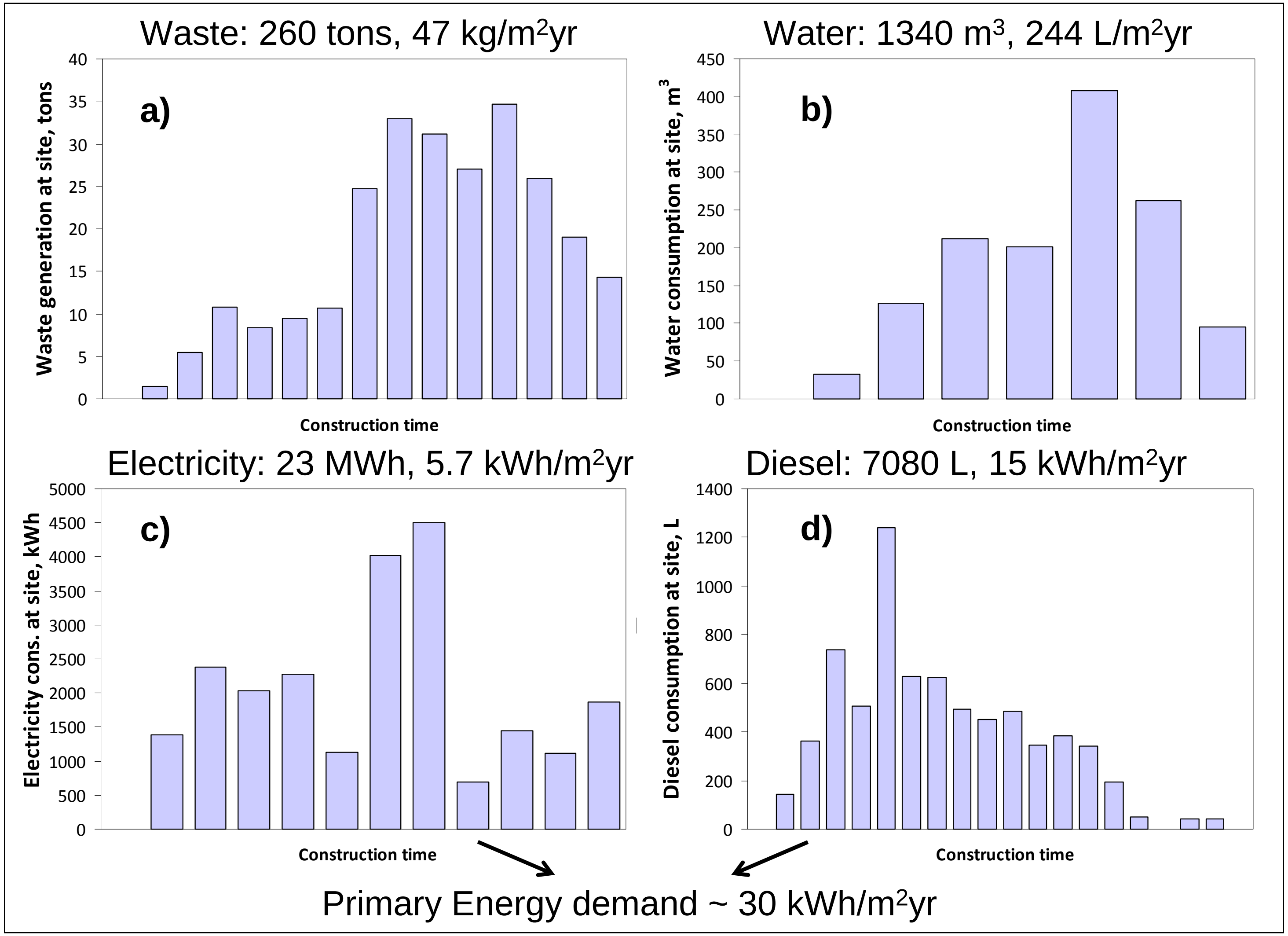


Figure 5.10: Real data from a construction site: a) waste generation, b) water consumption, c) electricity consumption and d) diesel consumption

Figure 5.11 and Figure 5.12 show waste generation performance of construction sites for different building types derived by the Construction Resources and Waste Platform, 2009. As observed, average values are around 15 – 20 m^3 of waste per 100 m^2 (around 100 – 150 kg/m^2). Lower waste generation is observed for industrial buildings, where, usually, more prefabricated elements are used and, therefore, less waste is generated at site. This behaviour is opposite if the amount of waste is derived per project values (Figure 5.11b), where industrial buildings show bigger rates because of the cheaper value of the project compared to other buildings.

Figure 5.12 shows waste typologies for different types of buildings. As observed, there are 4 main fractions of waste: bricks, concrete, mixed waste and inert fraction. Hazardous waste is a very small fraction. The rest is composed of timber, packaging waste, metals, etc. The composition of wastes is quite similar for all building types, except for public and industrial buildings. The supposed simplicity for industrial buildings in their composition, make the generation of waste concrete higher than for other buildings. Public buildings construction generates a significant amount of inert waste, which may be a consequence of bad accounting or a measurement methodology for inert and concrete wastes.

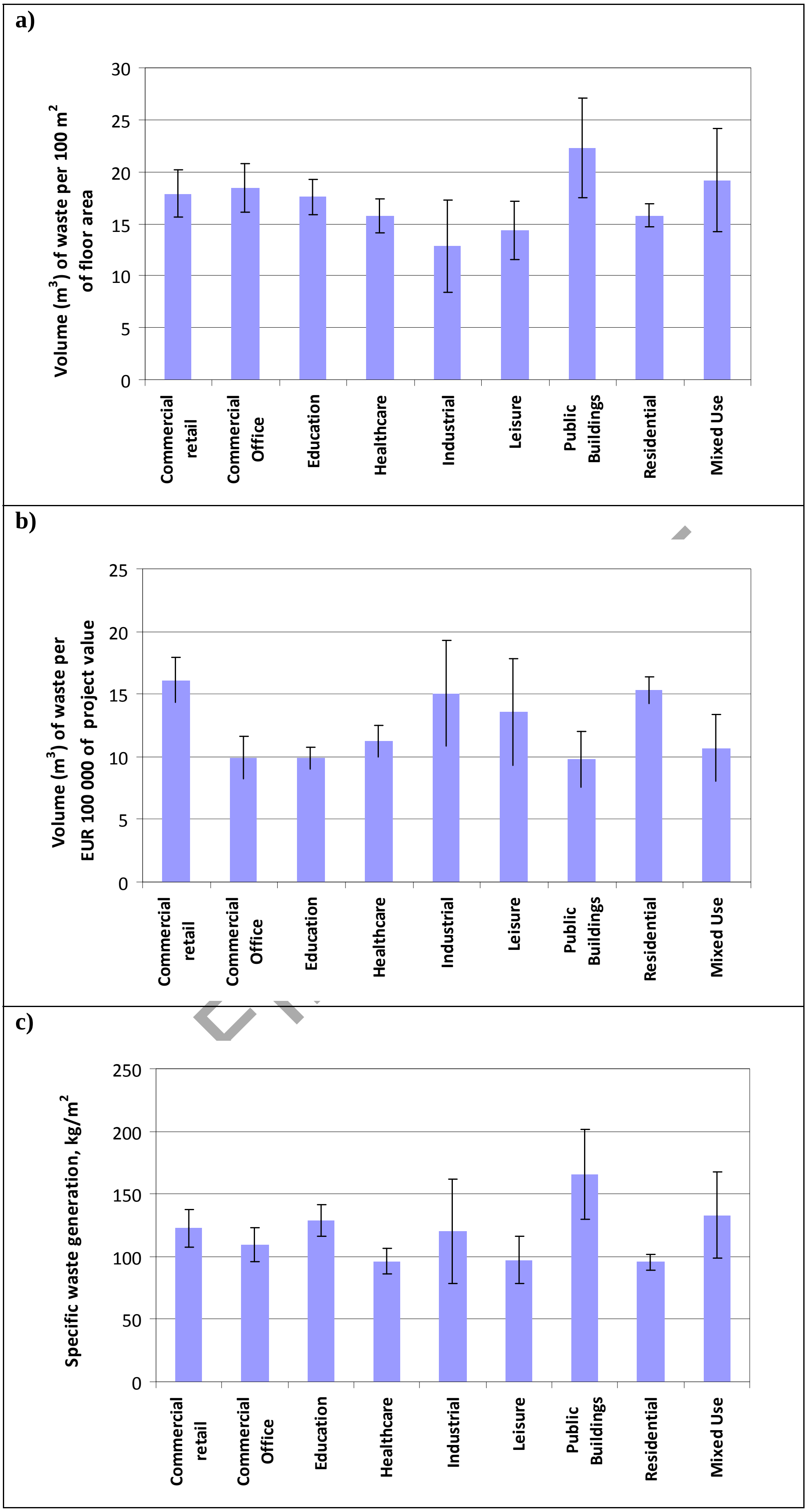


Figure 5.11: Waste generation during construction for different types of buildings

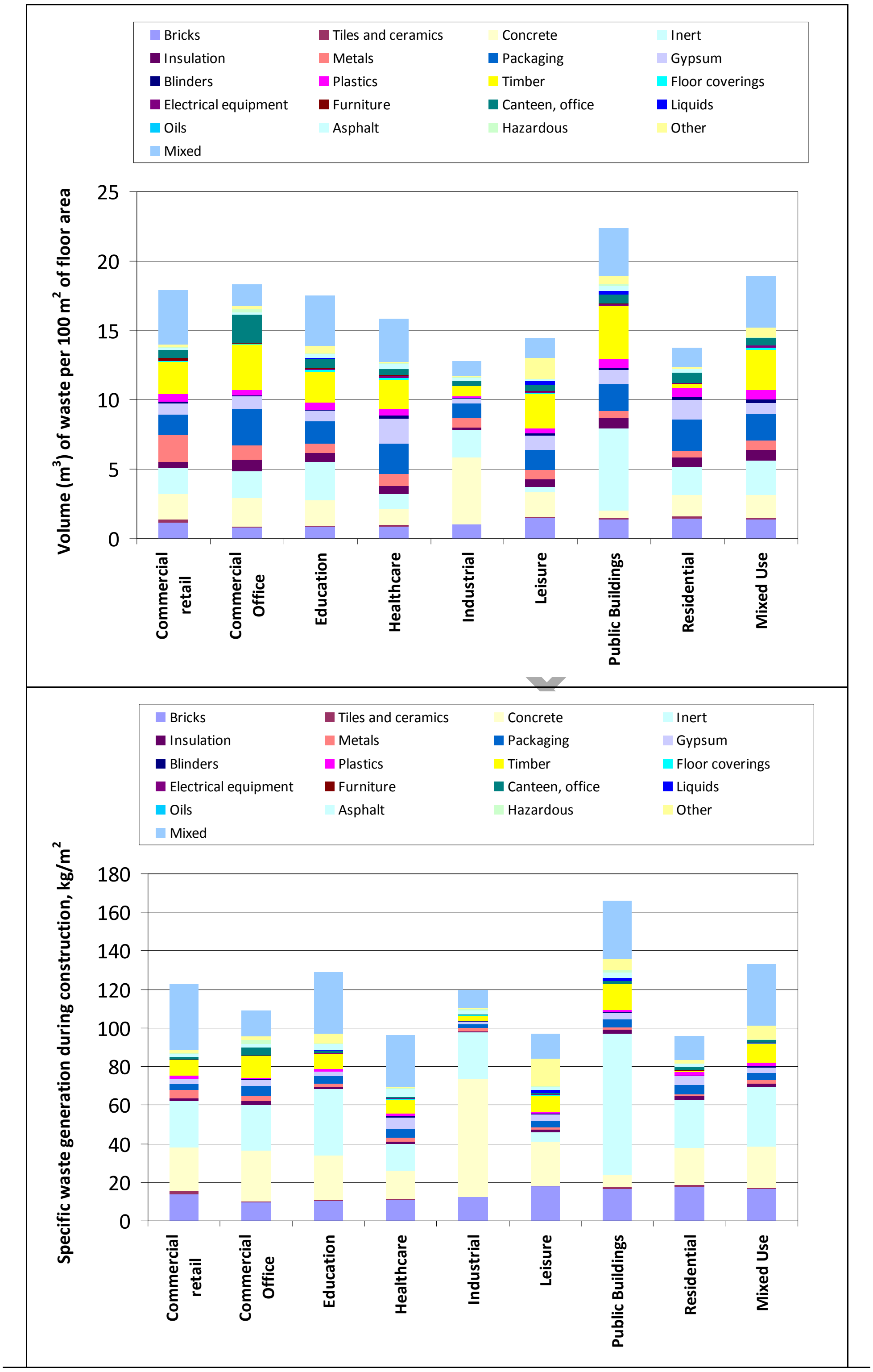


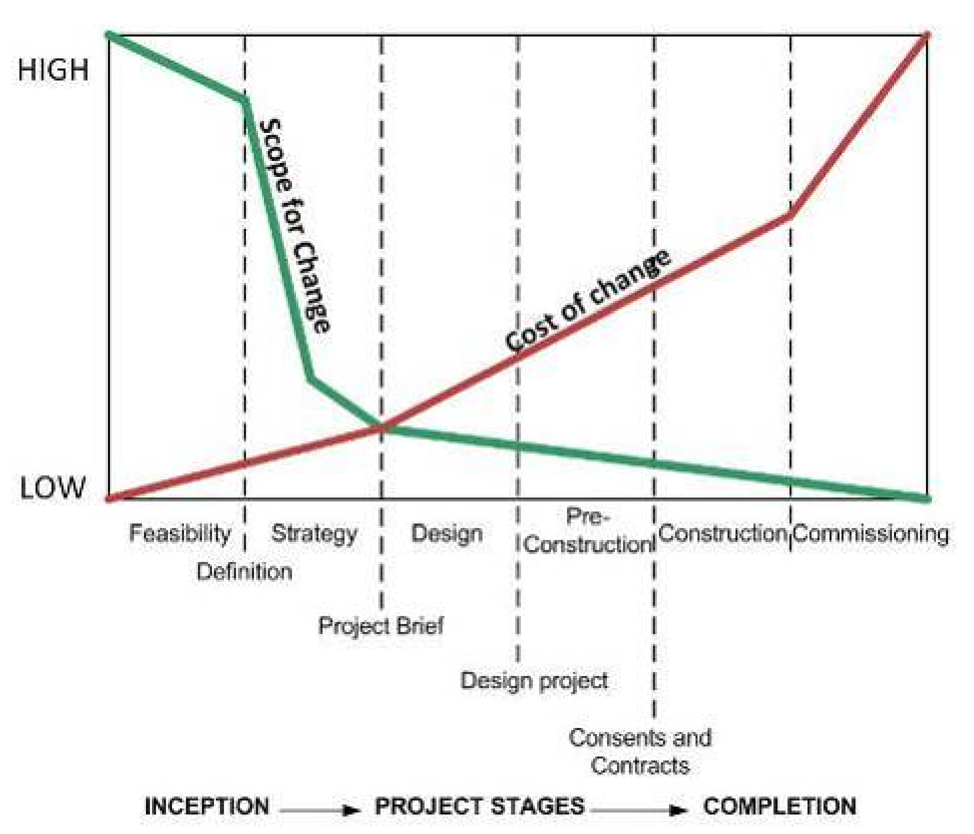
Figure 5.12: Waste generation per type during construction for different types of buildings in volume and mass units

5.4.2 Technical background

In this chapter, some technical background information is given in order to support the description of techniques that may be considered best environmental management practice. This chapter is divided into these sections:

- Pre-construction: planning and organisation of construction activity
- Site preparation
- Earthwork
- Construction and demolition waste definitions
- Pre-fabricated elements
- Concrete works
- Machinery and equipment
- Health and safety plans.

Figure 5.13 illustrates how the construction process fits into the business structure and how the scope for change and the cost of change can evolve during the life cycle of the project. This figure, adapted from CIB, 2002, is from the perspective of a customer. In order to reduce the cost of design changes, feasibility and strategy stages are very important, as project definition is, somehow, frozen here. Improvement of the environmental performance of the construction product or of the construction process should be defined in the project brief, as costs would most likely increase if environmental improvements are decided during the construction phase.



Source: CIB, 2002 with modifications

Figure 5.13: Relationship between scope for change and cost of change

5.4.2.1 Pre-construction: planning and organisation

This stage, after the design is concluded, consists mainly of the planning, organisation, and preparation of the construction process. In the references (CIB, 2002), this stage also includes the design process, which is not considered in the definition given here. Once the constructor accepts the project or wins a public tender, the preconstruction stage considers all the steps necessary before starting the operation. For instance, all the consents and contracts with the customer and the designer, agreements with subcontractors and suppliers, pre-assessment of construction site (groundwater sampling, geological tests, etc.) This stage is considered to end when the construction activity starts. Important decisions regarding environmental management should be made here, as a consequence of the design and the foreseen environmental performance.

5.4.2.2 Site preparation

Firstly, before any earthworks and the construction itself, the company has to prepare the site and determine areas for construction equipment and certain construction processes. Ground and groundwater conditions have to be determined and recorded. Also, test pits and test drillings are performed. The construction area has to be analysed to find barriers and difficulties, such as old cables, pipes and foundations. Often, existing infrastructure has to be redirected by detours planning, with protection and safety signals set up around the site and their changes during construction. A plan and an inventory of the selected site have to be prepared to minimise negative impacts on the pre-existing environmental conditions on the selected site (Cole, 2000).

To ensure a well functioning construction site and to minimise impacts on the environment and land use, all relevant supply and utility lines needed throughout the whole construction process have to be considered and, as far as possible, already applied before construction starts.

Within the construction phase, a huge amount of logistic processes are performed, so the site should have sufficient transport ways and circulation areas. Those areas are prepared in advance, while existing environmental and infrastructure conditions are affected. The design of these circulation areas should minimise land use and should, if possible, not be changed during the construction phase. Unnecessary circulation should be avoided. In general, the compaction and sealing of soil has to be reduced to secure sufficient and safe run-off during heavy rainfall and to minimise the eutrophication potential and the impact on the change of the groundwater level. Within this context, it would be favourable to use biodegradable lubricants. Nevertheless, the ground has to be protected against spilled hazardous substances. Truck weights should be reduced as far as possible, as heavy lorries increase the extent of soil compaction.

Certain arrangements have to be installed and a safety management plan has to be established to protect workers and the surroundings. Besides fences, platforms, scaffoldings, safety cloths and various other safety equipment, all personnel should be trained in health and safety issues.

Water management, including water supply, drainage, water cleaning and groundwater protection on site, is essential for ,and during, the whole construction process. From the environmental perspective, groundwater pollution through hazardous substances and materials resulting from construction and transportation activities has to be avoided. Therefore use of solvent-based substances should be minimised and stored safely. Processes with a possible hazardous impact on groundwater should be performed within certain areas, where the ground is protected by pavements or waste water treatment systems. If processes to be carried out on site might affect groundwater, the site management has to apply flexible ground protection facilities, such as impermeable covers or mobile waste water treatment systems. Furthermore, water consumption on site has to be optimised. Additionally, rainwater and grey water should be collected and used wherever possible, such as for equipment cleaning and toilets.

Generally, pumps are applied to supply the construction site with water, to eliminate surface water in excavation pits, to transfer sewers and to lower the groundwater. In this case, submersible motor-driven pumps are used for construction operations, as these water pumps are able to pump sewage and slurry, besides pure water. Lowering of the groundwater becomes necessary when the foundation of the building is lower than the groundwater table, or when ground upraise by groundwater is expected. There are different procedures depending on the ground conditions and conditions imposed by public administrations (König, 2005).

Different portable buildings are necessary on site during the construction process, for worker accommodations. Sanitary facilities, offices and storerooms for tools, equipment and construction materials have to be placed on site. The arrangement of these portable, modular buildings should require the minimum space, to reduce their impact and to guarantee safety. Moreover, they can be located to protect existing vegetation from being trampled and to reduce soil compaction by workers (Dress, 2002; Cole, 2000)

5.4.2.3 Earthwork

The spectrum of earth or soil in construction activities is very wide, encompassing fine grain sizes up to solid rock and easy extractable and applicable soils, such as sand and gravel up to more difficult applicable soils, such as silt and clay. Earthworks are the activities arounds the change of soil in terms of form, location and density. Earthwork includes especially soil removal, such as building of cuttings, pits and ditches as well as soil application, e.g. land fills. Hence earthwork encompasses loosing, loading, transportation, unloading as well as the application and densification of soil. Transportation is the most expensive activity of earthworks. Transport distances have to be minimised to reduce costs and to reduce the environmental impact of this activity. For transportation of a huge amount of soil, often conveyors are used. Often the extracted material is prepared as construction material for concrete works or road ballasts, such as the crushing of stones and washing and filtering of gravel sand (Bauer, 1994).

On construction sites, soil is removed by excavators, with different digging tools, such as dippers, backhoes, loading shovels, grabs, scraper bodies, dozer blades and buckets. Solid rock has to be exploded or ripped by heavy caterpillars with ripper teeth, until the rock is small enough to be removed by an excavator or loader. Space can be reduced, by using hydraulic excavators with breaker hammers to loose rock.

Excavation works in deep water require dredgers, although sometimes it is possible to use normal excavators and to place them on a pontoon.

A selection of earth works equipment is listed below:

- hydraulic excavators
- hydraulic crawler excavator
- wheel loader
- backhoe-loader
- dump truck/dumper
- caterpillar
- scraper
- motor grader.

One very important aspect is to consider the noise produced by this equipment, which can be up to 100 dB, can be reduced in general up by to 15 dB through shielding of the engine and via the installation of sound absorbers on intake and exhaust systems (BG-BAU, 2010).

Soil compaction is performed to increase the soil density by reducing the pore volumes filled with water and air. Densification enhances the load bearing capacity and avoids deformation and settlements, to secure the foundation quality of a structure. Different compaction methods can be applied, depending on the soil type and its composition. Soil can be grouped in cohesive, non-cohesive, mixed soils and solid rock. Compaction methods include static and dynamic compaction, whereas dynamic compaction it is necessary to differentiate between vibration and ramming compaction. With regards to the soil type and the thickness of the soil layer, the soil compaction equipment are vibration rammer, vibration plate and vibrating roller (König, 2005)

Topsoil has to be removed and stored separately, to be able to apply it to the site at the end, after all the construction work is finished. It has to be protected for later re-cultivation. Erosions through wind and rain on unstable soil is a major risk for people and the environment on construction sites, as they can result in water pollution, dust generation and dangerous situations in connection to earth-moving activities, such as clearing, grading and excavating. Hence the construction company has to include certain erosion control activities in their risk management plan (MIDWESTIND, 2010).

Earthwork also has a significant impact in the form of dust emissions. Dust emissions can be reduced by sprinkling heavily on dry days. For sprinkling or cleaning purposes, water out of the settling basin or collected rain water should be used. Also, process water from construction sites contains mineral fines; this water has to be collected in a settling basin. Water from concrete production has to be neutralised because it is basic/alkaline. For process water in contact with oil or fuel, oil separation becomes necessary.

Construction noise needs to be reduced as far as possible to avoid nuisance to the surroundings. In general, this is an important issue in the selection of construction equipment, such as compressors. Furthermore, it is a good practice that construction companies inform beforehand the surrounding residents about the type, the degree and the duration of the construction process, before starting. Critical noise and dust generating activities should be scheduled to minimise disturbances. Necessary noisy construction equipment should be placed as far away as possible from residents by taking into account natural and artificial noise barriers. Windless areas should be chosen for stockpiles of sand, soil and aggregates (Cole, 2000; Conrady, 2007, CIRIA, 2010, BG-BAU 2010).

5.4.2.4 Construction and demolition waste: definition, reporting and recycling options

As defined in the Waste Framework Directive, WFD, 2008/98, waste is any substance or object which the holder discards or is required to discard (EP, 2008). Construction and demolition waste is categorised as a waste under category 17 of the European List of Wastes, as shown in Table 5.10 (EC, 2000).

Table 5.10: Construction and demolition waste according to the European List of Wastes

17 CONSTRUCTION AND DEMOLITION WASTES (INCLUDING ROAD CONSTRUCTION)	
17 01 Concrete, bricks, tiles, ceramics, and gypsum-based materials	17 01 01 Concrete
	17 01 02 Bricks
	17 01 03 Tiles and ceramics
	17 01 04 Gypsum-based construction materials
	17 01 05 Asbestos-based construction materials
17 02 Wood, glass and plastic	17 02 01 Wood
	17 02 02 Glass
	17 02 03 Plastic
17 03 Asphalt, tar and tarred products	17 03 01 Asphalt containing tar
	17 03 02 Asphalt not containing tar
	17 03 03 Tar and tar products
17 04 Metals (including their alloys)	17 04 01 Copper, bronze, brass
	17 04 02 Aluminium
	17 04 03 Lead
	17 04 04 Zinc
	17 04 05 Iron and steel
	17 04 06 Tin
	17 04 07 Mixed metals
	17 04 08 Cables
17 05 Soil and dredging spoil	17 05 03* Soil and stones containing dangerous substances
	17 05 04 Soil and stones other than those mentioned in 17 05 03
	17 05 05* Dredging spoil containing dangerous substances
	17 05 06 Dredging spoil other than those mentioned in 17 05 05
17 06 Insulation materials	17 06 01* Insulation materials containing asbestos
	17 06 02 Other insulation materials
17 07 Mixed construction and demolition waste	17 07 02* Mixed construction and demolition waste or separated fractions containing dangerous substances
	17 07 03 Mixed construction and demolition waste other than those mentioned in 17 07 02

Source: EC, 2000. Waste categories with * correspond to hazardous wastes

In the WFD, an objective for recycling, preparing for reuse and other recovery operations (e.g. backfilling) rate is set at 70 % by 2020, excluding category 17 05 04 (naturally occurring material, excavated in construction works). Nevertheless, the reporting of wastes generation is usually not performed under category 17 of the European List of Wastes. There is a need to understand how official statistics are regulated, as many companies base their reporting on them. A different classification system, under the regulation 2150/2002 on waste statistics (EP, 2002), is used for national reporting. The main category reflecting the waste generated by the construction sector (F code of the NACE rev. 2 classification) is category 12 on mineral waste. These different definitions and reporting issues may lead to different approaches for construction companies when dealing with wastes monitoring, especially their recovery rate and on the definition of targets. In order to establish a harmonised understanding for this document, Figure 5.14 shows the links of different approaches for wastes monitoring in the construction sector.

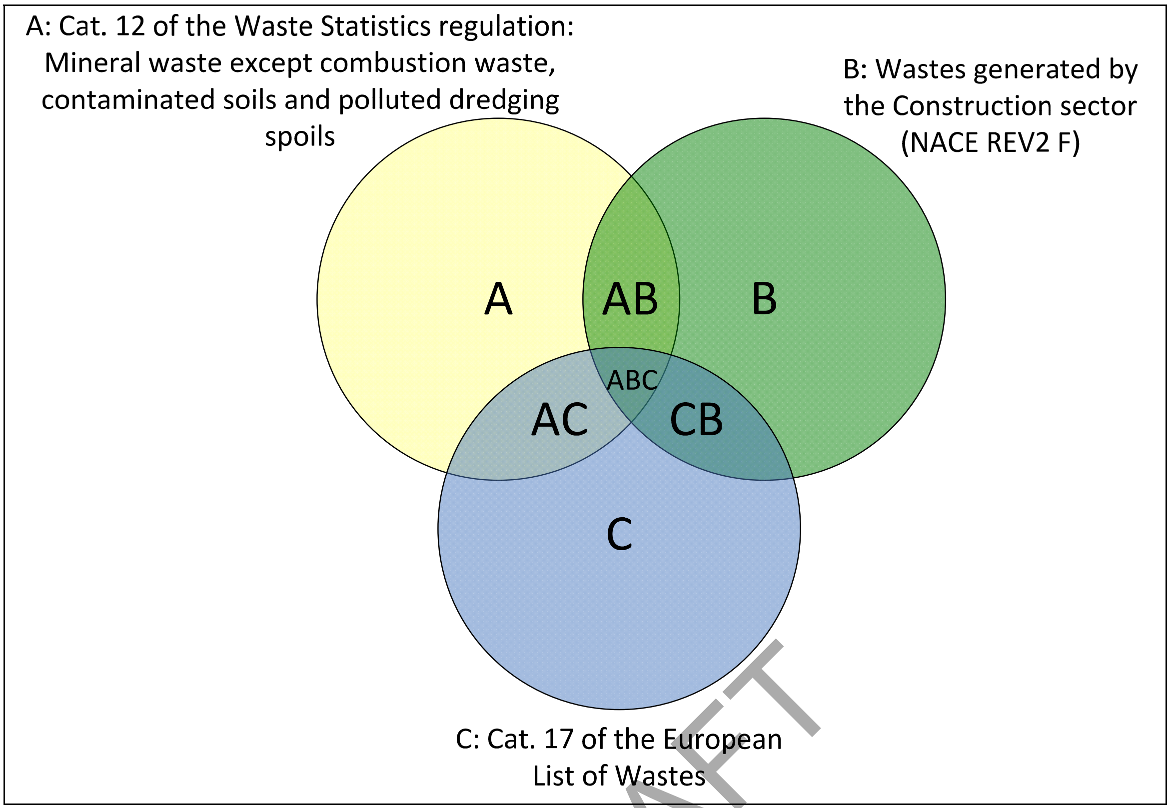


Figure 5.14: Links between different approaches to define wastes in the construcion sector

As aforementioned, the most important category from the waste statistics regulation for the construction sector is number 12, mineral wastes, which should gather the data for:

- 12.1. Construction and demolition wastes
    - 12.11 Concrete, bricks and gypsum waste
    - 12.12 Waste hydrocarbonised road-surfacing material (asphalt, tar products, insulation material containing asbestos)
    - 12.13 Mixed construction wastes
- 12.2. Asbestos wastes
- 12.3. Waste of naturally occurring minerals
    - 12.31. Waste of naturally occurring materials
- 12.4. Combustion wastes
    - 12.41. Waste from flue-gas purification
    - 12.42. Slags and ashes from thermal treatment and combustion
- 12.5. Various mineral wastes
    - 12.51 Artificial mineral waste
    - 12.52 Waste refractory materials
- 12.6. Contaminated soils and polluted dredging spoils
    - 12.61 Polluted soils and rubble
    - 12. 62 Polluted dredging spoils.

The main contribution to category 12 of the waste statistics regulation should come from construction and industrial sectors. According to data reported in Eurostat, the average contribution of construction sector to total category 12 except for combustion waste, contaminated soils and polluted dredging spoils (i.e. AB/A in Figure 5.14) is about 47 % (with wide variability among Member States). So, the construction sector produces about half of total mineral wastes in Europe (including excavated materials).

The proportion of wastes from category 12 of waste statistics regulation on the total waste generated by the construction sector (i.e., AB/B), is about 89 % for the EU27 (with a range from 60 to 95 % for Member States). There is no reported data for category 17 of the European list of wastes on construction and demolition waste. This category classifies waste according to its nature, so one can say that construction waste from sectors other than F (Construction) is included in this category. At the same time, all the wastes coming from the construction sector are not just construction and demolition activities, as there would be a significant part for packaging materials, office-related wastes, etc. So, the scope of the waste sections of this document focuses on the intersections AB and CB of Figure 5.14 and can be described as:

Non-hazardous and hazardous wastes, generated by companies belonging to the construction sector (activity code F), of category 17, plus mineral inert wastes from special activities and composed of cement, concrete, bricks, gypsum, ceramics, tiles, asphalt, tars, insulation material with and without asbestos, naturally occurring materials coming from excavation, soils, dredging spoils, wood, glass, plastic, metals, other inorganic materials and mixtures of them.

When it comes to waste monitoring on site, it depends on how the wastes are sorted and separated. A very important factor for waste management is the available space for several types of waste collection, the foreseen quantities and the presence of appropriate waste managers and recycling infrastructures in the region, which may lead to clear inconsistencies. The waste generator (e.g. the construction company) assumes the costs for waste separation, sorting and its management costs, but this should be done in accordance to the final treatment process for every waste fraction..

Besides waste prevention, several methods exist to reduce construction waste and produce cost savings through reuse and recycling. Within this context, reuse describes materials used as they are or converted on site, while natural materials are removed from the site. Recycling is the next level, when there is no possibility of reuse. The implementation of reuse methods on site has several benefits, as the need for new materials is reduced and landfilled waste is minimised. Especially, on-site reuse reduces emissions, such as greenhouse gases emissions, as well as energy and water consumption related to the production of construction elements and its transport. Moreover, through recycling and reuse, waste disposal costs are minimised, and revenues can be derived from recycle, reuse and recovery.

5.4.2.5 Pre-fabricated elements

When pre-fabricated elements are used, a certain level of standardisation is achieved. This implies repetition and continuity and supports the optimisation of materials and construction elements. Standardisation is therefore good to optimise the building in an economic and environmentally-friendly way. Pre-fabrication is an excellent technique to implement standardisation within the construction process. It describes the manufacturing of construction elements off-site, which are assembled on site afterwards. Manufacturing off-site facilitates fast and standardised mass-production connected to enhanced quality and less impacts on the environment, such as reduced vibration, noise, dust and waste generation on site (Powerhouse, 2010), while transport needs may increase. Economic optimisation relies on the reduction of construction time and in the reduction of resources needed (see Section 3.4.7).

5.4.2.6 Concrete works

Concrete is the most popular and most commonly applied material in construction. Complex shapes can be made out of concrete, as it is fluid in the preparation phase and becomes solid and resistant against pressure after hardening. Furthermore, it can be combined with steel, where it becomes tensile as well. Concrete consists of cement, water, a range of aggregates such as gravel, limestone and granite, and finer aggregates such as sand and fly ash (Drees and Krauß, 2002; SustainableBuild, 2010).

Conventional concrete is not environmentally-friendly, either in production, in use or in disposal. Many resources are needed, mainly energy and water, to gain and treat raw materials. The production of raw materials also results in environmental degradation and pollution. Furthermore, concrete has a large impact on global warming, as cement plants emit more than one billion tonnes of CO_2 per year, which is up to 5 % of the world's total amount of CO_2-emissions. The high energy consumption is mainly caused by the production of clinker, which requires very high temperatures. So, as clinker is the main component of cement, the more cement is included the more energy is necessary for one cubic metre of concrete. The main research and development efforts are focused on reducing the impact of concrete life cycle by reducing cement content and by using recycled materials (Wecobis, 2010; SustainableBuild, 2010; Innovations Report, 2010). The environmental impact of concrete and other materials life cycle is shown in Table 5.11, as reported by Zabalza et al., 2011. Concrete has less environmental impacts and primary energy demand in its life cycle than other materials, but the use of concrete and cement in construction (at least, 60 % of the building weight) makes the impact of concrete high in absolute terms.

Table 5.11: Life cycle primary energy demand and global warming potential of several construction materials

Construction material	Primary Energy demand MJ/kg	Global Warming Potential kg CO_2 / kg
Cement	4.2	0.82
Cement mortar	0.2	0.24
Reinforced concrete	1.8	0.18
Concrete	1.1	0.14
Ceramic tile	15.6	0.86
Quarry tile	2.2	0.29
Ordinary brick	3.6	0.27
Steel	24.34	1.53
Aluminium	136.8	8.57
Sawn timber, softwood, planed, air dried	18.395	0.267
Particle board, indoor use	34.65	0.035

Source: Zabalza et al., 2011

Usually concrete is premixed in stationary plants and then transported by trucks. A mixing plant on site is very expensive and only useful, when a great amount of concrete is needed, e.g. for tunnels, bridges and power plants. Mainly, there are two mixing systems, rotay and shaft mixers. Today small rotay mixers are only used for small amounts of concrete. They consist of a rotary barrel mixer with a mix and guiding plate attached. For the production of high quality concrete, the shaft mixer is used (König, 2005; Drees and Krauß, 2002).

One important environmental issue regarding concrete mixing facilities is the recycling of the remaining concrete. Remaining concrete comes from the construction site, as well as from facilities cleaning. Concrete is rinsed within the recycling facility, and at the same time water loaded with cement and aggregates are separated. So, aggregates and about 50 % of the cement water can be reused within the concrete production facility. Noise is also an important environmental aspect of concrete mixing facilities. The noise of the facility itself can be minimised with the help of an overhead noise barrier. Furthermore, noise through wheel loaders and transportation vehicles has to be considered. The third major environmental aspect is dust emissions. Dust is mainly generated by transportation and weighing of cement. Here, special filters and security valves on the cement scale and the mixer reduce dust emissions (König, 2005).

After mixing, concrete is mainly transported by truck mixers of different sizes onto the construction site. The sole exception is in road construction. Here, articulated lorries with a steel basin are used for the enormous concrete amounts required.

At the construction site, concrete is placed in many different ways with respect to the amount of concrete needed for a component, the height of a structure and the required consistency of the concrete. The concrete pump is regularly used to move the concrete from the mixer into the formwork. Portable and/or stationary concrete pumps can be used: stationary ones are applied on major construction sites, as they are more efficient there. If the structure is too high, the concrete is placed with a crane and a concrete bucket (König, 2005; Drees and Krauß, 2002).

Concrete is compacted through vibration. Vibration reduces the friction within the grain structure; the grains settle denser and the air void content decreases, so high concrete quality and strength is obtained after hardening.

There are several concrete vibrator types available, encompassing internal, external and surface vibrators. Internal vibrators are mostly used for in-situ concrete on construction sites. Here, the vibrator is dipped directly into the concrete. The external vibrator is connected to the formwork and vibrations are transferred from outside through the formwork to the concrete. Surface vibrators are vibration plates used to gain a clean surface of ground slabs and roads. Vibration noise can be reduced in general through the setting up of a cover for noise protection around the vibrator and by the installation of sound absorbers on intake and exhaust pipes of the vibrator (König, 2005; Drees and Krauß, 2002; DG-BAU, 2010).

After concrete pouring and until hardening, concrete has to be protected against damage and needs to keep moist, achieved with the help of plastic or jute membranes or by adding a vapour retarder paint, to avoid cracks from shrinkage. After hardening, concrete finishing works include certain coating and texturing methods to create a desired texture, smoothness and durability of the raw material. Major components of these coatings and paints are pigments/colour, a binder, holding the paint together and a carrier, dispersing the binder. Often volatile organic compounds (VOCs) are used in binders, carriers, stabilisers, thickeners and driers. VOCs contribute to ground-level ozone formation and to global warming (Bauer, 1994; SustainableBuild, 2010).

The construction company can reduce the environmental impact of finishing works by reusing membranes for the protection of poured concrete, to reduce waste, as well as by applying low-VOC, no-VOC or natural paints and coatings to minimise hazardous emissions (Bauer, 1994; SustainableBuild, 2010). Therefore, several ecolabels have been developed by different countries to indicate that the paint has fulfilled certain environmental requirements, in accordance with respective government regulations. In general eco-labelled outdoor paints and coatings are produced according to strict ecological criteria, contain no heavy metal, carcinogenic or toxic substances, include reduced white pigment quantities and release less solvents. In 2009/543/EC certain VOC limits are defined with respect to the European directive 2004/42/EC. A selection is shown in Table 5.12 (EC, 2010a; EC, 2008).

Table 5.12: VOC content limits for outdoor paints and vanishes regarding 2009/543/EC

Product Classification (Directive 2004/42/EC)	VOC limits (g/L including water)
Coatings for exterior walls of mineral substrate	40
Exterior trim and cladding paints for wood and metal including undercoats	90
Exterior trim varnishes and wood-stains, including opaque wood stains	90
Exterior minimum build wood stains	75
Primers (for exterior use)	15
Binding primers (for exterior use)	15

Source: EC, 2008

Spraying of concrete is a technique where concrete is sprayed at high speed against tunnel walls, walls of construction pits and against other construction elements. The concrete builds a formed mat on the surface, which is coverage to prevent loose rocks and soils. The concrete is strengthened and its water resistance is increased with the inclusion of steel fibre. Two major methods of sprayed concrete are available. In the dry method, dry premixed cement and aggregates are transported with pressured air from the spray machine to the spray nozzle. Water is added right before the concrete exits the nozzle; hence the consistency of the concrete can be regulated by the amount of applied water. The dry technique is especially adequate for smaller areas due to its high flexibility. This technique generates dust and quality problems. The wet-mix technique was implemented especially for tunnelling and will soon represent more than 80 to 90 % of all sprayed concrete works worldwide. The ready-mixed concrete is pumped and sprayed directly against the wall. The wet-mix method is often automated, connected to high quality control and cost effective execution. Recently research and development is being carried out in environmentally safe admixtures, such as alkali-free concrete accelerators, which protects the environment by reducing groundwater pollution through aggressive bases and increases work safety, as, for instance, reducing risks to respiratory diseases (Drees and Krauß, 2002; Ross, 2006).

Formwork and falsework has to secure the load transformation under construction, has to fit exactly and should be as economical as possible in use. Formwork consists usually of steel brackets and braces and formwork facings out of steel, wood or plastics. It is needed for most in-situ concrete structures. Falsework is usually a steel frame, either used as a temporary support of formwork and other construction elements, or as a working platform and safety scaffold. As formwork and falsework are quite expensive, their flexibility and longevity is highly important, so that they can be reused several times. Hence high resistance material is used, such as high-tensile steel. New inventions focus on modular design principles with the advantage of fast and flexible setting up and disassembling and at the same time gentle treatment of material to support material durability (Drees and Krauß, 2002; Bauer, 1994, Schaltec 2010)

Another innovative design principle is self-supporting formwork: precast concrete elements, which remain in the structure and are therefore formwork and construction elements at the same time. These precast elements can be produced to meet the individual structure-specific requirements. There are certain environmental and economic benefits connected to this technique. Less waste is generated, no additional formwork has to be produced, no disassembling and no storage area are needed, and the material remains as a structural element.

The reinforcement of concrete helps structures to bear and transfer tensile stresses, as concrete itself has high compressive strength but only little tensile strength. Reinforcement is available as pre-stressed or not-pre-stressed steel and as mats or bars. To prepare the steel in general, cutting and bending machines are used (Drees and Krauß, 2002).

5.4.2.7 Machinery and equipment

The selection of equipment depends principally on the characteristics of the construction material, the dimensions of the structure, extent, complexity and duration of the process, on the construction time schedule and the conditions on site (Bauer, 1994).

The major environmental impact of construction equipment results from energy consumption in the form of electric power and fuel. Emissions are produced from electricity or fuel consumption, as direct or indirect emissions. Some CO_2 emissions factors are shown in Table 5.13.

Table 5.13: Direct CO_2-emissions from fossil fuel combustion process of certain energy sources (LFU, 2004)

Fuel	Direct CO_2-emissions factor	Lower heating value [MJ/L, MJ/kg]
Petrol	2.33 kg CO_2/L	32.4
Diesel	2.64 kg CO_2/L	35.6
Liquefied gas	1.53 – 1.74 kg CO_2/L	23.8-26.3
Natural gas	2.75 kg CO_2/kg	46.5
Electric Power	0.62 kg CO_2/kWh	

Electric power does not generate CO_2-emissions directly, but does through the energy mix a resulting in 0.62 kg CO_2/kWh (BLU, 2010).

In this section, some common machinery used in construction processes is described for piling, drilling, transport, lifting and loading.

Piling machines are used to pile and pull steel sheet piles, beams, casings, tubes and carrier sections necessary to prevent collapses of pitwalls and foundation trenches. They consist of the pile and pull instrument and the support frame, which is usually a cable or hydraulic excavator. They can generate huge noise levels, up to 120 dB, which meets the pain threshold of human beings. Vibration piling reduces noise by about 15 dB. Additionally noise can be reduced by using sound absorbing casings around the equipment and the pile itself. Besides positive effects on the environment through the selection of the right technique and equipment, different designs of sheet piles, ducts and carrier sections can reduce the environmental impact of this construction activity (König, 2005; BG-BAU, 2010; Protherm-AG, 2010; Transzvuk, 2010).

Drilled piles are usually applied for the foundation of large structures and for highly resistant, water resistant or permanent retaining walls, to transfer the load into deeper, more stable ground layers. The adequate type of drilling machine is selected, with respect to the pile diameter and length, the soil type and its stability, available space and the drilling technique. (König, 2005).

Materials, components and elements are transported by trucks, rails and sometimes by ships over long distances or from regional distribution centres to the site and are moved by trucks and smaller vehicles on site. The size and capacity of the vehicle need to be optimised regarding the load, to increase the fuel efficiency and reduce emissions (Cole, 2000). For the selection of the transport equipment, especially trucks, the European emission standards, the Euro-Norm, need to be taken into account, which specifies limits for the emissions of trucks measured in g/kWh. Limits are set for carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) and particles. Table 5.14 lists emission standards for diesel engines.

Table 5.14: EURO emission limits for trucks with diesel engines

EURO emission standards for trucks [g/kWh]	Carbon monoxide [CO]	Nitrogen oxides [NO_x]	Hydrocarbons [HC]	Particles [PM]
EURO I	4.5	8.0	1.10	0.4
EURO II	4.0	7.0	1.10	0.15
EURO III	2.1	5.0	0.66	0.10
EURO IV	1.5	3.5	0.46	0.02
EURO V	1.5	2.0	0.46	0.02
EURO VI	1.5	0.4	0.13	0.01

Source: (EG, 2009; DieselNet, 2010)

Trucks fulfilling emission standards of EURO V operate with reduced gasoil consumption. Fuel consumption and CO_2-emissions of different trucks are shown in Table 5.15 below.

Table 5.15: Gasoil consumption and CO_2-emissions of trucks with control gear EURO V

Truck type	Vans				Platform trucks			
Engine [kW/Nm]	65/250	80/300	100/330	120/360	65/250	80/300	100/330	120/360
Diesel consumption [l/100 km]								
In town	12.6 – 13.7	11.5 – 12.5	11.5 – 13.0	11.6 – 12.7	13.7 – 15.2	12.5 – 13.3	13.0 – 13.6	12.3 – 12.7
Out of town	8.4 – 8.8	8.1 – 8.4	8.2 – 8.6	8.3 – 8.6	8.8 – 9.5	8.4 – 8.7	8.6 – 8.9	8.4 – 8.6
Combined	9.9 – 10.6	9.4 – 9.9	9.4 – 10.2	9.5 – 10.1	10.6 – 11.6	9.9 – 10.4	10.2 – 10.6	9.8 – 10.1
CO_2-emissions for the combined operation [g/km]								
	261 – 279	247 – 261	247 – 269	249 – 265	279 – 304	261 – 274	269 – 279	258 – 265

Source: Volkswagen, 2010

Some used measures to reduce fuel consumption are (Daimler, 2010):

- aerodynamic auxiliary equipment reduces fuel consumption by up to 10 %
- fuel consumption can be reduced when all tarpaulins are fixed
- having sufficient air pressure in truck tyres reduces fuel consumption by up to 8 %
- foresighted driving can result in 10 – 12 % less fuel consumption.

A partial shift from trucks to rail transport of excavated materials and pre-fabricated parts can reduce CO_2-emissions significantly. For instance, demonstration projects in Vienna showed CO_2-emission reductions around 55 % to 90 %, depending on the train traction type, diesel or electric (Vienna, 2004).

Lifting equipment encompass different crane types, such as tower, mobile and truck-mounted cranes, forklifts, construction elevators, as well as jacks and winches. The selection of the respective lifting and loading equipment requires certain considerations regarding process engineering, such as the construction method, project size, time and available workforces, as well as technical aspects, including geometry of the structure, maximum necessary bearing load, necessary lifting height, lifting pace and available space. Economic aspects to consider are costs for transport, assembling and disassembling, use and rent. The key environmental aspects regarding lifting and loading equipment are energy efficiency and air-emissions. Depending on the size and capacity of cranes, forklifts and excavators, energy consumption can vary enormously. For instance, the hourly fuel consumption of wheel loaders depends on the loading sequence per hour and can be calculated (Liebherr, 2002). Table 5.16 gives average gasoil consumptions and CO_2-emissions of diverse state of the art wheel loaders.

Table 5.16: Gasoil consumption and CO_2-emissions of diverse state of the art wheel loaders

Wheel loader capacity [m^3]	Loading sequence per hour	Fuel consumption [L/h]	CO_2-emissions [kg/h]
2.0	48	8.3	21.9
2.4	40	10.0	26.4
2.5	40	10.0	26.4
3.0	35	11.4	30.1
3.5	33	12.1	31.9
4.0	24	16.7	44.1
4.5	23	17.4	45.9
5.0	22	18.2	48.1

Source: Liebherr, 2002.

5.4.2.8 Health and safety aspects

On construction sites workers have to handle many toxic substances, including solvents, paints, pesticides, adhesives, wood preservatives and sealants. Health risks need to be prevented through the selection of materials that are safe to handle, by avoiding hazardous solvents and fibres, heavy metals and caustics. Hazardous substances should be labelled clearly, should be stored and disposed securely and waterproofed. In general, the construction company has to establish an occupational safety and health administration responsible for the safety and health of the workers over the whole construction phase. This organisation outfits the workers with safety helmets, shoes and glasses, as well as protective clothing, absorbent materials and dusk masks. Moreover, safety training for general and specific construction activities and training in clean-up procedures have to take place for all workers.

Additionally, the construction company should decrease the health risks to people close to construction during the construction process and also to building occupants after the construction process. Therefore construction zones in occupied buildings have to be isolated by airtight barriers, airlock-type doors, and separate ventilation systems have to maintain lower pressure in construction zones related to the occupied area. As mentioned before, construction companies have to select construction products and methods with low- or no-VOC reduce health impacts for later tenants (Cole, 2000)

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5.5 Techniques Portfolio

Against the given background and according to the knowledge gained with the background document, the input of the technical working group, technical visits, meetings with experts and the review of existing literature, the list of techniques that may constitute a best environmental management practice, BEMP, is shown in Table 5.17.

Table 5.17: Identified Best Environmental Management Practices for Construction Activities

Section	BEMP	Covered aspects and main focus (D= direct, I = indirect)	Techniques	Target audience
5.6.1	Best Environmental Management Practices for site organisation			
5.6.1.1.	Improving environmental performance through better management: definition of environmental management plans and specific needs for environmental management systems	All	Environmental Management Plans, Risks Assessment, Site workers awareness	Construction companies, subcontractors, service providers, developers, customer, public administration
5.6.1.2.	Monitoring the environmental performance of sites	All	Monitoring through management, specific monitoring of env. Aspects: dust, noise, claims, etc.	Construction companies, subcontractors, service providers, developers, customer
5.6.2	Best Environmental Management Practice for the construction process			
5.6.2.1	Waste prevention and management	Waste (D)	Reducing waste amount by increasing prevention and reduce the impact of waste through better management	Construction companies, subcontractors, service providers, developers, customer,
5.6.2.2.	Increasing materials use efficiency	Waste (D)	Networking, logistics optimization, reverse logistics to reduce resource consumption	Construction companies, subcontractors, service providers, developers, customer,
5.6.2.3.	Reuse of materials	Materials, Waste (D/I)	Reuse practices for construction and auxiliary materials.	Construction companies, subcontractors, service providers, developers, customer, public administration
5.6.2.4	Use of recycled materials	Materials (D/I)	Increase the use of low impact, recycled materials	Construction companies, subcontractors, service providers, developers, customer, public administration
5.6.2.5.	Water Drainage Management and Erosion Control	Water, Soil (D)	Water drainage management, protection of soil	Construction companies, subcontractors, service providers, developers, customer, public administration
5.6.2.6.	Dust prevention and control	Air (D)	Reducing dust and particulate materials in air through removal or minimization of the origin	Construction companies, subcontractors, service providers, developers, customer, public administration

Table 5.17: Identified Best Environmental Management Practices for Construction Activities

Section	BEMP	Covered aspects and main focus (D= direct, I = indirect)	Techniques	Target audience
5.6.2.7.	Disturbance management	Air emissions (D)	Prevention and mitigation of the impact of noise, vibration and night lighting.	Construction companies, subcontractors, service providers, developers, customer, public administration
5.6.2.8.	Improving energy efficiency and reducing pollution from engines	Water (D)	Reducing energy demand of machinery and their associated air and noise pollution. Energy and water management of site cabins.	Construction companies, subcontractors, service providers, developers, customer, public administration

5.6 Best environmental management practices in construction and refurbishment activities

5.6.1 Best Environmental Management Practices for site organisation

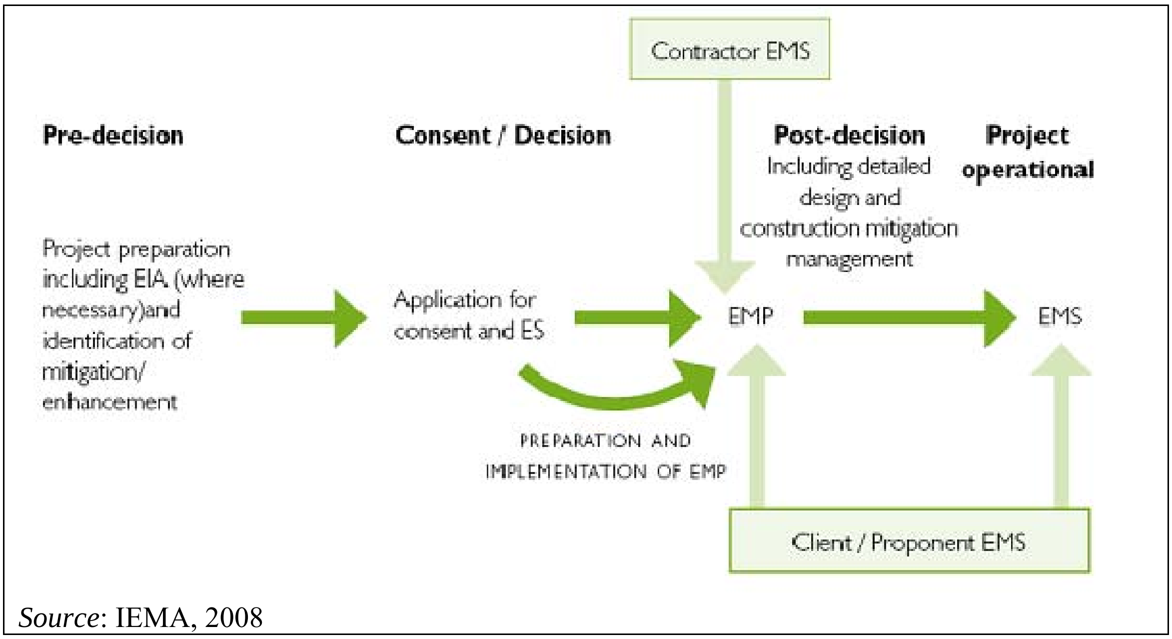
5.6.1.1 Improving environmental performance through better management: definition of environmental management plans and specific needs for environmental management systems

Description
This section identifies some of the best elements of environmental management systems at construction sites with a high impact on the environmental performance of the construction activity:

- Site specific environmental management plan, which is usually, integrated in other management plans, such as quality and health and safety.
- Monitoring system, which is essential for any environmental management system. Performance measurements show the improvement potential of a company or a site. Due to its relative high importance, this element is described in Section 5.6.1.2.
- Assignment of resources, roles and responsibilities for the environmental management system.
- Workers awareness and training.

<u>Environmental Management Plan</u>
An Environmental Management Plan (EMP) is a tool to ‘outline the mitigation, monitoring and institutional measures to be taken during project implementation and operation to avoid or control adverse environmental impacts, and the actions needed to implement these measures’ (Tinker et al., 2005).

The objective of an EMP is to link the design phase of a project, the consents and decisions made in the pre-construction stage (including decisions and mitigation measures coming from the Environmental Impact Assessment process, EIA, where appropriate) with the construction phase, where an environmental management system is put in place (Figure 4.10). EMPs are site-specific and should give a clear picture on how to manage environmental aspects at the site level (IEMA, 2008), with specific requirements, decisions and consents coming from the customer or other stakeholders. EMPs can be required by public administrations in public tenders. While in some countries, EMPs are not required and environmental performance is driven by legislation, there are some examples (e.g. Spain and United Kingdom) where the administration may ask for mandatory environmental management plans, where the content has been clearly identified. Also, some administrations require site waste management plans. Public administrations, even in the same region, may have no homogeneous requirements about the environmental management of construction sites.



Source: IEMA, 2008

Figure 5.15: Links between Environmental Impact Assessment (EIA), Environmental Management Plan and Environmental Management Systems as adapted by IEMA in 2008 (ES: Environmental Statement, EMP: Environmental Management Plan; EMS: Environmental Management System)

In Catalonia, Spain, management of regional infrastructures is made by a public company called GISA. Although this public company provides the service to other administrations, it cannot be considered the developer of projects, as the funding is usually provided by other administration. Nevertheless, GISA is defining project requirements and setting public tenders for the execution of works (building or civil works) and defining the requirements for the quality, health and safety and environmental plans. For the environment, it defines the structure and the content of the plan and establishes inspection points that are revised periodically.

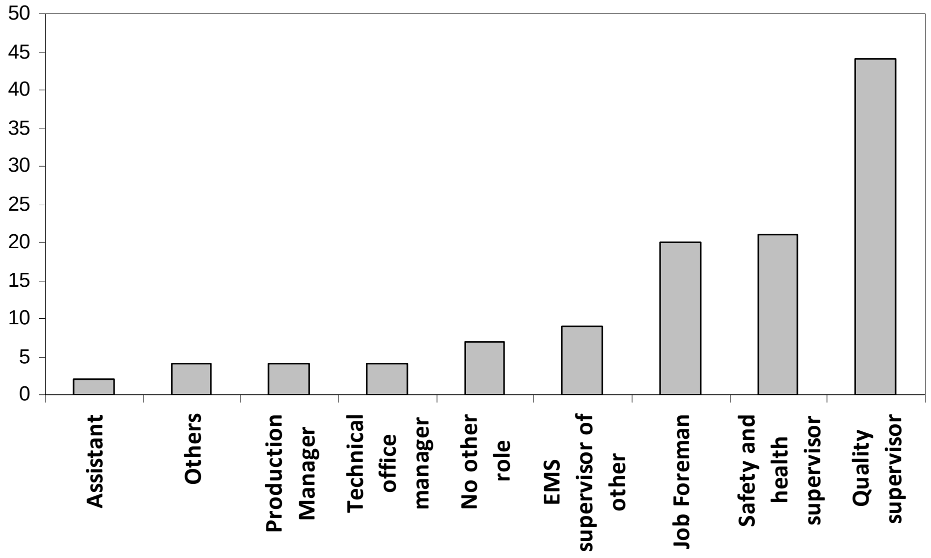
The implementation of EMPs needs good leadership and coordination in the construction phase. Also, the involvement of constructions workers is required to achieve the best environmental performance, especially the foreman, according to several consulted construction companies, as this position is the final one responsible for the correct implementation of on-site measures.

In some countries, especially for projects requiring EIA, there is a control mechanism for verifying the performance of the EMP. IEMA gives some references from these countries (IEMA, 2008). For instance, Honk Kong implements an Environmental Monitoring and Auditing system in order to make EIA predictive methodologies more effective and to check the right implementation of mitigation measures.

Allocation of resources

EMAS regulation and ISO 14001 states that the company should ensure they have sufficient resources for implementing the environmental management system, including human resources and specialised skills. Roles and responsibilities should be defined, and the top management should appoint a specific management representative to ensure that EMS is established, implemented and maintained, and who should also report the performance of the system to the top management. A Spanish study from 2006 (Rodriguez, 2006), published partially in English (Rodriguez, 2011), showed that special attention should be paid to the role of environmental management supervisors, as they can experience some specific problems: lack of resources, multiplicity of tasks and not enough training and autonomy. Also, according to observations made during the development of this document, the construction sector in Spain is highly important and become competitive environment, especially for public tenders. Since these public tenders usually award certified environmental management systems, such as EMAS or

ISO14001, the implementation of such systems is economically driven and inefficiencies can arise. Often, the assignation of resources, roles and responsibilities is seen by companies as an extra cost or not as a ‘normal’ cost and it is minimised by allocating environmental management tasks to existing roles.



Source: Rodriguez et al., 2011.

Figure 5.16: Other roles of environmental managers in the study of Rodriguez et al., 2011.

Against this background, identified best practice would be the integration of environmental management objectives and targets in the production management, which is usually economically oriented. Expertise, sound training and solid knowledge of the company would be three essential requirements of environmental managers.

Awareness and training

At a site level, the awareness of workers, foremen and the people in charge of works seems to be the key for the implementation of environmental mitigation measures. Environmental management is a cross-cutting issue and better environmental performance should be the objective of all the organisation's departments and not only of the environmental management unit. Also, optimal integration of environmental objectives would help to identify environmental management tasks as part of daily work for all staff, instead of ‘extra’ tasks to be added on to the ‘normal’ job. The environmental objectives of the contractor and of the developer should be effectively communicated to all relevant stakeholders through e.g. training practices, communication, economic incentives, etc.

Achieved environmental benefits

Overall environmental benefits from EMS and EMPs are difficult to measure and allocate to the system as a whole. Nevertheless, the framework given by an EMS is unique to ensure the adoption of best practices to mitigate or to prevent any impacts on the environment. A very important element for this would be the implementation of EMP in the pre-consent phase, as EMP helps to ensure effective communication and feedback between operators, public administration and the managers (IEMA 2008).

If applied well, EMPs help the identification of environmental aspects, improve materials use efficiency, identifies potential savings and optimises waste management on site (which can also produce cost savings).

Appropriate environmental indicators

Preparation and implementation of site specific EMPs should be controlled by Management Performance Indicators. As construction companies typically work in several sites at the same time (for the biggest companies, this can be hundreds of sites), the percentage of sites with an EMP seems to be a good performance indicator. The timeframe for this indicator can be very relevant for this indicator, as the duration of works depends on the size of the final product, the nature of work, etc. So, two versions can be adopted:

- Percentage of new contracts with implemented EMPs and regular audits from the customer in a limited time frame (1, 2, 5 years, etc.)
- Cumulative percentage of contracts with implemented EMPs and regular audits from the customer since the environmental policy was implemented.

Cross-media effects

Optimised and well prepared EMPs and correct integration with an EMS on-site lead to the establishment of synergies, no negative effects anticipated.

Operational data

Environmental Management Plans

The structure of the environmental management plan can vary and several recommendations are given in the literature. The UK IEMA provides a 'good practice' structure of an EMP. Also GISA, in Spain, gives a generic framework that contractors should fulfil regarding the quality and environmental management plan in public works. Table 5.18 shows and compares both document structures.

The two examples shown in the table can be considered equivalent. The structure provided by GISA is a requirement for a public tender, but is not restricted to the points shown. In fact, some contractors provide more exhaustive environmental management plans and, most of the time, include specific chapters differentiating the quality management plan from the EMP. Also, the integration of this plan into an overall environmental management system has a strong synergic effect. While certified ISO 14001 or companies registered in EMAS have wider scope in their EMS, EMPs tend to be project specific (IEMA, 2008).

Environmental risk assessment

The implementation of an environmental management plan should be done, preferably, according to EMAS or ISO 14001 procedures, as these have been successfully implemented in many construction sites and allow the possibility of homogenising the environmental practice across sites. In 'Build only' projects, the degrees of freedom to reduce the environmental risks of a construction are lower and a more comprehensive assessment of corrective and preventive measures, regarding their relevance, should be performed.

During project inception, the designer should consider strategic environmental issues that are the responsibility of the client. For instance, in Willmott Dixon, at project inception it is best practice to undertake an environmental risk assessment to ensure that the design takes account of local factors that could impact on the design solution to be chosen. They developed a simple solution in which experts weighed the environmental risk of every design option. This, of course, can be done for tenders at concept stage for a 'Design and Build' project, or at tender stage for a 'Build only' project.

During design a slightly more detailed assessment is then undertaken that goes in to specific detail that can be used to assess the risk of the project, ranking all the projects at the same time (Willmott Dixon may have up to 180 projects at any one time).

The more detailed risk ranking is used to manage compliance risks/impacts in design and to inform construction teams of higher risk issues to be managed. The assessment is then used to monitor changes in risk as the project goes from design to construction/ demolition and is used to prioritise the inspection and audit frequency.

Table 5.18: Examples of an EMPs structure, showing IEMA and GISA proposals

IEMA adaptation of the format from Environment Agency and Scottish Power	GISA requirements on quality and environmental management plan
1. Cover Sheet (modifications, version control and revisions)	1. Cover sheet (modifications, version control, revisions and approval)
2. Content	2. Content
3. Introduction (summary of project)	3. Environmental conditions of the site (particularities, photos and any other information relevant to quality and environmental management).
4. Project team and responsibilities	4. Project team, organisation chart and functions
5. Summary of procedures [7. Environmentally significant changes]	5. Documentation control 6. Project revision (parts of the project to be carefully checked to detect hotspots) 7. Procurement procedures 8. Site activities and zoning 9. Requirements on materials (management of certificates, tests and accepted samples).
6. Consents and permissions	[16. Permits and licenses]
7. Environmentally significant changes 8. Generic environmental actions	11. Identification of environmental aspects on-site (also those considered in the environmental document of the project or in the EIA where appropriate) [6. Project Revision]
[12. Technical schedules]	12. Testing schedule (quality control)
9. Register of site specific environmental actions (core of the document)	13. Inspections point control (quality and environment)
-	14. Measurement equipment
[8. Generic environmental actions] [9. Register of site specific environmental actions]	15. Environmental training
[6. Consents and permissions]	16. Permits and licenses
[8. Generic environmental actions] [9. Register of site specific environmental actions]	17. Waste management plan
[8. Generic environmental actions] [9. Register of site specific environmental actions]	18. Earthworks
-	19. Emergency situations
10. Liaison and consultation requirements 11. Register of variations	20. Non-conformities, corrective actions, complaints management
12. Technical schedules	[12. Testing schedule]
13. Appendices	-

Awareness and training

Raising the awareness of workers at construction sites is usually the responsibility of the main contractor, even for those working indirectly , e.g. for subcontractors. In fact, many construction companies do not have any own labour, instead subcontracting smaller companies for specific works. The foreman, in charge the activities of the construction site, has, therefore an important influence on the environmental performance of the construction site: if he has a proactive attitude to the environment policy, e.g. through economic incentives, the performance of the site (e.g. waste segregation, disturbance to the neighbourhood, dust management, etc.) will improve significantly.

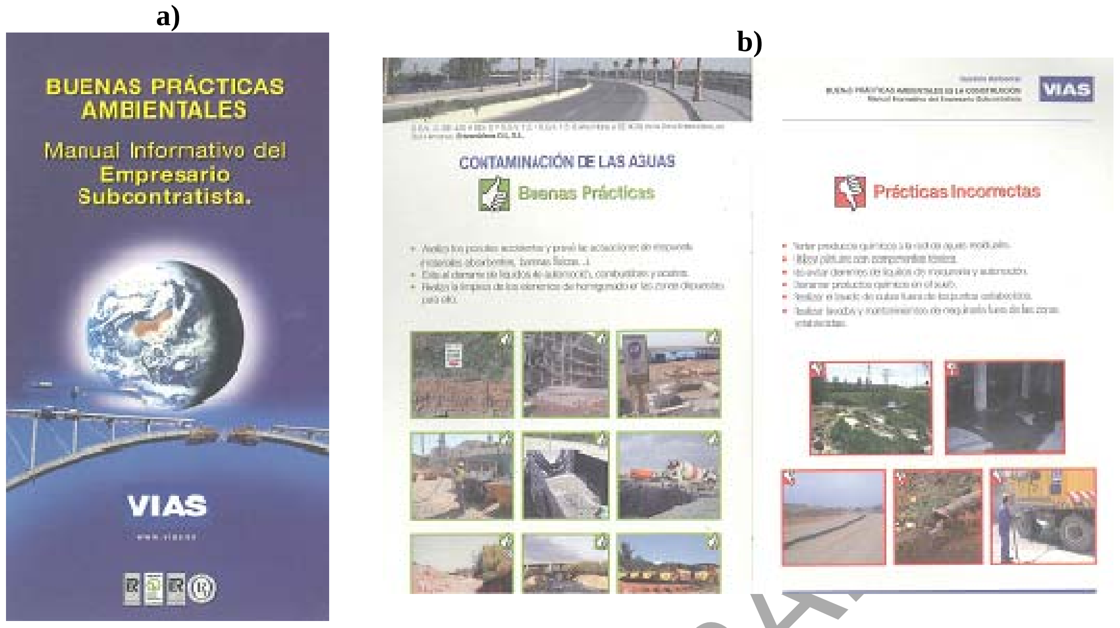
There are a number of ways to train workers: specific training courses organised by the main contractor, specific guidance and uptake of the environmental policy objectives by the subcontractor and specific actions directed to improve the effectiveness of management operations at the site.

As an example, Figure 5.17 shows some best practice guidance used in training courses for construction sites, for safety, health and environmental training of workers, using even foreign languages where appropriate.

Source: DECO, 2011

Figure 5.17: Best practice manual for labourers at construction sites: a) first page, b) explanatory drawings on bad and good practices for waste sorting, c) safety issues translated to workers' language d) drawings on noise prevention

Another approach is to develop best practice guidance for the workers of subcontractors not directly trained by the main contractor. In these cases, communication and consents between the different contractors should be clearly established. As an example, Figure 5.18 shows a best practice manual for the information of subcontractors (CACEC, 2012).



Source: CACEC, 2012.

Figure 5.18: Best practice guidance for subcontractors a) first page b) layout for description

CIRIA and the Environment Agency in the UK produced an environmental good practice pocket book (see Figure 5.19), which is usable by any worker at the construction site, although it is especially directed to managers, supervisors, engineers and contractors (CIRIA, 2005). It is produced in the form of a checklist and covers all environment-related aspects at construction sites:

- archaeology and the built environment
- buying, storing and managing materials
- dust, emissions and odours: avoid causing a nuisance
- ground contamination
- noise and vibration
- traffic management
- waste
- water
- wildlife and nature issues.

The book is presented as a comprehensive checklist, but can, at the same time, be used as a checklist reference for the development of a site-specific monitoring system, and for benchmarking (see section 5.6.1.2).

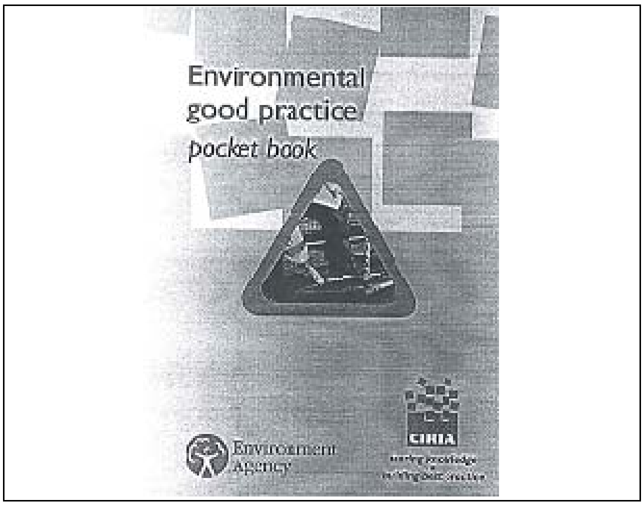


Figure 5.19: Environmental best practice guidance published by CIRIA

Some caution should be exercised when assessing the performance using these best practice guidances. They are usually referred to as best practice, but often are more committed to developing practices to meet legal standards or requirements, correct (but not best) practices and practices without the description necessary to achieve them. For instance, some examples are extracted from the CIRIA pocket guide::

- legal requirements practice: 'Store materials in suitable containers that are appropriately labelled with fitted lids, taps and tops in good condition', 'store waste in a designated area and separate into different waste streams'
- 'correct' practices: ' when ordering materials, avoid over-ordering, or inappropriate lengths or deliveries at the wrong time', 'when storing materials avoid damage or contamination from incorrect storage'
- 'non-descriptive' measures: 'avoid loss, theft and vandalism', 'stock piles should not cause silty run-off'
- best practices: 'make sure those materials do not contain contaminants and that pH levels are suitable for use where the site is located. Undertaken by: a laboratory analysis of contaminants and leachate tests of these contaminants'.

Although these guidance documents do not focus only in what is considered 'best' in this reference document (i.e. practice leading to best environmental performance), it is highly recommended to follow the rationale of CIRIA, 2011, as it maximises the information provided to stakeholders in charge of the environmental performance of the site.

Applicability

Some of the reported best practices in this section can be considered mandatory in some countries, as the administration asks for them or competition makes these best practice become almost a requirement in public tenders. No restriction on the applicability of this practice is detected, and they would be applicable for public or private contracts nd for building or civil works. Although EMPs and training/raising awareness protocols should be elaborated by the construction company, their scope and optimal impact on sites performances is also the responsibility of the developer and/or the customer (a private company or a public administration).

Economics

The implementation of EMPs, in a voluntary or mandatory scheme, can have very important economic benefits, since:

- it saves the approach to take to address environmental aspects

- it provides a document to demonstrate legal compliance with any specific requirements imposed by regulators
- can avoid delays
- clearly identifies responsibilities
- it integrates mitigation measures in the overall management plan
- it is an added value of the project.

Driving force for implementation

Main driving forces for the implementation of this practice are:

- legal compliance
- reduction of risks in the quality, environmental or health and safety management plans
- enhanced knowledge of company activities and better monitoring of own activities
- better environmental performance can produce costs savings
- enhances the environmental credentials for public administration and customers

Reference organisations

An example of a public administration requiring EMPs in all public tenders is Gisa (infrastructures public company of Catalonia, Spain), www.gisa.cat.

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Tinker L., Cobb D., Bond A., Cashmore, M., 2005. Impact Mitigation in environmental impact assessment: paper promises or the basis for consent conditions? *Impact Assessment and Project Appraisal,* 23, 4

5.6.1.2 Monitoring the environmental performance of sites

Description

In this section, some outstanding monitoring practices of construction activities are described. It is considered to be best environmental management practice the monitoring of the consumption of energy per process and per fuel, the consumption of water per process and per water source, the control of waste generation per process and per type, control of construction products and auxiliary elements per process and per type, the use of checklists for the implementation of best practices or for the control of specifications and requirements for site management, emissions control, machinery maintenance and other project specifications.

The main focus is covers:

- recommended indicators to develop a good picture of the environmental performance of the construction process. the estimation of the environmental performance in the pre-construction phase
- how some construction companies have established monitoring schemes to determine the improvement potential and systems to compare performance through checklists

EMAS Regulation 1221/2009 and, therefore, ISO 14001:2004, define in their requirements that the organisation should establish, implement and maintain a procedure to monitor and measure the key characteristics of its operations that can have a significant environmental impact. Under EMAS, organisations should be able to demonstrate the improvement of their environmental performance, defined as the measurable results of the organisation's management of its environmental aspects. Measurement of an organisation's performance should be made by environmental performance indicators.

Regarding the EMAS regulation, core indicators should be reported according to Annex IV part C for energy efficiency, material efficiency, water, waste, biodiversity and emissions. Proposed indicators can give an accurate assessment of the environmental performance, and should be understandable and unambiguous. For companies in the construction sector, these indicators do not allow year on year comparison, comparison within the sector, or the establishment of benchmarks, etc. Construction products (buildings, roads, bridges, etc.) typology is quite heterogeneous and the production profile can vary a lot from year to year,so the performance of an organisation is not comparable, even with specific indicators, due also to the temporary nature of sites.

In general, it can be said that an indicator expressed per square metre of built area, per EUR million turnover or per employee is not valid for comparison between construction companies producing very different products or for comparing the performance of one company for two consecutive years, as their activities profile would have changed. The main rationale for this is the typology of products: construction companies produce nearly always different products with different environmental profiles, even in the construction phase. Nevertheless, the use of EMAS core indicators is recommended since they make the company to become more aware of their total environmental impact. The process level approach seems to be the only possibility for comparing quantitatively the performance of the construction activity. For instance, fuel consumption per square metre of built area is not comparable from different sites but machinery fuel efficiency, the use of fuel per tonne of sand or gravel or CO_2 emissions per tonne kilometre are good parameters to control the environmental performance of earthwork processes. Nevertheless, this level of monitoring actually consumes a significant amount of resources and time, since the construction process is quite complex and some shortcuts seem to become necessary in order to gain an understanding of the full environmental performance of a process.

Monitoring also plays a significant role in a construction project life cycle. Figure 5.20 shows how the environmental performance of construction is influenced in a top-down approach, with a very little weighting on the redefinition of objectives and redesign. The original design of construction projects is usually changed during later phases in order to fit customer needs, specific site circumstances or possible design failures. The probability of environmentally-friendly redesign options to be accepted by the developer depends on the cost of the measure. Also, environmental monitoring of the construction site may be required if the EIA results mandate it or if the monitoring results are used to enhance communication with stakeholders (customers, developer, neighbourhood, public administrations, etc.).

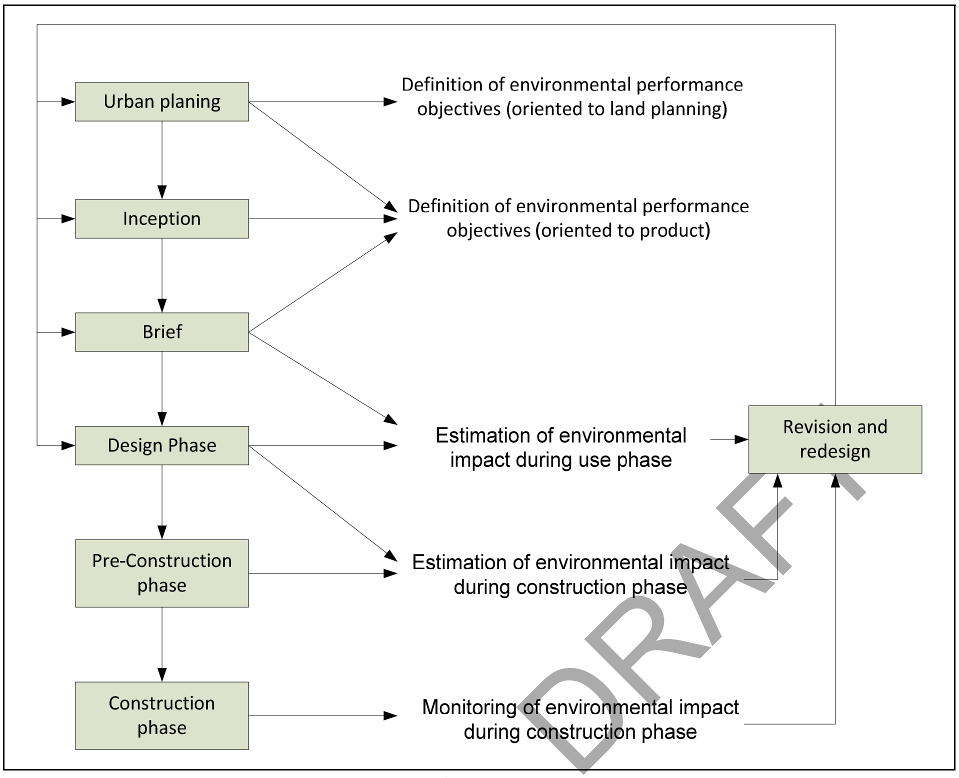


Figure 5.20: Conceptual diagram of the influence of environmental monitoring in the construction project life cycle

Best monitoring practice is not only the implementation and maintenance of a detailed and comprehensive environmental performance measurement system but also the practical consequences on the organisation's activities. At an organisational level, Global Reporting Initiative has published a sector supplement for the Construction and Real-State sector, where guidelines tailored for the construction and real estate sector are given for the so-called GRI Guidelines. The new G3 GRI Guidelines can be used by organisations to measure and to report on the sustainability of their activities, products, and services. Although the guidelines are quite comprehensive, the potential for comparison between companies or between projects in the same company is really difficult except for certain indicators.

In Table 5.19, the indicators used by a medium-size enterprise are shown. These indicators are a good example of how a company can monitor its environmental performance. Although comparability still depends on design issues, it can be seen that the company would be able to:

- identify environmental hotspots of its activities
- identify strengths and weakness of its environmental management system
- establish objectives and benchmarks
- improve audits and prevention and corrective measures implementation
- identify energy-saving potentials, cost-saving potentials
- increase knowledge of own-activities
- identify training needs
- influence decision-making processes of customer, developer or public administrations
- show compliance with legislation

- feed data to research and development.

Table 5.19: Some self-developed indicators from a real construction company

Indicator used by the company
Global or Non site specific
Percentage of achieved environmental goals
Percentage of implemented improvement options
Carbon footprint, tCO_2/empl.
Water footprint, m^3/empl.
Wastes, tonne / employee
Resources consumption in offices (electricity, water, paper, etc.)
Awareness improvement actions (number)
R&D projects or registered patents
Percentage of offers with sustainability criteria
Percentage of won tenders with sustainability criteria
Percentage of environmentally assessed suppliers
Classification of suppliers attending to their performance (y/n)
Register of claims to suppliers (number)
Site specific
Volume of waste (per type)
Percentage of reused and recycled waste
Percentage of reused materials from earthworks
Waste management cost (per site and per area)
Resources consumption (electricity, water, fuel and transport)
Number of internal audits or checks by environmental coordinator
Valuation of internal audits
Number of emergencies with environmental impact
Number of customer claims
Meeting deadlines / economic margins
Training investment
Average duration of non-conformities

Apart from those shown in Table 5.19, the company is reporting according to GRI, e.g. the use of materials, affectations to soil, biodiversity, groundwater, etc.

The company in the example shown in the previous table is reporting annually 75 indicators. Some of them are easy to measure and others require complex methodologies and time-consuming measurement methods. Staffing and resources allocation to monitoring tasks should be justified in the environmental and sustainability improvement achieved, the communication of environmental credentials and as a response of society's demand. Nevertheless, all these objectives are also achieved by means of comparable indicators. In this sense, it is important to notice that a construction company is providing a product not defined by them. For instance, waste generation depends on many factors: nature of site, earthworks, piling system, demolition of existing buildings, etc. Even in specific terms, e.g. per m^2, comparability depends on design. On the other hand, many comparisons can be established at a management level. For instance, constructors can compare the percentage of recycled or reused waste. But, if the region lacks waste management facilities, this indicator would need to be altered and would not be valid for comparison.

Two innovative practices regarding the monitoring of environmental performance have been detected during the development of this document:

- Estimation of environmental performance at the pre-construction phase. In the organisation and planning of construction, once the tender has been won and the project is well defined, constructors can estimate the impact of construction site, as it is highly dependent on the design. This methodology seems to be really innovative and only one R&D example has been found (Gangolells et al., 2009). It helps with the identification of significant environmental impacts through an analysis of the technical parameters of the building. Although it can determine the relative importance, it does not measure the real environmental pressure, as lacks some numeric correlations between technical parameters of the building and final impact during construction phase. This method would help in the implementation of environmental management systems, but would not allow comparison of an organisation's performance, as the measured parameters depend on the product design.

- Methodologies based on checklists to compare the performance of sites. This methodology is based on an assessment of the management performance, which is supposed to have a direct and proportional influence on the environmental performance. These checklists can be based on the verification of protocols implemented on site or to the application of best practices and may be used to assess and to review the significance of environmental impacts.

Performance estimation at pre-construction phase

This description is based on the work done by Gangolells et al., 2009 and other publications of the Group of Construction Research and Innovation of the *Universitat Politècnica de Catalunya*. They propose a process-oriented approach, with a comprehensive methodology for risk assessment (environmental and health and safety), which is intended to be applied in pre-construction phases (after the design and in the planning of the construction) (Gangollels et al., 2010). The main outcome for environmental management systems is a procedure to assess the significance of environmental aspects in the pre-construction phase, by establishing links between building design and environmental impact during construction (Gangollels et al., 2011).

It is proposed to use technical parameters based only on the data available in project documents. They have assessed 55 construction sites documents (25 single family and 30 multifamily). Many indicators are also qualitative, based on predefined scales. Also, third parties concerns are taken into account and combined with a best practice application checklist approach. In total, 37 indicators were developed. Four levels of performance were established, and the best performers were 16 % of the total (those over the average, plus standard deviation).

Table 5.20: Technical parameters as indirect indicators proposed by Gangolells et al., 2009, and links to environmental aspects and indicators

Technical parameter	Low impact if less than:	Environmental Aspect linked	Potential process performance indicator (quantitative)
Volume of excavated material per m^2 of floor area (m^3/m^2)	0.55	Generation of GHG emissions	kg CO_2 per m^3 of excavated material
		Generation of inert waste during earthworks	kg inert waste per m^3 of excavated material
		Dust generation (earthworks and machinery)	PM/m^2, or PM/m^3
		Dumping due to the use and maintenance of machinery	kg/m^3
		Fuel consumption during the construction process	L/m^3
Quantity of thixotropic fluid kg per m^2 of floor area	2.6	Water emissions	L water per kg of fluid
		Soil alteration	m^2 affected soil per kg fluid
Quantity of in-situ concrete per m^2 of floor area	0.3	Water emissions	L water per kg concrete
		Soil alteration	m^2 affected per kg concrete
Average number of workers per day	13	Water emissions	L / worker day
		Generation of MSW	kg / worker day

Table 5.20: Technical parameters as indirect indicators proposed by Gangolells et al., 2009, and links to environmental aspects and indicators

Technical parameter	Low impact if less than:	Environmental Aspect linked	Potential process performance indicator (quantitative)
Percentage of synthetic paints and varnishes, %	5 %	Emissions of VOCs and CFCs	-
Floor area, m^2	691	Generation of inert waste during earthworks	kg inert waste per m^3 of excavated material
		Generation of hazardous waste	kg hazardous waste per m^2
		Generation of wood, plastic, metal, paper, cardboard or glass wastes	kg waste per m^2
		Electricity consumption	kWh/m^2yr
		Dirtiness at entrance	-
		Fire at storages	-
		Traffic affectation	-
		Spillages	-
Site occupation per floor area (m^2/m^2)	0.17	Soil alteration by land occupancy for storage	kg of stored material per m^2
		Biodiversity: vegetation removal	?
		Biodiversity: affectation to topsoil	?
		Biodiversity and soil alteration: Soil erosion	?
		Breakage and affectation to services (electricity, water, etc.)	-
Use of concrete	In-situ concrete not used	Use of chemicals (release agent)	kg of release agent per kg concrete
Percentage of facing brick closure	15 %	Use of chemicals	kg of agent/m^2 façade
		Dust generation (cuts)	kg dust/m^2 façade
Percentage of floor area having discontinuous ceramic and stone surfaces	30 %	Use of chemicals	kg of agent/m^2 floor area
		Dust generation (cuts)	kg dust/m^2 floor area
Water consumption m^3 per m^2	0.06	Water consumption	m^3 water/m^2 per process
Weight of structural floors, foundations, facades, partition walls, pavements and roofs kg per m^2	1095	Raw materials consumption	?
Number of cranes	2	Visual impact	-
Length of entrance	500	Soil alteration (compaction)	m entrance / m^2 occupied
Number of contact points with river beds	1	Affectation to natural waterways	-
Time of activity and use of special machinery	Normal activity without no special machines	Noise generation	dB

NB: Process performance indicators may be qualitative or y/n indicators. For biodiversity, no process oriented indicator available

Checklists based performance

The environmental performance of construction sites depends mainly on the initial design, on the performance of the land planning and on many factors that are not directly manageable by the construction company. Against this background, if a company wants to know the achieved improvement or its potential. This cannot be controlled through its environmental performance. Nevertheless, the improvement of the management performance can be easily controlled through checklists, and some construction companies are doing so. Also, other proposals control the implementation of best practice as a control mechanism of the environmental management performance, among other objectives.

As an example, the case of a Spanish construction company, called DECO, is shown below. They have developed a checklist of 180 control points with 4 levels of performance each one and calculating an overall management indicator called INDICA. Control points are divided in several categories and subcategories (DECO, 2011):

- Licenses and permits (35 checkpoints)
- Environmental and quality management plan (15 checkpoints)
- Waste Management (56 checkpoints)
    - General
    - Debris control
    - Common waste
    - Hazardous materials packaging wastes
    - Hazardous waste
    - Subcontractors waste
- Signposting, tidiness and cleanliness (20 checkpoints)
- Atmosphere (31 checkpoints)
    - General
    - Dust minimization
    - Cutting machines
    - Machinery
    - Power generators
- Procurement (13 checkpoints)
    - Efficient stock of materials
    - Subcontractors machinery
- Consumption (3 checkpoints)
- Communication (3 checkpoints)
- Emergency and incidents (3 checkpoints)
- Improvement measures (1 checkpoint)

In the 'Operational data' section more data on the implementation of this type of checklist controls are given.

Achieved environmental benefits

The allocation of environmental benefits to the environmental performance monitoring systems may not be considered quantifiable. Monitoring cannot be considered as a best practice by itself. It has to be considered as a parte of a whole decision-making process designed to improve the environmental performance.

Regular audits of the environmental performance of sites have a positive impact on management practice, as it makes management personnel more aware of the environmental aspects to be controlled. This pressure on management is much more efficient if environmental requirements are imposed by customer. Making a regular check of environmental management systems can also produce synergies, by reporting achieved environmental benefits, fulfilling environmental legislation compliance and detecting opportunities for costs savings.

Appropriate environmental indicator

The appropriate indicator for the monitoring system should be its presence (y/n indicator) and the amount of environmental indicators controlled, independently to the significance of the environmental aspect.

The main environmental indicators proposed in this document are listed in section 11.2.2.

Cross-media effects

No negative cross-media effects of the environmental monitoring system are detected.

Operational data

Performance-estimation based indicators

As aforementioned, one outstanding methodology to monitor the performance of a site, in the preconstruction stage, was presented by Gangolells et al., 2009. In this work, the significance of an environmental aspect can be easily calculated at the initial design of the building. Table 5.21 presents the results for 4 case studies, compared with the benchmark (16 % best performers). The links with environmental aspects are also indicated in the table.

Table 5.21: Example of environmental performance assessment at preconstruction stage four the case studies presented in Gangolells et al., 2009

Technical indicator	Low impact if less than:	Site 1	Site 2	Site 3	Site 4	Linked to Environmental Aspect
Volume of excavated material per m^2 of floor area (m^3/m^2)	0.55	2.00	0.45	0.97	0.89	Generation of GHG emissions
						Generation of inert waste during earthworks
						Fuel consumption during the construction process
Floor area, m^2	691	300	1130	7200	1100	Generation of inert waste during earthworks
						Generation of wood, plastic, metal, paper, cardboard or glass wastes
						Electricity consumption

The design of a site is, then, directly linked to the environmental performance of the construction site and rough estimations can be performed In Table 5.22, the environmental performance of the 4 sites shown in the table above is estimated through several factors found in the references. As observed, proportionality between technical parameters of the building design and the impact during construction phase is not fully assured and should be expressed in specific terms (e.g. per m^2 of floor area) if both tables are compared. Although the relative impact of several aspects can be estimated, an assessment at the pre-construction stage is not a substitute for the real environmental impact that should be monitored in a more comprehensive way. In addition, the lack of real and comprehensive data about the real performance of sites means that estimation procedures should be taken as a rough estimate only to help identify aspects but not to quantify them.

Table 5.22: Estimated environmental impact of four construction sites

Environmental Aspect	Unit	Site 1	Site 2	Site 3	Site 4	Source for estimation
Generation of GHG emissions	kg CO_2	35984	30594	418908	58562	Li et al., 2010
	kg CO_2 / m^2 floor area	120	27	58	53	
Generation of inert waste during earthworks	m^3 of waste	591	450	6349	976	Gangolells et al., 2009
	m^3 of waste / m^2 floor area	1.97	0.40	0.88	0.89	
Fuel consumption during the construction process	L of diesel	2399	2040	27927	3904	You et al., 2011
	L diesel / m^2 floor area	8	2	4	4	
Electricity consumption	kWh/yr	1800	6780	43200	6600	Own estimation
	kWh/m^2yr	6				
Generation of debris waste during earthworks	Total debris, m^3	155	607	3138	544	You et al., 2011
	Total debris, m^3/m^2 floor area	0.52	0.54	0.44	0.49	

Checklists based performance

The use of checklists to determine the environmental management performance should always be complemented by the monitoring of the real environmental impact to help determining if the best environmental management is leading to best environmental performance.

In the case of DECO's global environmental management indicator, INDICA, the levels of performance defined for the management aspect seem to be significant for the final relationship between best management and best performance. For instance, the waste generation checklist controls the points shown in Table 5.23 for each waste typology, and outlines additional checking for hazardous wastes.

Table 5.23: Example of INDICA checklist and punctuation

Waste management	Best (= 4)	3	2	Worst (=1)
Bin is always available	Yes	-	-	No
Identification	Signs available	-	Signs with defects	No signs
Separation	Optimal separation	Separation with punctual errors	Separation with systematic errors	No separation
Documentation	Delivery to manager verifiable	-	-	No document to verify appropriate waste management

It is noticeable that the maximum score can be reached only by means of the best management option. Figure 5.21 shows the overall score achieved for 23 sites and its change from the first audit to the last. In general, the influence of the checklist can be regarded as positive and its proper control can make the construction company implement measures to improve and to gain knowledge about the most common inefficiencies of the management system.

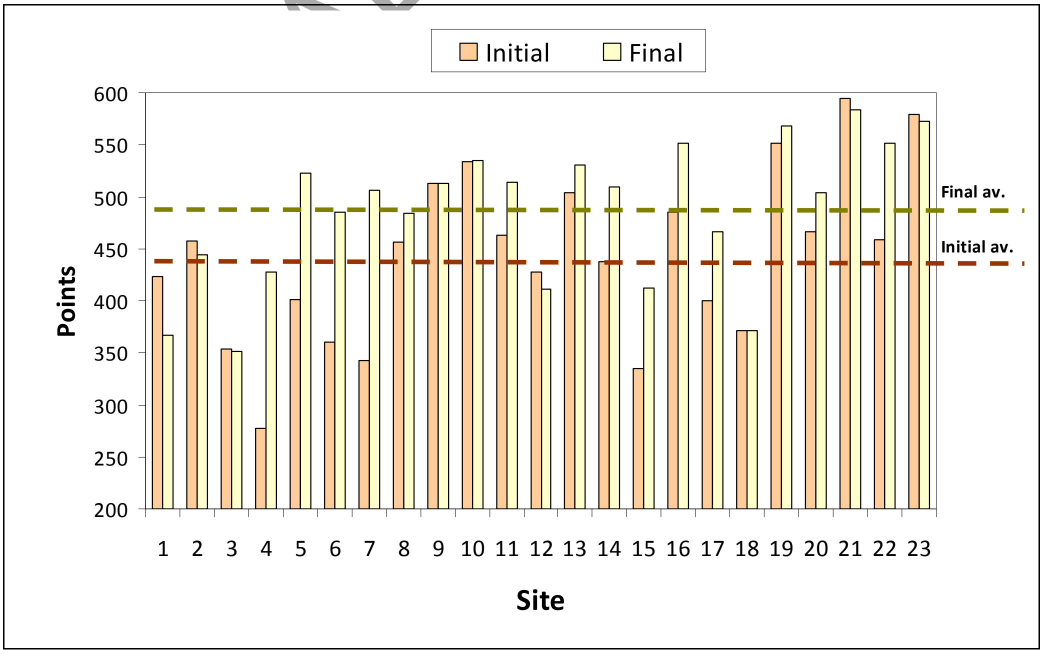


Figure 5.21: Environmental management score of several sites at starting and finishing construction works

Periodic checks are made on a monthly basis. The evolution of construction sites can be easily assessed, as shown in Figure 5.22 for three construction sites (non-residential buildings). As shown, construction sites 1 and 3 of the figure have almost constant performance (around 450 for site 1 and around 500 for site 3) and site 2 shows an improvement from the starting of construction works. As shown in Figure 5.22b, the environmental impact produced at site, e.g. waste generation, is independent of the management performance. A significant conclusion is confirmed from this: best management of the construction company would not lead necessarily to best performance, as many factors coming from the design influence this. From another perspective, it can be said that best management is always necessary to achieve best performance.

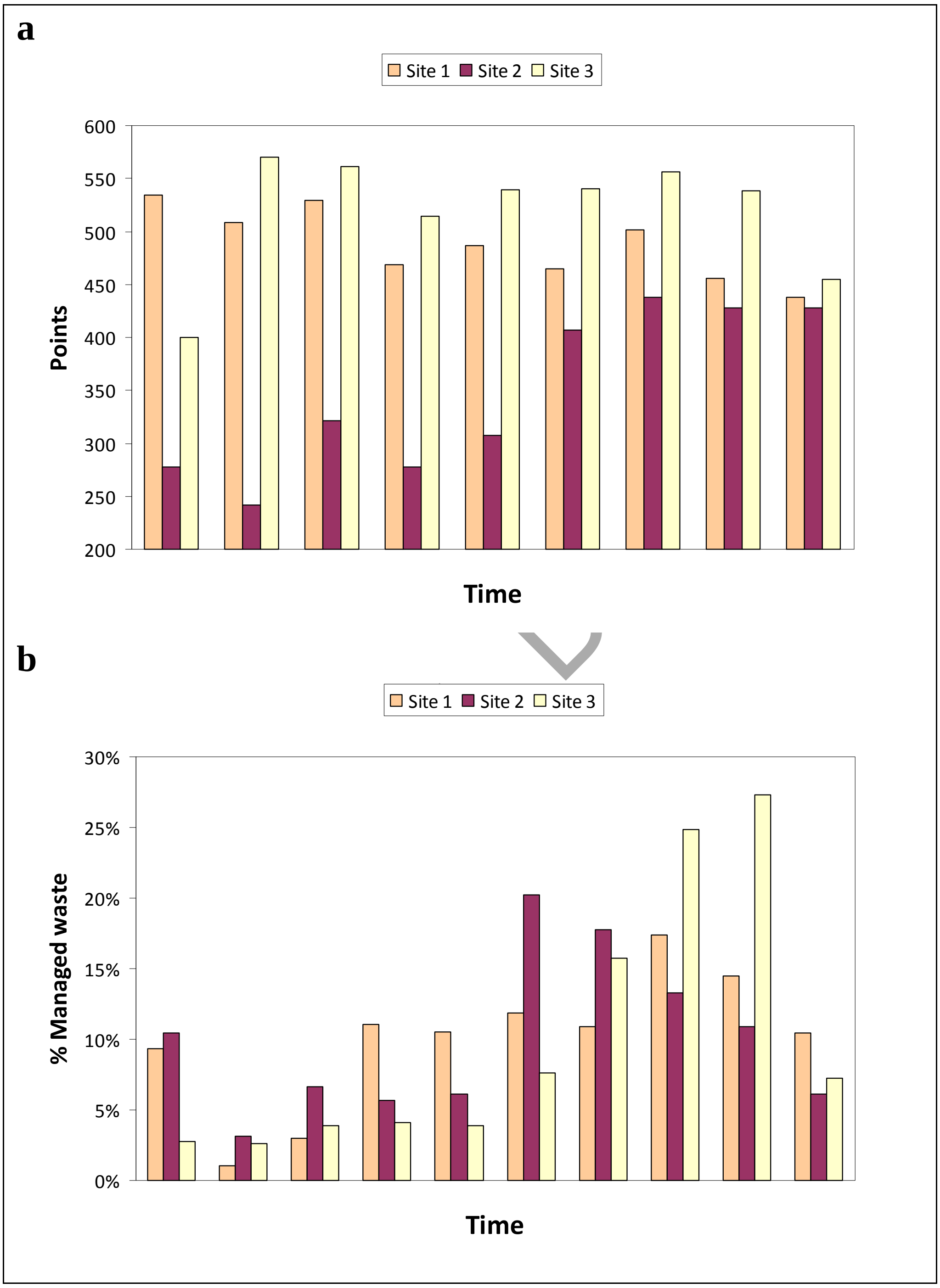


Figure 5.22: Evolution of environmental management punctuation of three sites and evolution of the amount of waste managed at the same sites

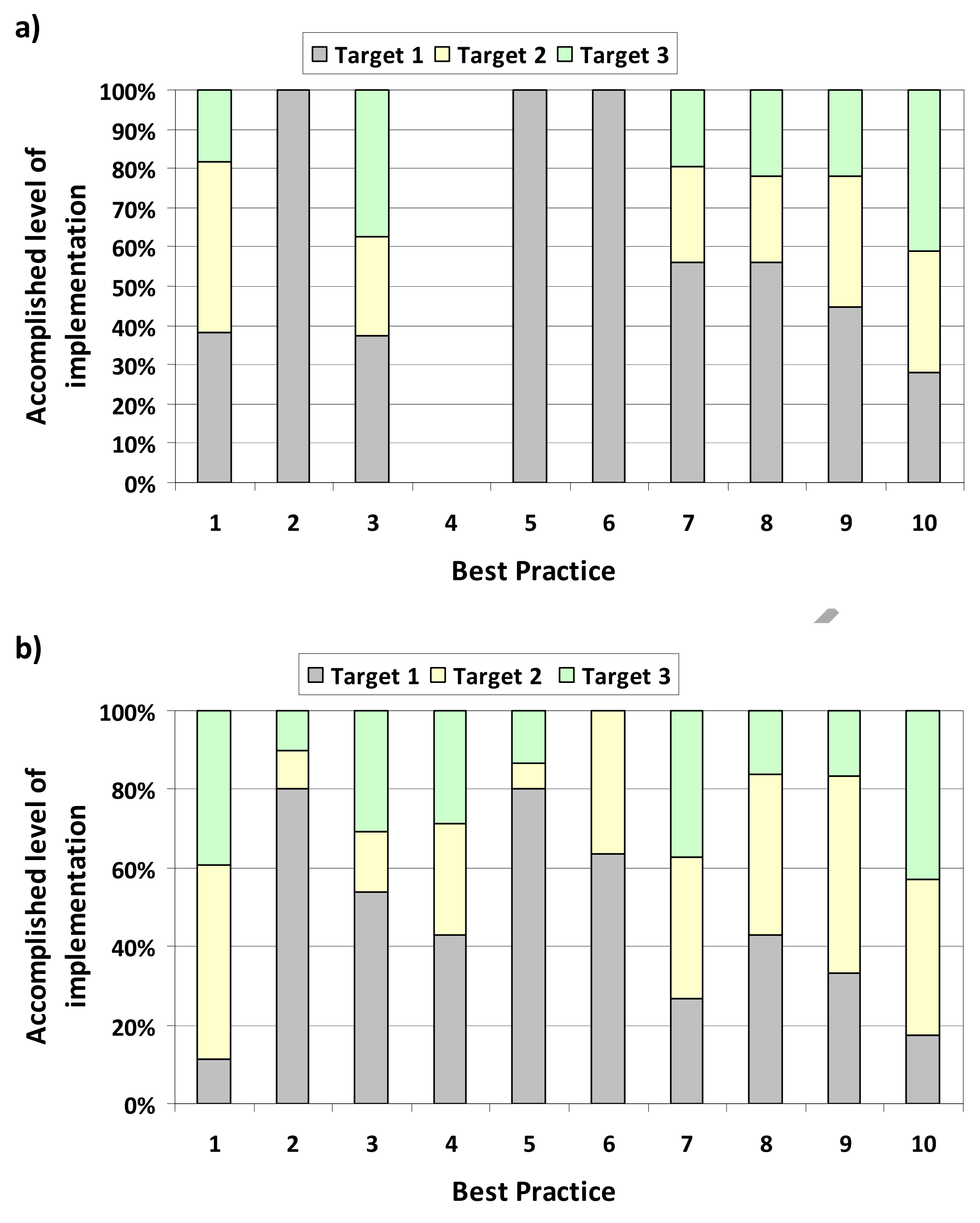
The case shown above is similar to the data reported by Jackson Civil Engineering in their environmental statement of 2008 (Jackson Civil Engineering, 2008), which is a good example of an environmental report for a construction company. They report their environmental management performance with the amount of non-conformities detected in periodic audits, although the intensity of control is far from that shown by INDICA.

Fomento de Construcciones y Contratas (FCC) is a Spanish construction company with ISO 14001 certification, with a good level of environmental performance reporting. They published an environmental communication in 2009 where a best practices programme is used to report the environmental management performance. For instance, Table 5.24 and Figure 5.23 show the implementation of best practices to minimise the impact of air emissions.

Table 5.24. Best practice, relative importance and targets to minimise air emissions according to FCC, 2009

Best practice	Importance	Target 1	Target 2	Target 3	Number in Figure 5.23
Dust reduction through irrigation	2	Sporadically applied	Frequently applied	Systematic application	1
Additives to reduce dust generation	1	Sporadically applied	Frequently applied	Systematic application	2
Use of screens to avoid dust	1	> 30 % of perimeter	> 60 % of perimeter	> 90 % of perimeter	3
Water atomizer to avoid dust	2	Implemented in more than 30 % of points generating dust	Implemented in more than 60 % of points generating dust	Implemented in more than 90 % of points generating dust	4
Dust capture through humidification or water curtain	3	One activity	Two activities or more	Five or more activities	5
Improvement of legal levels	3	Improvement for 5 % of parameters	Improvement for 15 % of parameters	Improvement for 30 % of parameters	6
Proper maintenance of machinery	2	Preventing maintenance in more than 30 % of machinery	Preventing maintenance in more than 600 % of machinery	Preventing maintenance in more than 90 % of machinery	7
Ecofriendly night lighting	1	30 % of directional light or light automation	60 % of directional light and light automation	90 % of directional light and light automation	8
Waste disposal through tubes and bins covering	1	More than 30 % of bins	More than 60 % of bins	More than 90 % of bins	9
Speed control	1	Speed limit sign in 30 % of sites	Speed limit sign in 60 % of sites	Speed limit sign in 90 % of sites	10

As observed, this methodology for controlling the performance also links best management with best performance. The best achievable performance of a project also needs the best management at sites. The differentiation of targets shown in Table 5.24 actually measures the level of implementation of a best practice, which is assumed to produce a better environmental performance.



Source: FCC 2009

Figure 5.23: Level of implementation of several best practices to minimise air emissions at construction sites: a) buildings, b) civil engineering works

Applicability

No restrictions on applicability are found for the implementation of a monitoring system. The environmental aspects to monitor may take into account the geographical scope, the surroundings, the construction typology, etc. to establish the most appropriate mechanisms.

Economics

The environmental monitoring of construction sites is a time consuming process, where the company has to put resources, staff and time to obtain an intangible benefit. A basic monitoring system, based on bills of waste management, water, electricity or fuels is easily achievable, as currently the use of information technologies to manage construction site is a common practice. The control through checklists, with higher periodicity than normal internal audits, and some submettering (noise, water, dust) needs some initial investment, and more specific and specialised staff to develop these tasks. Synergies can be considered among environmental and other management systems, such as quality and health and safety.

The benefit of environmental monitoring may produce cost savings due to the detection of inefficiencies of the management system and due to the introduction of new prevention and corrective measures.

Driving force for implementation

Main driving forces for the implementation of this practice are:

- legal compliance
- reduction of risks in the quality, environmental or health and safety management plans
- better knowledge of company activities and identification of opportunities for costs savings
- better environmental performance through the application of best practices
- enhanced environmental credentials towards public administration and customers.

Reference organisations

DECO is a small size construction company based in Barcelona (Spain). They developed the INDICA system and make checks of the environmental management performance every month.

FCC Construccion is a large enterprise, based in Spain but also works in other European countries. They have developed their own best practice programme.

Jackson Civil Engineering is a civil works company based in the UK. They are EMAS registered and they have developed an exemplary environmental statement.

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5.6.2 Best Environmental Management Practice for the construction process

5.6.2.1 Waste prevention and management

Description

This section describes best options to prevent the generation of wastes through better organisational practices, such as the elaboration of waste management plans, monitoring and the implementation of prevention measures. Designing out waste options are not described here (see section 3.4.7.1. Actions oriented to help this process are also described, such as the estimation of wastes, provision of resources and the optimisation of waste logistics.

The first priority in waste management is prevention. A list of examples of waste prevention is shown in Table 5.25, covering all areas of construction, from design to implemented methods on site.

Table 5.25: Some waste prevention activities

Waste management element	Activities
Designing out waste	• See section 3.4.7.1
Waste management plan	• focus on specific wastes for waste prevention (e.g. inert waste) • develop a waste management plan • communicate the waste management plan in meetings and promote the results
Construction and working site methods	• use prefabricated elements • central cutting areas for wood and other materials • rent and reuse scaffolds, formworks, e.g. choose reusable wood, metal or fibreglass forms • clearly mark areas for material storage, central cutting and recycling stations • prevent loss or damage by practical material storage and handling
Procurement	• natural, recycled or recycled-content materials and equipment • optimise amount of material delivered to site • up-to-date material ordering and delivery schedule: minimise the materials on-site and reduce the chance of damage • replace toxic materials with less toxic or non-toxic products to reduce packaging for safety reasons • choose products with minimal or no packaging • choose suppliers using and picking-up returnable pallets and containers (e.g. euro pallets) • require suppliers to take back or buy-back old or unused items

Source: Adapted from GASW, 2010

Waste prevention depends mainly on the design phase, as design definitely influences the amount of wastes to be produced during construction. Nevertheless, some opportunities are also identified for the construction phase, especially if a company manages several sites at the same time, where some optimisation activities can be well implemented to avoid excess materials purchasing or bad handling practices. In some countries, the elaboration of waste management plans is a legal requirement, as is the case for Spain (SG, 2008) and England. Nevertheless, this legal requirement defines only basic elements of the waste management plan. The best environmental management practice should be based on an overall strategy, which identifies wastes as a significant aspect, not only for environmental performance but also for the economic performance of the site, with an aim to minimise the costs for waste management (e.g. through prevention, reuse and increased material efficiency), reduce the impact produced by them and taking care of its correct treatment. This strategy should produce exemplar, tailor made waste management plans for construction sites. The following procedure, shown in Table 5.26, can be considered as one of the best examples of guiding principles for the development of waste management plans.

Table 5.26: Development of a waste management plan

Plan design
Establish the waste management plan
identify materials to be recovered, reused, recycled and disposed and appoint waste managers, outline procedures, objectives, and results for monitoring, collecting and promoting waste management planning, define a coordinator responsible for implementing the plan, set waste management goals, e.g. 'Recycle 75 % of construction waste', define waste types, estimate the amounts, disposal method for each material reused on site, recovered, recycled or land filled, handling procedures for removal, separation, storage, and/or transportation, communicate the plan to all employees on site, document waste management requirements, including subcontracts and specifications, communicate the results
Find recycling options
identify accepted materials, specific guidelines for each material, separately source mixed materials and determine costs, spot drop boxes and pick-up services, collect options and charges , train staff, track types and quantities for the use of recycled materials
Identify recycling materials
determine potentially recyclable materials and the recycling method, select recyclable materials, identify costs and revenues for recycling different construction wastes, mixed and separated, identify costs for waste disposal, recycle on site whenever possible, partner with local businesses, community groups, and others to determine if there is local interest in using construction waste materials
Plan implementation
Communicate and explain plan
share the formalised plan and control procedures with everyone involved in project administration, discuss waste handling requirements with workers and subcontractors, post signs with information about waste management easy to read, sign recycling drop boxes and the respective content clearly
Define space and areas
place waste bins and recycling drop boxes for all different waste types close to generation point, but away from traffic, focus on frequent collection, use smaller containers to dump into large containers at the end of the day, use containers with multiple compartments to separate properly and to minimise the number of containers on site at the same time, use trash cans to collect recyclables generated in smaller amounts.
Make waste handling easily
place the recycling drop boxes as close to the work as possible, provide a container for waste near the recycling containers, provide maps of the site regarding placement and pickup of waste
Promotion and training
include waste management into the safety training, or design a separate recycling education programme, choose a name or slogan for the recycling programme, incentives to make the plan work and to encourage suggestions on more efficient methods, use signs and simple clear instructions on site, include everyone in the process
Prevent contamination
clearly label the recycling bins and list recyclable materials, provide trash bins to collect non-recyclable items and empty them regularly, regular controls and supervision of bins regarding contamination and recyclable materials, have the polluter pull out the contaminants themselves.
Documentation
keep the receipts from recycling and disposal for planning estimates for waste management budgets of future projects, use worksheets to track quantities and to report the results and cost savings from recycling on site, share the success by communicating the material volume reused or recycled

Source: GASW, 2010

Best practices when managing generated waste during construction or demolition depend on four essential principles that should be given in the waste management scenario to achieve better overall results (Symonds, 1999):

- All construction actors should accept recycled materials as the substitute for natural materials, especially as backfilling materials, base materials for roads and many other applications.
- There should be the possibility of treatment for recycling (especially crushing and classification of materials) inert construction and demolition wastes.
- Those responsible for construction and demolition waste should assume higher costs if wastes are not well sorted to increase the potential recyclability of materials.
- If wastes have to be deposited on landfill, landfills should be well managed and illegal landfilling should be strongly punished. Landfill option should not be cheaper than the recycling option.

The first option, on the acceptability of recycled materials, is described in Section 5.6.2.4. The second one, on the possibilities of treatment, should be regarded as an issue where the public administration role is very relevant: diverse mechanisms, such as taxes or incentives, resources and infrastructure for the best resource efficiency should be in place to encourage the economic activity to deal with construction and demolition waste. Landfilling (the fourth option) should be the very last option for construction and demolition waste, which may not be recycled because of different reasons, such as lack of infrastructures or lack of market for recycled products.

Waste management on site (the third option on the list above) is the main object of this section. Here, it is important to distinguish between construction and demolition. The main output of demolition practices is wastes and recyclable materials, so its management is essential during the demolishing activity. So, a separate chapter is drafted and best environmental management practices for demolition and deconstruction are laid out in Chapter 6.

Among all the single activities that may be considered best environmental management practice for waste management, several elements are highlighted here:

- Estimation of waste generation and provision of resources for its management
- Collection and segregation techniques
- Procedures and methodologies to ensure best management options for construction and demolition waste
- Provision of waste logistics

Estimation of waste generation and provision of resources for its management

Best segregation options for a construction site should be analysed in advance of the beginning of works in order to allocate enough resources for waste management. The estimation of wastes to be generated during the construction activity should based on a good, tailor made estimation (Martínez and Tomé, 2009), which should be optimised with the help of the previous experience of the company. The estimation model should take into account the amount of all construction products, auxiliary materials and dimensions to estimate the remaining fraction. On top of that, especial characteristics of the construction site and the proximity of other construction sites to increase the proportion of materials to be reused and recycled should also be considered. Nowadays, some estimation models exist and many companies are developing their own databases for the development of accurate estimation models. Figure 5.24 shows an example of how the estimation can work. Some authors have developed factors for the generation of wastes (Llatas, 2011) that may be used to complete the previous experience of the company, the amount of losses, the reuse opportunities (to be identified during preconstruction phase) and correction factors derived from previous experiences and the special characteristics of the construction site, regarding the construction phases. Also, constructors may use public databases and results from research projects to improve their own estimations.

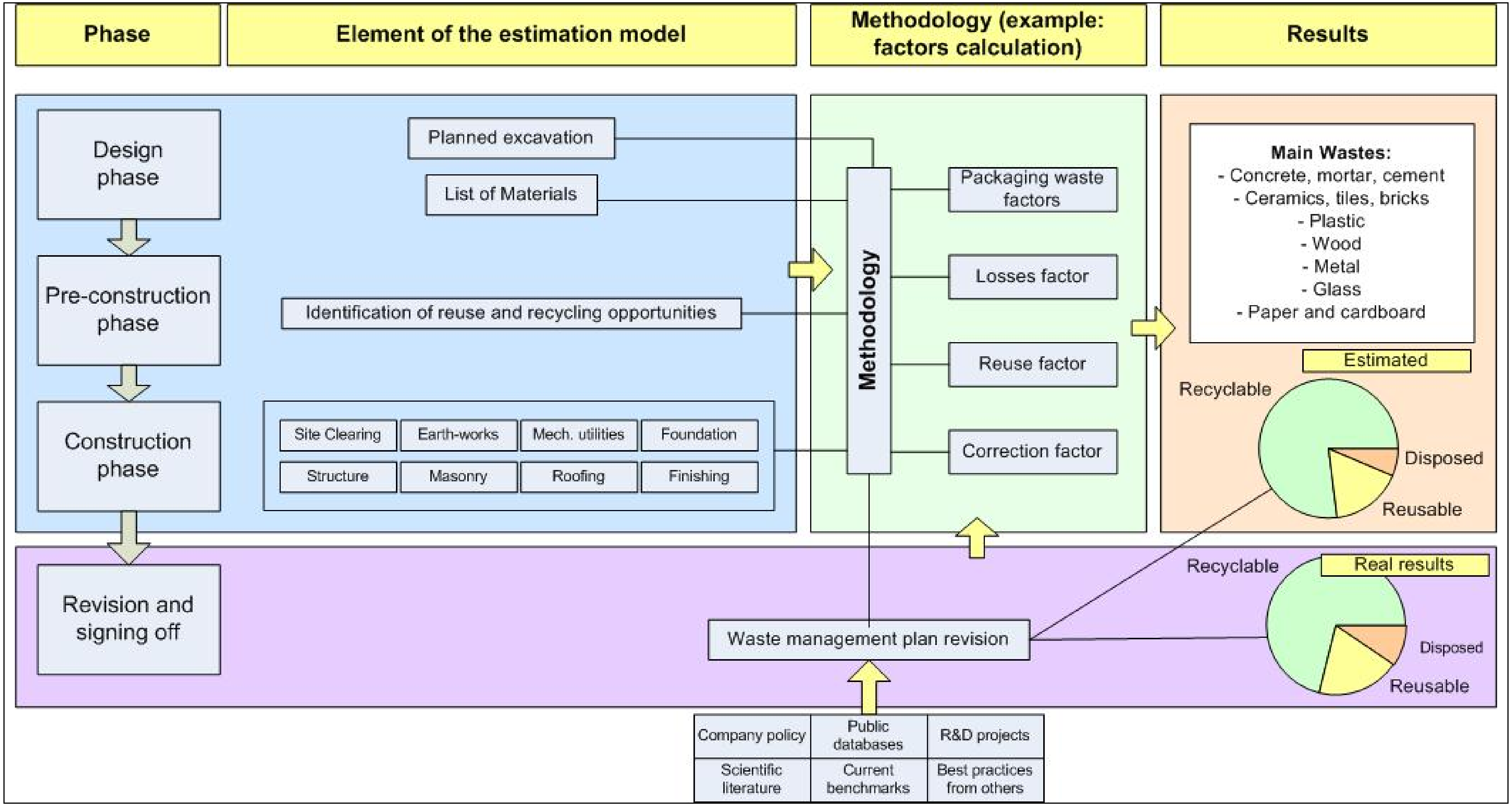


Figure 5.24: Example of a procedure to estimate waste to be generated during construction

The final outcome of an estimation procedure should always be the provision of enough resources and, if possible, the schedule for these needs. Companies managing several sites (e.g. at the same time in the same geographical zone) can use these estimations to optimise and negotiate with waste managers all the resources needed for sites and to reduce the overall management costs. Recycling and reuse opportunities can become obvious with some centralised thinking on resources (Martinez and Tomé, 2009).

In the construction sector, subcontractors routinely use the waste management service of the main contractor (or the subcontractor in charge of waste management), although each subcontractor should be responsible for all the wastes they generate. An accurate estimation method can identify the needed provisions per subcontractor and the allocation of resources needed per subcontractor. So, a more efficient control system can be implemented.

Other benefits from an accurate estimation method are summarised below:

- Setting goals, targets and benchmarks on waste management according to the estimation made during the design phase.
- In some countries, a deposit should be made before starting the construction activity. The deposit is calculated according to the foreseen amount of generated waste. The construction contractor may be required to present certificates issued by the waste manager to prove correct management.
- Estimation procedures are helpful to detect easy achievable measures to increase materials efficiency for the current design and can feed learning processes for designers.
- Innovation in construction would need a good understanding of the very complex construction activity. An estimation methodology would always be needed to feed this process.

<u>Collection and segregation techniques</u>

Several collection techniques are needed to help site labourers to perform correctly waste management. Identified standard practices are those having the following characteristics:

- Waste collection bins are identified for each type of waste; the size of each bin or container is appropriate taking into account the amount to be generated, the number of containers and the predicted transportation of wastes.
- Waste collection bins are usually placed in the same point of the site (e.g. labelled as 'ecopoint', 'recycling point', etc.).
- Temporary collection points are usually placed next to working positions in order to increase the efficiency of waste management and usually due to the accessibility characteristics of the position.
- Hazardous wastes are collected in a separated point, protected from wind, rain and over a sealed surface with the appropriate measures to prevent and minimise pollution of rainfall water.
- Workers (from main contractor or subcontractor) are aware and know what to do with all wastes they generate.
- There is enough space for the delivery of waste with a truck.
- Waste collection points are identified in a site plan, which is available for all site workers.

A sample of common techniques, bins and containers is shown in Table 5.27. Some techniques for the transport of wastes on-site are shown in Table 5.28.

Table 5.27: Waste collection techniques

Container / Technique	**Name / Description**
Temporary waste storage	
	Common wheeled bin. Usually designed to collect domestic wastes, may be used also to collect wastes from sites with less space. Suitable for wastes of low density, hazardous waste included. Volume varies from 60 to 3000 litres.
	End loaders. They can be loaded from the front or from the rear. Used for low density compactable wastes with volumes from 3 to 12 m^3. For construction sites, they can be used for temporary storage of segregated or mixed waste. They are emptied with RCVs (Refuse Collection Vehicles).
	Skips. These are the traditional containers used by the construction sector to collect and to segregate wastes. Volume is quite variable, ranging from 2 to 12 m^3. Usually, waste transport organisations do not allow skips to store hazardous wastes.
	Covered skips. They can be used for any fraction of waste. Useful for sensitive situations, where wind can blow light materials (fines, cardboard, plastics, etc.) or to avoid unauthorised access, fire, water pollution or to store asbestos.
	Roll-on roll-off containers. Volume ranges from 9 to 40 m^3. Used for long term storage. Uncovered containers should be covered to avoid contamination of water or to preserve in good conditions wastes suitable for reuse. They can also be used with roll packers.

Table 5.27: Waste collection techniques

Container / Technique	**Name / Description**
Temporary waste storage	
	Plastic or metal crane lift tubs. To be used for temporary storages at the working position. Ranges from 250 to 1100 litres and removed with cranes.
	Skip trolleys. Wheeled trolleys can be used for temporary storage and, if feasible, wastes sorting.
	Waste Bags. Temporary storage of up to 1 tonne, to be transported with forklifts.
	Waste cages. Several volumes. To be used for paper and cardboard.
	Drop bottom skips. To be transported with cranes and forklifts. Also for handling construction materials.
	Tipping skips. To be used at the working position to storage waste for inaccessible sites.

N.B. *Source*: Adapted from WRAP, 2009

Table 5.28: Waste transport techniques

Container / Technique	**Name / Description**
Waste handling and transport	
	Forklifts, wheelbarrows and others, used for transport of construction products can also be used to transport waste to temporary waste storage points.
	Motorised mini dumpers are suitable for hard working conditions and for heavy weight handling (up to 400 kg).
  	Trailers, wait and load trucks, lorries and other on-site transport services

N.B. *Source*: Adapted from WRAP, 2009

Procedures and methodologies to ensure best management options for construction and demolition waste

With proper wastes estimations and achieving optimised product segregation on site, a by-products 'market' can also be established among construction companies working in the same geographical zone, with a high economic benefit, through the reduction of waste management costs and through the trade of reusable products (Martinez y Tomé, 2009). To ensure best management options at the end of life of construction products several actions are available in order to maximise their segregation, to increase reuse and to contribute to the final recyclability of wastes:

- On-site control of wastes output through visual inspection and computerised or photographic register/
- Signs, symbols and information provided to workers on waste management.
- Issuing and control of waste management certificates to ensure best management option.
- Integrating the waste management plan on an overall environmental management plan (see 5.6.1.1) and establishing a management system (e.g. ISO 14001 type) to ensure that capabilities and resources are rationally allocated for wastes management.
- Pre-treatment of wastes on-site may be an option to be considered as best environmental management practice when high segregation rates are achieved, when it makes sense from the economical point of view and/or when site size is big enough. Waste transport companies availability is also a circumstance to be taken into account, since their activity

depends on the accessibility of recycling infrastructures. Table 5.29 shows a short description of some pre-treatment options.

Table 5.29: Waste pre-treatment techniques

Technique	**Name / Description**
	Compactors (small size) Small compactors can be used to reduce the volume of segregated waste. This will allow reducing the potential contamination of segregated waste, reducing transport costs and avoiding wind blowing. Size up to 1 m^3. Applied usually to packaging waste.
	Roll packer and portable compactors: suitable when large amounts of compactable materials are foreseen. Roll packers can be attached to big containers (up to 40 m^3). Static compactors are less useful on temporary sites.
	Cardboard baler: to compact and reduce the volume of paper and cardboard wastes.
	Trommel: to increase reuse of wastes on-site, waste screening with trommels can be used to classify waste materials by size to directly reuse or to increase the efficiency of waste management on-site.
 	Shredders (picture), grinders and choppers: for wood, green waste and others, several pre treatment options are available. For construction waste, pre-treatment in portable plants (picture) may not be affordable for small or medium size companies and when the amount of waste is not enough to justify its application.

N.B. *Source*: Adapted from WRAP, 2009

Waste logistics

Waste transport is usually performed by waste logistics companies. These companies usually operate in the same region, as the economics of construction and demolition waste processing does not justify long transportation distances. Construction companies managing several construction sites in the same region are able to optimise and to decide the best logistics options for their waste in order to reduce the costs of treatment and to increase recyclability and reuse rates.

WRAP, 2010, carried out a research project to identify best logistics management options for wastes. Environmental and economic benefits from an efficient management options depend on several factors:

- Good understanding of the several waste types, their density, the relationship between apparent volume and weight, the connection between waste composition and treatment options and the importance of best segregation based on the recyclability of different fractions.
- Logistics on-site: availability of space for waste storage; handling and transport on site, availability of big bags and other containers to be placed at different site positions (see Table 5.27), need for pre-treatment, etc.
- The waste management pricing system can be quite complex and varies depending on the contractor.
- Environment monitoring system, including supply chain and logistics of waste management. Data on emissions, fuel consumption and others of waste management companies should be considered when optimising the environmental performance of waste logistics.

Usually, two on-site collection methods are carried out. For large fractions, such as debris, concrete and other large volume fractions, a full skip is substituted by another empty skip. For this option, regular service may not be an option, and then a specific service for the site is needed. For smaller volumes of wastes, such as those similar to municipal wastes (e.g. those generated from canteens or by labourers), a regular service is more suitable, as wastes can be collected from several sites in an optimised route.

Generally speaking, the objectives of the waste management contractor and of the construction company should be the same. The contractor is interested in optimising vehicle use, to reduce the number of skips and to increase the recyclability of the waste material for their commercialisation after treatment. The construction company is interested in reducing the space for waste management (especially for sites with less available space), reducing labour and efforts for waste management and increasing the segregation of wastes to reduce the fee for mixed wastes. Synergies of waste managers and companies managing several sites at the same time are evident. But this optimised system would need estimations of wastes to be generated, a comprehensive monitoring system (of the company and of the site) to be applied, and the construction company own expertise and the capabilities assessment of the waste manager.

For several product categories, reverse logistics are available (plasterboards, wood flooring, vinyl flooring, etc.) where a take back system is performed by suppliers (or by an intermediate transport service). This directly increases material use efficiency, as less weight losses would be in place. For several reusable auxiliary materials, reverse logistics are also applied (e.g. for pallets). Also, applicability of consolidation centres for unused materials may not be applicable or acceptable for the management board of several construction companies (see section 5.6.2.2).

Achieved environmental benefit

According to WRAP, 2010, the segregation of wastes in a construction site can lead to a rate of wastes treated in recycling processes from 90 to 95 %. WRAP presents several so-called exemplary case studies for waste management, which are used in Table 5.30 to show the benefits of optimised waste prevention and minimisation strategies in the full life cycle of a building project.

Table 5.30: Waste management performance of several exemplary construction sites in the UK

Case Study	Waste diverted from landfill (%)	Other environmental benefits / comments
Woolwich Civic Centre	> 90 %	Costs savings of 1.95 % of total construction value 5600 tonnes of concrete recycled into aggregates and used on site
Commercial building refurbishment	88 %	Waste management costs were reduced by 75 % from standard practice
South east electricity substation	99 %	Reduction of packaging requirements. Project on waste management produced cost savings and reduction of CO_2 emissions associated to transport
ASDA building refurbished	99 %	Special focus on design stages, savings of 4.5 % of total project costs
Queens building at Heathrow airport	99 %	Demolition project
University of the West of Scotland	96 %	Combined with compaction techniques to reduce the environmental footprint of transport

At the organisational level, the commitments of several construction companies seem very relevant. Wates, Henry Boot and others, in the UK, have a very ambitious target of zero non-hazardous waste sent to landfill. Many of their sites are currently achieving 99 to 100 % of wastes diversion.

Some Spanish companies are reporting waste segregated for recoveries higher than 97 % (CACEC, 2012). The Swedish company Skanska reports, for several locations in Northern countries, diversion from landfill higher than 95 % (e.g. Bassängkajen and Garda in Sweden achieve 95 % diversion from landfill, the Nordhuset site in Denmark achieves 96 %, etc) (Skanska, 2011).

The introduction of construction and demolition waste management objectives should be in line with the availability of enough facilities for waste management. Low materials recovery rates in several countries does not necessarily mean poor management but it can be a sign of lack of enforcement, lack of facilities and low accessibility to waste management services. In Europe, the average recycling rate is 46 %, with an uncertainty range from 40 to 60 % (BioIS, 2011).

According to the observations made during the elaboration of this document, **a benchmark of excellence**, already achieved by several construction sites and agreed during the final meeting of the technical working group for the development of this document, **is that less of 5 % of total waste is sent to landfill or incineration without energy recovery**.

Appropriate Environmental indicators

A common indicator for the environmental performance is, of course, the amount of waste generated on site. This can be measured on a mass or volume basis. Density is quite variable, so volume seems to be a quite good unit to control waste management on site, as the manager can easily check the movement of waste containers. Nevertheless, the environmental impact and, thus, the materials efficiency of construction costs should be controlled using a mass basis.

Apparent densities for several construction and demolition wastes categories are shown below (Table 5.31).

Table 5.31: Construction and demolition waste apparent density per category

Waste	Category	Apparent density, t/m^3
17 01 Concrete, bricks, tiles, ceramics, and gypsum-based materials	17 01 01 Concrete	1.50
	17 01 02 Bricks	1.25
	17 01 03 Tiles and ceramics	1.25
	17 01 04 Gypsum-based construction materials	1.00
	17 01 05 Asbestos-based construction materials	n.a.
17 02 Wood, glass and plastic	17 02 01 Wood	1.10
	17 02 02 Glass	1.00
	17 02 03 Plastic	0.60
17 03 Asphalt, tar and tarred products	17 03 01 Asphalt containing tar	1.00
	17 03 02 Asphalt not containing tar	
	17 03 03 Tar and tar products	
17 04 Metals (including their alloys)	17 04 01 Copper, bronze, brass	1.50
	17 04 05 Iron and steel	2.10
	17 04 07 Mixed metals	1.50
	17 04 08 Cables	1.50
17 05 Soil and dredging spoil	17 05 03* Soil and stones containing dangerous substances	1.62
	17 05 04 Soil and stones other than those mentioned in 17 05 03	
	17 05 05* Dredging spoil containing dangerous substances	
	17 05 06 Dredging spoil other than those mentioned in 17 05 05	
17 06 Insulation materials	17 06 01* Insulation materials containing asbestos	n.a.
	17 06 02 Other insulation materials	
17 07 Mixed construction and demolition waste	17 07 02* Mixed construction and demolition waste or separated fractions containing dangerous substances	1.25
	17 07 03 Mixed construction and demolition waste other than those mentioned in 17 07 02	

Source: Adapted from CYPE, 2012

The amount of generated wasted should be controlled per category according to best environmental management practices for monitoring (see 5.6.1.2). The use of relative or specific units (per built m^2 or per million EUR project value) is usually performed by companies to assess their efficiency on waste generation. Nevertheless, only companies making very homogenous buildings (e.g. a specialised company which only builds schools of similar size) are able to set benchmarks on this type of indicators. Usually, building construction generates from 120 to 180 kg of wastes per m^2. Demolition or deconstruction projects generate about 1000 to 1500 kg of wastes per m^2 and buildings projects with demolition and construction phases would generate an intermediate amount of wastes according to the mentioned values.

To establish an easily controllable waste indicator, it is proposed to use the **amount of waste diverted from landfill as a percentage of total generated waste,** correctly segregated and managed towards materials recovery, reuse or any other type of valorisation. To define and calculate this indicator, several aspects should be considered:

- the total amount of waste for the calculation should be the real value and not an estimation, if possible
- efficiency of materials recovery of treatment plant should be considered
- not recovered wastes are also separated in proper conditions within the site, but, due to management activities (optimal or not), they are not properly segregated and the waste manager should send it to landfill
- incineration with heat recovery is preferred against landfill and may be considered for the total waste management efficiency indicator.

Cross-media effects

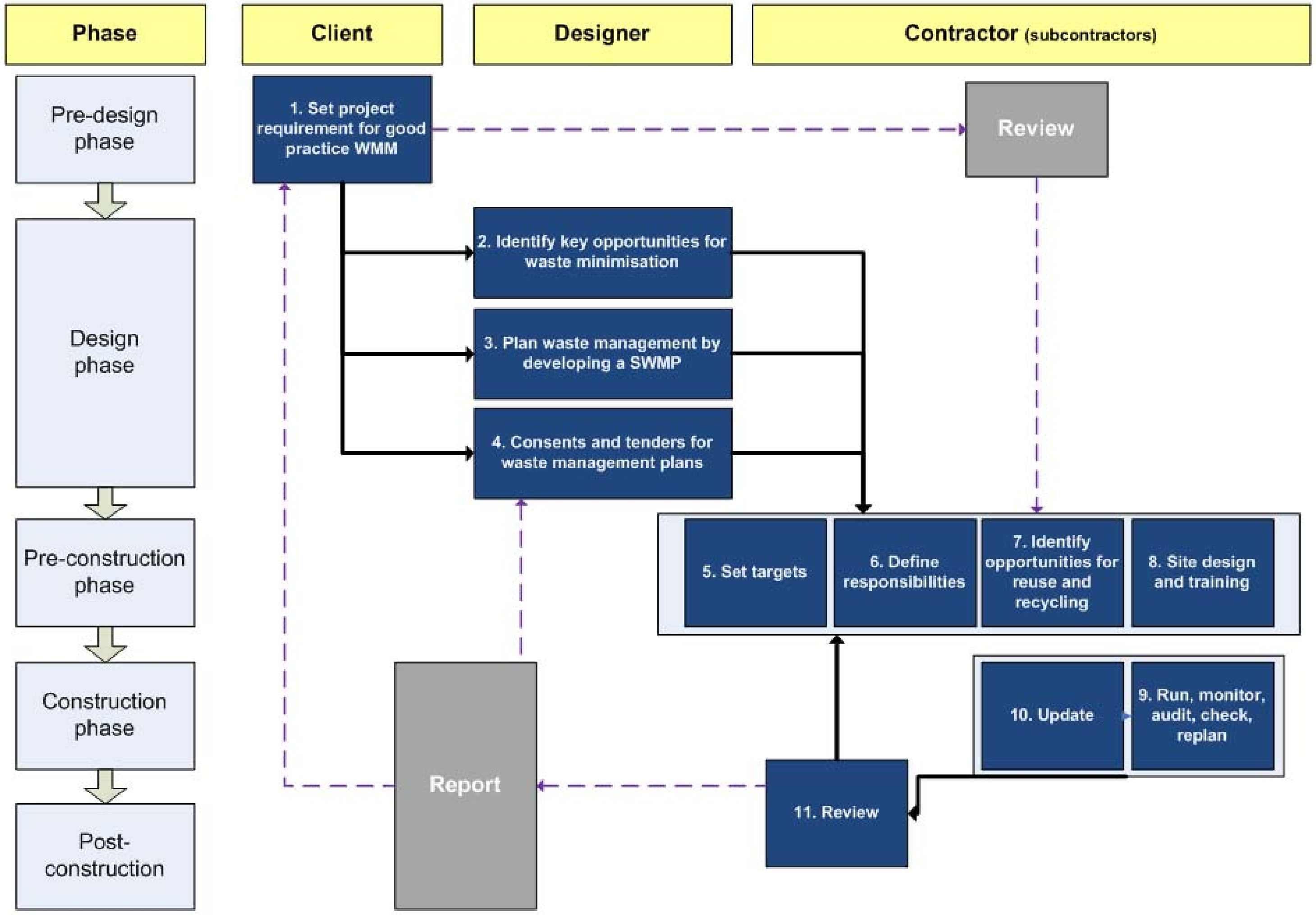
Although best environmental management practices for wastes are able to reduce the total amount of wastes to be disposed off and to increase the available recyclable materials in the market, it should be taken into account the increased logistics needs when high segregation rates are achieved. This means that collection vehicles would increase their fuel consumption and their associated emissions, especially CO_2. The application of optimisation, compaction or reverse logistics techniques would reduce these environmental impacts.

Operational data

Definition of a waste management strategy

The definition of a strategy for waste management does not start in the construction activity. It should be defined from the very beginning with the active participation of the client and the designer. The client should have a clear idea of the waste management objectives, establishing targets, updating them and reviewing all the information provided by designers, contractors and subcontractors. The main motivation for this is economical, as best management options would always produce important costs savings (see economics section). Figure 5.25 shows an example of definition steps of a waste management strategy, adapted from that proposed by the Waste Resources Action Programme of the UK (WRAP, 2012b). The client should be prepared to ask for the best waste management on site. Clear objectives should be stated from the very beginning, setting quantitative measures according to defined benchmarks and adapted to the specific project. If the client is a public administration, the aim of the project should also consider the best options for the best resource efficiency, fitting to best environmental standards and complying with the urban planning sustainability objectives. Then, the designer may fit to the strategy by designing out waste, where the main opportunities are identified. A waste management plan (or study) may be mandatory and is usually a key point of tenders and contractual requirements.

After studying the project, clear and quantifiable targets should be established. Specific needs for the site may come at this point, such as specific responsibilities, consents and specific training. During execution of projects, contractors are the main responsible of the waste management strategy. They should monitor, audit, revise and update the plan, reporting periodically to designers and to the client, who may take action in the form of corrective actions by reviewing the existing plan. This is linked with the definition of environmental management plan, described in section 5.6.1.1 and with the general requirements of certified environmental management systems. In all these processes, the identification of opportunities should become an effective reduction of waste and reuse and recovery increase (see Figure 3.57)



Source: Adapted from WRAP 2012. SWMP: Site Waste Management Plan

Figure 5.25: Waste Management Strategy definition.

Case studies on waste management strategy

Balfor Beatty carried out the **Birmingham New Hospitals Project** (WRAP, 2010b). The project involved the construction of several hospitals with more than 1300 beds. In this project, several waste management activities were carried out to ensure minimum waste generation through designing out waste, establishing a monitoring system with several benchmarks to be achieved, establishing take back systems with suppliers, using closed loop recycling, using a waste management contractor to coordinate the management on site and controlling the destination of recovery operations of wastes off-site. This project can be considered exemplary, as the amount of wastes to be generated and the proximity of sensitive areas (residential and protected) made the available space for waste management very limited. As Balfour Beatty was in charge also of the design of buildings, several designing out techniques were applied to prevent waste generation. It was made by modularisation and standardisation of elements. The waste management strategy established an objective for recycling 80 % of waste materials (i.e. recovery of the 80 % of the material contents from waste as construction products after treatment). This applied for timber, metal, plastics, packaging, bricks, blocks, concrete and glass. A take back system for plasterboard, pallets, vinyl and tiles was arranged and contracted with suppliers. Final results showed how the construction company, Balfour Beatty, and the waste manager could establish a waste management strategy from an early stage of the project through the inclusion of waste management objectives into contracts. Achieved recycling rate was higher than 88 %, with a total generation of 2.45 m^3 of wastes per EUR 100000 of project value. Final landfill diversion rates varied from 93 to 98 %.

The waste manager of the project used 230 containers, 184 with a capacity of 660 litre, 34 of 820 litres and 12 of 240 litres. The position of each container was carefully selected and varied during the construction activities. The waste management contractor was working on site with 10 full time positions in order to ensure appropriate waste segregation. Compaction to several wastes fraction was performed before collection. This allowed reducing the entrance of vehicles 13 fold (WRAP, 2010b). It avoided 250 km in waste transport per day (about 45 litres of diesel per day) during five years. According to the waste manager, the use of a waste compacting system was able to reduce total waste management costs.

The **Middlehaven hotel** in Middlesbrough can be also considered as an exemplary case, where the client put clear objectives on waste generation. They demanded to the designer that generated waste should be less than 15m^3 per 100 m^2 (150-200 kg per m^2) and waste management costs should be less than 0.2 % of total project cost. The site should be designed in order to minimise the amount of soil to be imported or exported. Recycled materials should be used on-site and materials should be use efficiently. The potential costs savings, compared to standard construction practice, were about EUR 450000. The use of prefabricated elements, standard materials and communication and management practices with the supply chain and the packaging materials lead to waste savings of 3140 tonnes (about 75 % from traditional construction practices). In this case, the waste management strategy was focused on the design phase and performed because of client specifications (WRAP, 2008).

Composition and estimation of waste generation

Main construction and demolition wastes (except for excavated soil) correspond mainly to these categories (common statistics categories, see Section 5.4.2.4):

- Concrete, mortar, cement and ‘clean’ debris
- Bricks, tiles and other ceramics
- Metals
- Wood
- Glass
- Plastics
- Paper and cardboard.

These categories correspond to the minimum segregation specifications asked in some regulations and may constitute the basis for estimations and for the establishment of deposits to be paid to the permitting authority. Other fractions, such as excavated material, are not considered in this list, as their management is usually performed by the same company or they are provided to other construction sites as filling materials.

To illustrate the different waste fractions in Europe, the main average composition of waste arising from construction works estimated by BioIS are shown in Table 5.32.

Table 5.32: Average construction and demolition waste composition in Europe

Waste category	%, min-max range
Concrete and Masonry	40-84
Concrete	12-40
Masonry	8-54
Asphalt	4-26
Others (mineral)	2-9
Wood	2-4
Metal	0.2-4
Gypsum	0.2-0.4
Plastics	0.1-2
Miscellaneous	2-36

Source: BioIS, 2011

Llatas, 2011, elaborated a model to estimate total wastes arising from construction projects, by developing factors and using a model similar to that shown in Figure 5.24. A full list of results can be found in the literature (Llatas, 2011). The most interesting point on the publication is the estimation of wastes generated per construction process, calculated in a chronological way. Table 5.33 shows a summary of these results. As shown, large amount of materials are produced at the beginning because of the need for site clearing and excavation needs. Then, packaging and construction and demolition waste are produced. Waste generation rate is lower at the final stages.

Table 5.33: Waste generation per category and per process (example)

Sitework process	Packaging waste, m^3	Mineral CDW, m^3	Excavated Materials, m^3	Total, m^3
Site clearing	0	0	180	180
Earthworks	0	0	569.2	569.2
Installation of Mechanical Utilities	3.21	1.51	51.64	56.36
Foundations	10.15	24.33	1.5	35.98
Structure	21.14	40.81	0	61.95
Masonry	118.32	52.27	3.3	173.89
Roofing	18.1	7.76	1.2	27.06
Services	18	18.7	0	36.7
Coatings	31.71	16.93	1.5	50.14
Carpentry	0.36	1.59	0	1.95
Glass	6.8	0.14	0	6.94
Paintings	8.3	0.07	0	8.37
Total	**236.09**	**164.11**	**808.34**	**1208.54**

Source: Llatas, 2011

The composition of wastes generated at construction sites depend mainly of the typology of building, local conditions, design and prevention measures, through designing out wastes and other prevention practices on site. For construction of new buildings, earthworks will generate the most important fraction of wastes (from 60 to 90 % in some cases), while packaging will be important in volume but not in weight. In the example of Table 5.33, the volume of packaging materials is presumed to be higher than the volume of mineral construction wastes. Nevertheless, this would depend on the final design and on the construction practice. According to the example shown in Table 5.33, packaging waste is composed of wood (70 %), plastic (13 %), cardboard (11 %), metal (5 %) and mixed packaging materials (1 %). Mineral construction wastes are composed by concrete (49 %), bricks (30 %), mixed fraction (14 %), municipal solid waste (2.1 %), mixed wastes (1 %) and limestone (0.5 %). Hazardous waste would be about 5 % of total construction and demolition waste, mainly consisting of gypsum and wood, containing losses of releasing agents and other chemicals.

Generalisation for the amount of waste per category and per type of construction works is usually not possible. It depends on the design, typology, allocation of resources, prevention measures, reuse practices, etc. A detailed, tailor-made, study on waste generation is needed per construction site.

Scheduled vs. reactive waste collection

Regular waste collection for construction and demolition waste can be performed for large construction process when the waste generation per type and per period is clear. Nevertheless, large construction projects with a pro-active management systems, including a good monitoring system, may include a reactive (requests in advance) collection system. Small and medium size projects have more problems to store wastes, so managers usually prefer to remove them when containers are full (WRAP, 2010a). Some problems may arise from this situation if skips are over full. Good communication between the construction organisation and the waste manager is essential.

This communication is very important for ad hoc waste service. Construction waste manager can use efficiently vehicles if collection is made around 24 hours after the request. Construction workers should be aware of the needs of the waste manager, so that they should foresee when containers will be full. At the same time, waste manager should understand that construction companies may not be able to store waste (e.g. they do not have enough space on site) if collection times exceed 24 or 48 hours after request.

Waste logistics

An example of enhanced waste logistics is presented by **AstraZeneca** (pharmaceutical company with a long experience on construction on their manufacturing sites). Their approach is to hire a separate logistics manager for the construction site. For the demolition of an old building at Aderley Park in Chesire, they hired Wilson James, a logistics company, to arrange with suppliers when to deliver to site, supervising delivery of materials, transfer materials on site, supply of appropriate containers, and transfer of waste on site and delivery of wastes to recovery and recycling materials. Results from the demolition activity have led to achieve a 96 % recycling rate. According to the company, the costs are not higher than those from 'normal' operation but the efficiency of operation was higher, there were fewer movements of vehicles and the segregation of wastes was improved.

Materials recycling facilities

According to WRAP, 2010a, construction and demolition waste economic recycling has a strong dependence on transport, so the best benefit from waste material recycling for certain types of waste are obtained when there are enough facilities in the appropriate distance for packaging, tiles, ceramics and insulation materials. Also, the economic performance of waste recovery from construction wastes depends on the quality of segregation.

Applicability

From the environmental point of view, appropriate waste management and best environmental management practices are always applicable and, for some clients, best practices may constitute a requirement. Nevertheless, market conditions may not be favourable for the economics of the most appropriate management option.

Economics

Waste treatment economics

Waste management costs in construction projects should no be higher than 3 % for common practice, while for demolition and deconstruction projects, waste management may apply the principal cost concept (see chapter 7). CYPE, 2012, showed an example on the calculation of total waste management costs. In order to have realistic results, good accuracy on the estimation of wastes to be generated should be achieved. Table 5.34 shows an example for a high-rise residential building.

Table 5.34: Example of waste management costs calculation

Total Project Value		**EUR 1930000**		
A. Waste Management Prices				
Category	Volume	Specific Cost, EUR/m^3	Total cost, EUR	% of project value
1. Excavated Material	2330	4	9300	0.48 %
2. Construction and demolition mineral waste (concrete, bricks, tiles, etc.)	570	10	5700	0.30 %
3. Packaging, metals, wood, etc.	150	10	1500	0.08 %
4. Hazardous waste	30	10	300	0.02 %
B. Other costs				
Concept			Total cost, EUR	% of project value
1. Leasing, renting, allocation of resources for management, etc.			2900	0.15 %
Total Waste Management Costs			**19700**	**1.02 %**

N.B. Source: CYPE, 2012. Specific prices for waste management could be outdated

During the elaboration of this document, some information on waste management prices were collected during visits and meeting with experts. As observed, there is not a standard price for wastes coming from construction sites. There could be negotiation processes with waste transport services and waste treatment plants leading to different treatment cost options. Table 5.35 shows some data on waste management prices from organisations (e.g. WRAP), construction companies and treatment plants. It is difficult to find homogenous waste management pricing, as they depend usually on local, regional and even national factors. Usually, prices are regulated to make more attractive for site managers their segregation and further recycling processes than their deposit in landfills. As shown in Table 5.35, in the UK, prices for small containers of 1 m^3 vary from EUR 6 to 9, plus a rent of EUR 0.11 per bin per day. For reactive waste collection, (skips and roll-on roll-off containers) prices in the UK vary from EUR 25 to 70 (depending on the type of waste) or a transport fee is charged, depending on the distance (WRAP, 2010a). Negotiation with waste managers can lead to 'all included' prices for 10 m^3 skips of, e.g., EUR 125 (UK) or EUR 110 (Spain) (WRAP, 2010; CACEC, 2012) and for 27 m^3 roll-on roll-off containers of EUR 265 (UK).

Table 5.35: Some waste management prices

Source	Year	Country	Type of waste	Price, EUR	Weight, volume or unit	Comments
WRAP	2010	UK	Mixed	6 to 9	1m^3 bin	Multi-modal waste collection (scheduled) plus a rent of EUR 0.11 per day per bin
			Several	125	10 m^3 skip	Schedule collection after negation (all in)
			Several	300	27 m^3 container	Schedule collection after negation (all in)
			CDW	25-70	per tonne	Average prices, depending on the final destination
CACEC	2012	Spain	Several	110	10 m^3skip	Price for a construction company: collection after negotiation (all in) by waste transport service
			Common waste	75	1 m^3	Assumable as municipal waste, landfilling
Treatment plant	2012	Spain	Concrete (clean)	6.5	1 m^3	Clean concrete with a limit of 0.5 % impurities
			Mixed	14.5	1 m^3	If container content has to be landfilled, 15 EUR/m^3
Construction company	2011	Germany	Mixed	65	1 m^3	Not segregated
			Wood	6 to 9	1 m^3	Any type of wood
			CDW	17 to 20	1 m^3	Mixed inert fraction
Treatment plant	2012	Germany	Mixed	14	1t	Mixed inert fraction
			Concrete (clean)	14	1t	For sizes higher than 200 cm, price would increase
			CDW	14	1t	Mixed inert fraction
Several comms.	2011-2012	Several	Wood pallets	3 to 12	per pallet	Take back system: included in initial bills as deposit, paid back after recovery.

Savings

According to a report on costs savings potential of 15 different projects for different building types in the UK (WRAP, 2012), the average cost reduction is about 0.40 % of total cost project. The costs saving potential is about 0.77 % and the additional investments are 0.37 % of total costs. The summary of this assessment for reducing costs by appropriate waste management techniques is shown in Table 5.36.

This assessment was made on the basis of reducing material input for 10 components, enhanced waste segregation and, for refurbishment projects, by maximising reuse of materials.

Table 5.36: Net benefit calculation of reducing the amount of waste

Building	Project Value, Million EUR	Material costs savings, EUR	Disposal costs savings, EUR	Potential savings, as % of project value	% of good practice costs	Net benefit, EUR	Net benefit, % of costs
Housing							
20 masonry houses	1.15	8740	10580	1.68	1.07	7000	0.61
20 timber-frame houses	1.495	16560	8165	1.58	0.79	11800	0.79
Small concrete residential block	8.165	30130	7015	0.46	0.28	15000	0.18
Steel frame halls of residence	11.27	66470	21390	0.78	0.25	60000	0.53
Commercial							
Supermarket	4.37	23805	6670	0.69	0.42	12000	0.27
Steel frame distribution centre	12.65	51175	32890	0.66	0.15	64500	0.51
Concrete frame office	26.45	116955	27715	0.55	0.13	111000	0.42
Public							
In-situ concrete frame hospital	204.7	513590	125465	0.31	0.03	573000	0.28
Steel frame secondary school	25.875	144785	39905	0.71	0.12	153000	0.59
Steel frame primary school	1.725	9430	3105	0.73	0.56	2900	0.17
Timber frame primary school	4.945	24265	32200	1.15	0.46	34000	0.69
Pre-cast concrete prison	5.635	10005	1380	0.2	0.17	1700	0.03
Refurbishment							
Social housing	1.725	3795	11845	0.9	0.42	8300	0.48
Small office	0.805	2990	1495	0.53	0.32	1700	0.21
Large office	3.795	14605	5060	0.53	0.18	13000	0.35
Small retail	1.61	8395	5520	0.86	0.62	4000	0.24
Average				**0.77**	**0.37**		**0.4**

N.B. *Source*: adapted from WRAP, 2012.

The results from Table 5.36 are mainly estimations based on the application of several measures and practices on the waste management of each building project:

- To develop a site waste management plan beyond legal compliance and high quality waste forecasts

- To develop a site strategy for wastes, planning timing, schedules for delivery of materials and collection of wastes
- To train operators
- To store materials in temporary shelters
- Additional resource time (about 2.5 hours per week during ¾ of the project time)
- Updating the waste management plan (4 hours each 3 months)
- To ensure good segregation and monitor reuse on site.

The environmental benefit foreseen with these techniques are in the range of 25-60 % of waste reduction and an increase of the fraction sent to recycling plants of 25-30 %.

Scheduled vs. reactive waste collection

Multi-modal collection (scheduled collection of small bins in a planned route through several sites) usually requires less fuel consumption for trucks and consequently less cost for construction companies. For ad hoc or reactive waste collection, an estimation of construction wastes produced on-site can help to identify savings from different collection techniques during the life cycle of a construction project.

Driving force for implementation

According to the description above and the observations made during the elaboration of this document, driving forces for the implementation of waste prevention measures and optimal waste minimisation strategies are:

- Reduction of construction costs through reduced waste management costs
- Reduction of environmental footprint of the construction site and of the company
- Anticipation of future legal requirements
- Increased reputation of the company towards the public, which may be useful for public tenders and contracts with the administration
- Increased knowledge of the activities, which would feed into a company's continuous improvement commitment and to the identification of new opportunities.

Reference organisations

Balfour Beatty is a construction company (buildings and infrastructure), mainly working in the UK, which has provided examples for the elaboration of this chapter and applies comprehensive waste management strategies.

CACEC is the Spanish advisory board for the certification of construction companies. It is composed of big construction companies, umbrella organisations, public administrations and AENOR, the Spanish standardisation body. The working group on the environment of CACEC contributed to the elaboration of this document. Companies from CACEC do not allow separate references, so references are given to CACEC communications.

SKANSKA is a Swedish construction company, working all over the world. Their sustainability approach is appreciated and information on best environmental management practices could be obtained from their webpages.

WRAP is the UK Waste Resources Action Programme. A lot of information could be obtained from their comprehensive knowledge database. WRAP commitment to resource efficiency and waste prevention is divided into seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient

- Recycling organic waste and recovering energy
- Increasing the reuse and recycling of priority products.

Those organisations referenced above are only a sample of all the local, regional and national public administration, construction companies and associations working, currently to improve the environmental performance of waste management.

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5.6.2.2 Increasing materials use efficiency

Description

In this section, measures to increase the materials use efficiency are described. This section should be understood as a compilation of practices to reduce the avoidable purchased materials fraction ending up as wastes. The most important techniques identified during the development of this document are:

- designing out waste,
- use of prefabricated structures,
- management of remaining materials and integration into a logistics scheme, and
- best storage and handling practices.

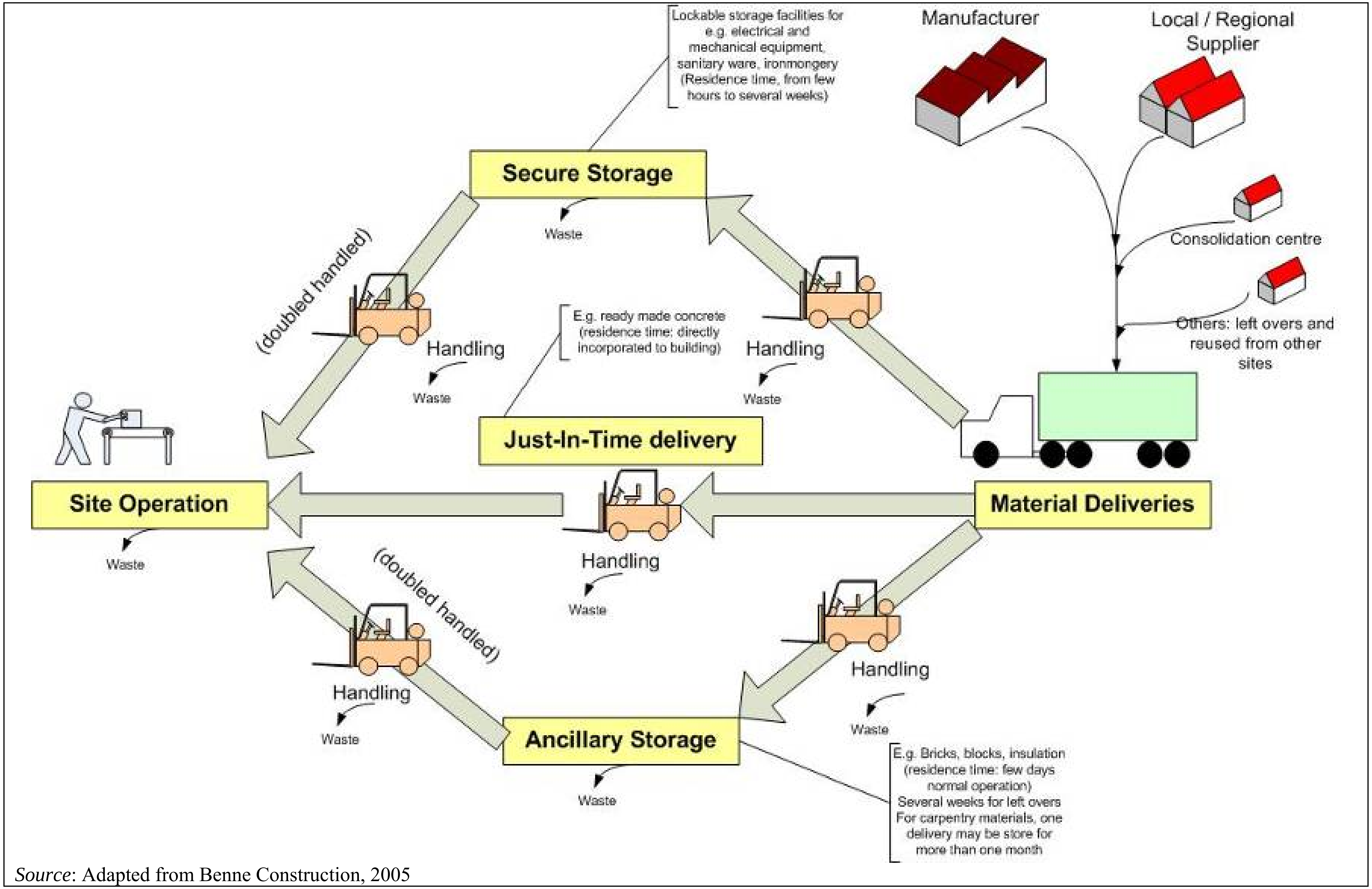
Designing out waste and prefabricated structures are described in Section 3.4.7. These practices reduce the amount of wastes not only by using construction techniques that generate less waste, but also design techniques that optimise the use of materials in order to reduce waste generated from losses.

For this section, best management options to increase materials use efficiency and, therefore, reduce the amount of waste should be considered. One of the options is to establish a logistics scheme allowing optimal material use and minimising the amount of raw materials lost because of a lack of good management.

Regarding best storage options and the integration of materials storage and use in a whole logistics scheme, *stockholding* is a term to be introduced (Constructing excellence, 2005). It describes the process of holding materials in readiness for subsequent activities. The majority of materials are put into stock when they arrive to a building construction site. This means that materials are double handled, increasing the risk of damage, which supposes an economic loss plus waste generation.

Research carried out by Denne construction, 2005, showed several options for stockholding according to the studies made on two construction sites. Several factors need to be assessed in order to avoid waste due to damage: the characteristics of the materials, means of working, transportation, storage and handling. For instance, some bricks are prone to distortion during manufacturing. These bricks can be up to 10 % of total bricks sent to a construction site. Packs of materials tend to rub against each other when transported and severe damage can be produced. The area for material storage should be hard, flat, well drained and material handling should be carried out with care, e.g. avoiding early removal of packaging.

Materials use efficiency is also a technique to consider efficiency of logistics. Important environmental impacts can be avoided when logistics are improved: less fuel consumption, less materials and product leftovers, less CO_2 emissions, etc., which can obviously produce important costs savings. Figure 5.26 shows a classical overview of how materials are supplied to construction sites and how they are supplied to the operation phase of building construction. Supply is made by manufacturers (for special, designed on demand, construction products), local or regional suppliers, urban consolidation centres and the same or other companies handling remainders from other construction sites, reused material from deconstruction projects or other material fractions owned by the company. Then, three techniques are observed: ancillary storage, secure storage and just-in-time delivery. Ancillary storage (e.g. for bricks, blocks, timber, etc) is used to buffer the supply of materials to the operation sites. Secure storage has similar functions, but is a locked storage for materials of high value (metals, kitchens, sanitary ware, etc.). The third technique, just-in-time delivery is the preferred one for some applications (e.g. ready made concrete).



Source: Adapted from Benne Construction, 2005

Figure 5.26: Schematic view of materials logistics at building construction sites

There is not a single solution to derive best environmental management practices for stockholding in order to increase material efficiency. While for construction sites with enough available space, ancillary storage can be large enough in order to avoid excessive vehicle movements or to reduce unitary costs through large orders. Usually, big cities have space problems in construction sites, so two solutions are usually taken: just-in-time ordering and/or delivery (which means that deadlines may not be met in the case of delivery delays) or a consolidation centre, which may be a good solution for smaller companies, working locally and with very similar building projects. Nevertheless, big companies consider consolidation centres as a costly item to be avoided by good management. Sharing a construction consolidation centre to be managed by logistics companies may be optimal, as the case for the London Construction Consolidation Centre operating during the Olympics 2012 facilities construction.

So, decisions on material logistics should be regarded for every site (or every site typology) for:

- needs of buffers against uncertainty
- lower purchasing price in large batches
- controlling vehicle movements
- availability of storage space.

Achieved environmental benefits

In general, an increase of materials use efficiency has a significant effect on site economics. In addition, environmental benefits are huge. The amount of waste is reduced and the consumption of fuel and emissions of CO_2 are significantly reduced due to less vehicle movement. The example of Central St Giles (WRAP, 2010) shows a reduction of plasterboard waste to 6.4 %, while the industry average is 22 %.

Appropriate environmental indicators

As explained in other sections, a common indicator for the environmental performance is the amount of waste generated on site. It can be measured on a mass or volume basis. Density is quite variable, so volume seems to be a quite good unit to control waste management on site, as the manager can easily check the movement of waste containers. Nevertheless, the environmental impact and, thus, the materials efficiency of construction costs should be controlled using a mass basis. Apparent densities for several construction and demolition wastes categories is shown in Table 5.31 (section 5.6.2.1). Also, it is recommended to use robust estimation methods for waste generation to control the environmental and economic benefits of improved material use efficiency through consolidation centres, just-in-time techniques and others.

The reduction of fuel consumption and CO_2 emissions is, maybe, difficult to control for the contractors, as they usually are not directly responsible for materials transportation. Nevertheless, vehicle movement is registered and can be easily controlled. Some indications for fuel consumption are given in 5.6.2.7.

Cross-media effects

Some construction sites may require more materials movements in order to avoid over ordering or over storage when space availability is high. Some of the problems can be substantially solved when a consolidation centre is used.

Operational data

Case study: Central St Giles.

This is a development in London with more than 37000 m^2 of office space plus 56 apartments and 53 affordable homes and 2400 m^2 of retail units and restaurants.

A material logistics plan was drafted for this building in the centre of London. A logistics management system was established as a pilot experiment. The key elements of this case study were the use of a Construction Consolidation centre, reducing the number of vehicle journeys

(956 fewer) and reducing carbon emissions to 75 %. The consolidation factor was 4.1 (there were 4.1 deliveries to the consolidation centre for each journey to the site). Just-in-time deliveries were produced in a 48 hours cycle, minimising materials stored at the site. Also, the waste amount was reduced using modern methods of construction (see section 3.4.7.1), i.e. for wall units and toilet pod walls. For the management of waste produced on site, reverse logistics were used (the trucks delivering materials were used to remove wastes). According to WRAP, 2010, delivery accuracy of 97 % was achieved and plasterboard waste was reduced to 6.4 %, while the industry average is 22.5 %. For the management of the logistics aspects, a site logistics manager was present during works. There is no economic data on the performance of the site.

Case study: London Construction Consolidation Centre

The London Construction Consolidation Centre is a facility of 5 000 m^2, able to handle more than 200000 pallets of construction products. This facility acts as consolidation centre to reduce the amount of movements of materials inside the city. A very important environmental benefit can be achieved, as less pollution inside the city will be derived (see previous case study). Over ordering is avoided and leftovers are well managed, as a take back system for wastes and materials is also arranged. The concept of a consolidation centre for construction sites is explained in Figure 5.27.

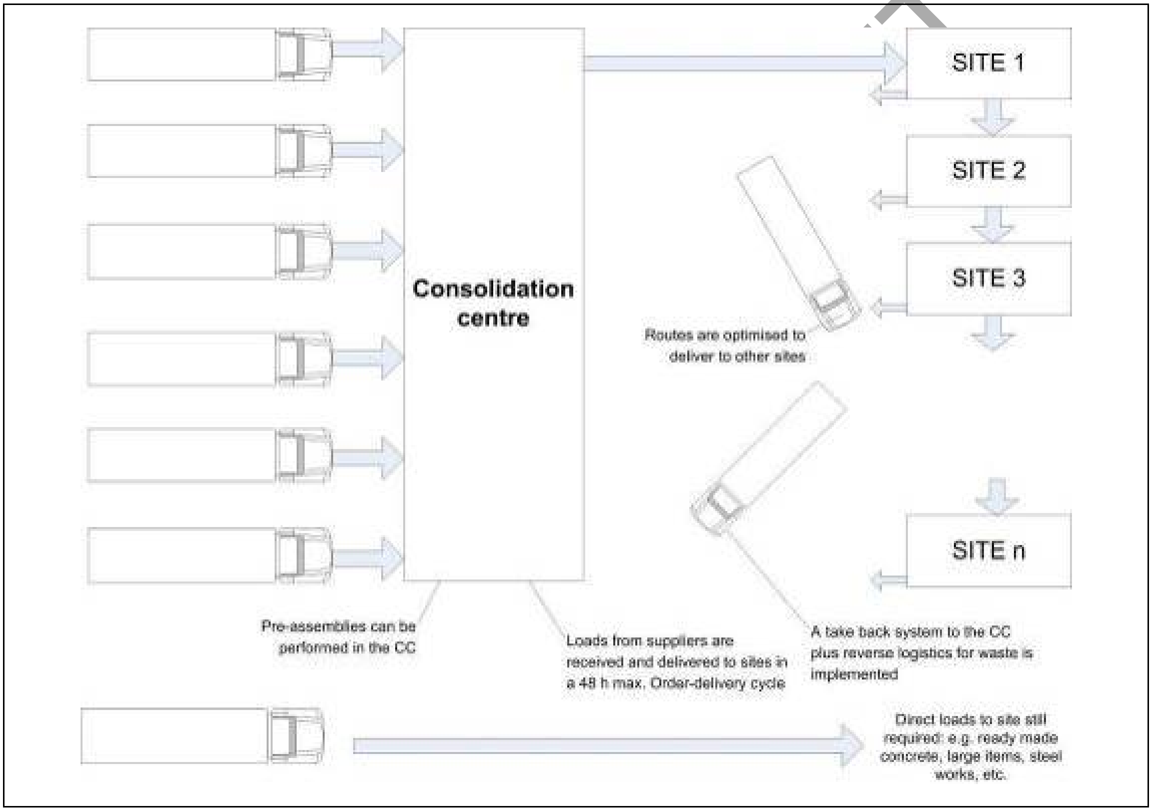


Figure 5.27: Construction consolidation centre concept (CC: Consolidation centre)

The London Construction Consolidation Centre is managed by logistics companies. As the consolidation centre is able to receive bulk deliveries, packaging waste is minimised (Constructing Excellence, 2012; WRAP, 2010). Also, the delivery is carried out in the next 48 hours after the order. A kitting procedure is implemented in order to prepare materials needed for specific tasks, so site double handling can be avoided by just-in-time deliveries. The centre performs also preassembly, such as air conditioning ducts lagging, which can be done in the centre and then loaded in to a delivery to the site. Less waste would be generated and the working efficiency would be higher.

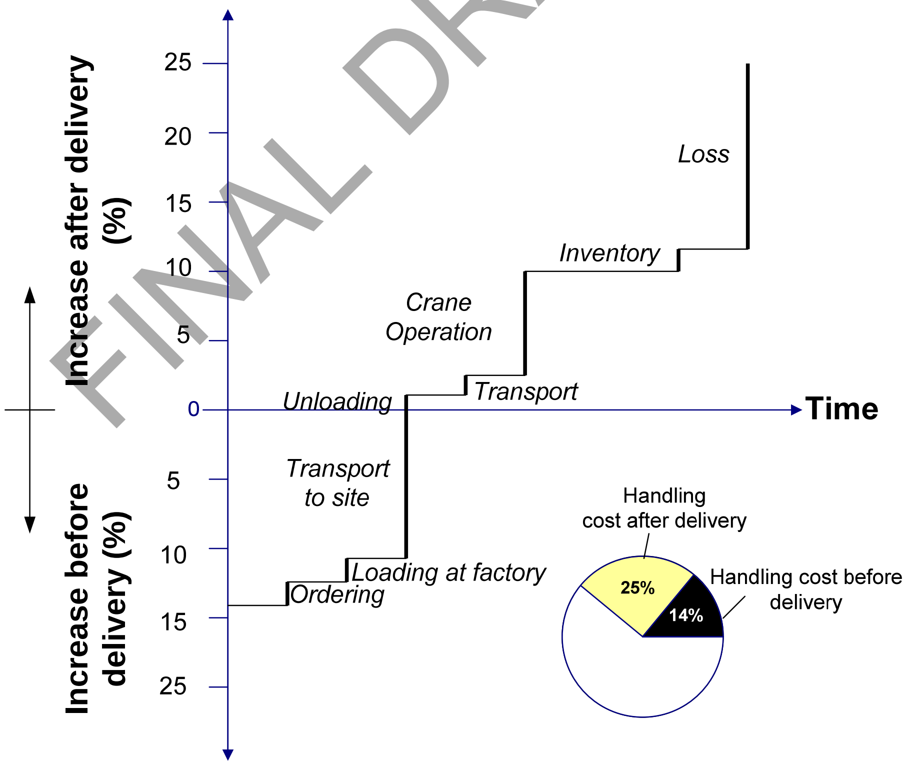
The construction consolidation centre can be considered a good practice, but it should be regarded in terms of land planning and urban environment, as an important reduction of traffic for materials transportation is achieved. For construction companies, dedicated logistics efforts may be required, although productivity may be improved.

Applicability

Proper material handling best practices to reduce wastage of construction materials is applicable to any construction company. The application of construction consolidation centers should take into account that they may become a requirement to reduce traffic in heavy congestion areas and would improve the performance of materials storage because of limitations on space (TTR, 2010).

Economics

The cost staircase for materials transport and handling in the building sector were calculated by a Swedish analysis (Bertelsen and Nielsen, 1997). It was notice that direct costs derived from transportation to construction sites were lower than those derived from handling and bad management on site (see Figure 5.28). Losses are really important if materials managing costs are evaluated (about 12 % of total cost increase after purchase). Transport and handling costs are also high and may be higher than 20 % of purchase costs. Also, 16 % of total work hours can be lost because of bad management costs and 10 % of total material cost can be caused by unforeseen events (breakage, over ordering, etc.). So, material use efficiency would always produce an increase in the cost efficiency of the site and, at the same time, less waste would be generated, deriving lower costs associated to waste management (see section 5.6.2.1).



Source: Adapted from Bertelsen and Nielsen, 1997

Figure 5.28: Cost staircase for mineral wool

Costs of using a consolidation centre do not increase operating costs to construction companies. The more frequent use of just-in-time deliveries and the better organisation of the site can increase significantly site productivity and reduce wastes due to losses. Also, waste management is improved because of a take-back system.

A study showed that freight consolidation centres are optimal when they are shared with other construction companies (see Table 5.37). The difference between using 50 % of transports with vans (up to 3500 kg vehicle) or 100 % is not significant. The increase in the number of vans has a positive impact, since the transport activities with big lorries, directly to site, are less intensive and higher loads can be considered.

Table 5.37: Estimations on management cost of materials in the consolidation centre, vehicle runs and environmental impact

	50 % runs with vans		100 % of runs with vans	
	Dedicated	Shared	Dedicated	Shared
Cost per pallet, EUR (in CC)	27.40	12.30	27.90	12.00
Total km, no CC	319500			
Total km, with CC	266500		220000	
Vehicle runs, no CC	9558		5676	
Vehicle runs, with CC	5186		6173	
Emissions, NO_x, no CC (kg)	1533			
Emissions, NO_x, with CC (kg)	1204		1114	
Emissions, Particulate Material, no CC (kg)	40			
Emissions, Particulate Material, with CC (kg)	27		21	

N.B. CC: Consolidation Centre, *Source*: TTR, 2010

In terms of construction site management, the London Construction Consolidation centre has shown a saving of 25 minutes per man day of construction tradesman time. Additional stock, as buffer for the construction site, can be significantly reduced thanks to the use of consolidation centres.

Driving force for implementation

According to the description above and the observations made during the elaboration of this document, driving forces for the implementation of material efficiency measures and optimal waste minimisation strategies are:

- Reduction of construction costs through reduced waste management costs
- Reduction of the environmental footprint of the construction site and of the company
- Anticipation of future legal requirements
- Increased reputation of the company towards the public, which may be useful for public tenders and contracts with the administration
- Implementation of tailor-made options for materials use efficiency, which may reduce operating costs.

Reference organisations

WRAP is the UK Waste Resources Action Programme. A lot of information could be obtained from their comprehensive knowledge database. WRAP's commitment to resource efficiency and waste prevention is divided into seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient
- Recycling organic waste and recovering energy

- Increasing the reuse and recycling of priority products.

The London Construction Consolidation Centre Partnership is a reference organisation, comprising Wilson James, Stanhope, Bovis Lend Lease and Transport of London.

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5.6.2.3 Reuse of materials

Description

According to the Waste Framework Directive, WFD, reuse is any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Following this definition, reuse is an operation for the management of materials, not waste. Also, the WFD defines preparing for reuse as an operation for products becoming waste, consisting of checking, cleaning or repairing to be reused.

These concepts have to be differentiated properly from recycling. This operation requires a waste to be reprocessed, and the final application of the recycled product could be the same or different as for the original material. On one hand, reuse operations are made on materials, which otherwise would become waste. On the other hand, recycling operations are made over waste, defined under the WFD and managed in a construction or deconstruction site as a waste.

Reuse is considered as best environmental management practice and can be performed over all the materials and construction products used or harvested in a site:

- Reuse of construction products and building elements. This is mainly applicable for materials harvested during deconstruction, which are reinserted in the materials cycle. For instance, bricks, tiles, concrete slabs, beams, wood frames, etc. It is directly linked to the performance of deconstruction site (see Section 7). Some opportunities are observed for construction sites, such as the use of remaining fractions as auxiliary materials.
- Reuse of auxiliary materials. This reuse flow is the more common in construction companies managing a number of sites. The reuse of wood structure from formworks, pallets, auxiliary structures, etc, is a common practice, as it has a significant impact on the economic performance of construction sites.

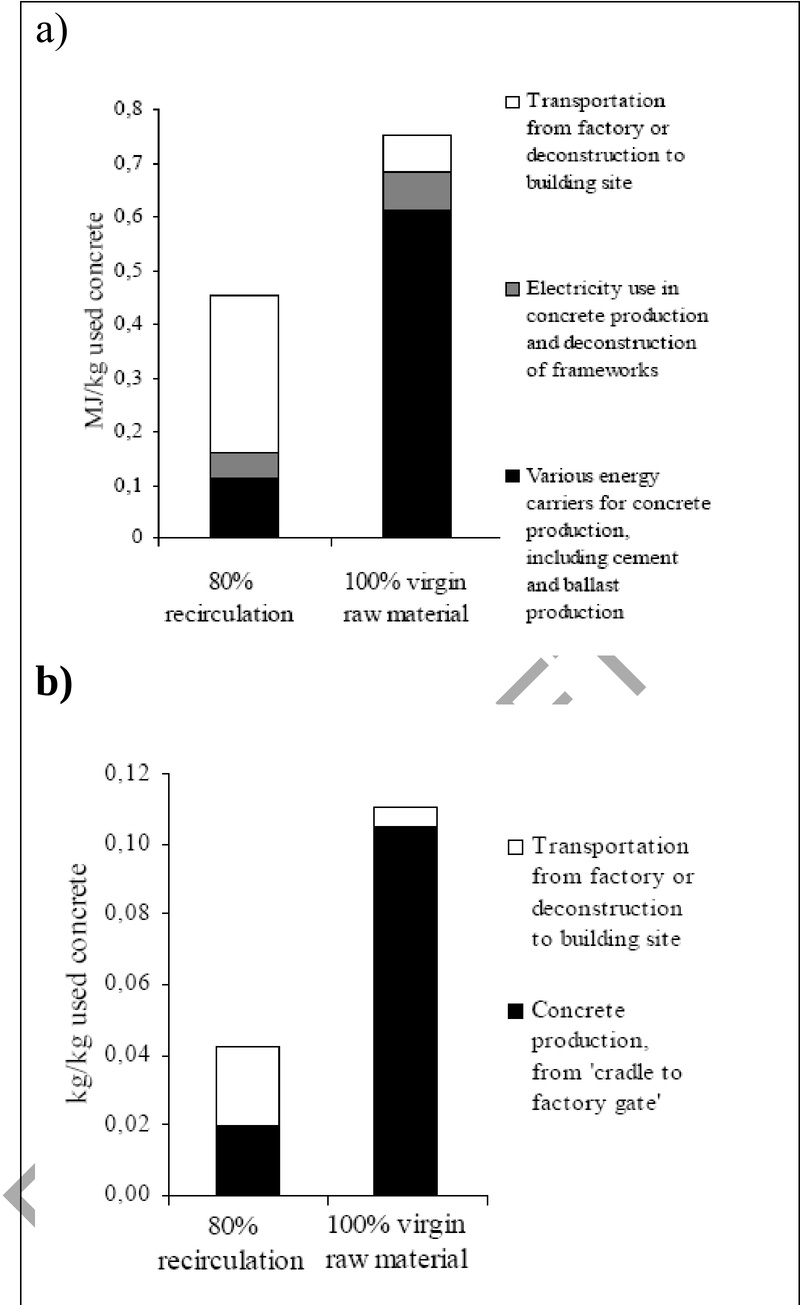
Achieved environmental and health benefits

Reuse has a significant impact on the performance of construction sites. Most reuse practices in construction sites refer to auxiliary materials (or the reuse of remaining fractions as auxiliary materials) and all of them have a significant economic effect, so most of them can be regarded almost as ‘common’ practice instead of ‘best practice’.

The example of the A46 motorway, provided by Balfour Beatty motorway, is an example of a best practice since reuse is integrated in an overall management scheme leading to 100 % recovery of material (see Section 8.5), with zero waste disposed in landfills. The achievability of the benchmark of excellence for waste management, i.e. 95 % of waste diverted from landfill, needs of reuse practices, not only to balance material flows but also to reduce operational costs of the waste management system.

Reusing building components and construction products has a significant effect on the overall life cycle. Generally speaking, the reuse of building elements and products has a significant effect on the environmental performance of materials. For example, Roth, 2005, studied the life cycle performance of building materials from prefabricated structures. Final results (Figure 5.29) show that a significant amount of energy can be saved (about 40 %) in the life cycle, although the need for transportation increases because of reuse. More than 60 % of the carbon footprint of the concrete structure is saved when reusing prefabricated slabs.

WRAP, 2008, published a reclaimed building products guide, where the main opportunities for reuse practices are given. For a typical UK house, CO_2 savings from recycling clay roof tiles, doors, joists, timber, bricks and flooring would be about 30 tonnes CO_2, the same CO_2 savings as from applying photovoltaic panels in the roof of that house for 13 years.



Source: Roth, 2005

Figure 5.29: (a) Life cycle energy consumption of a concrete structure and (b) Associated CO_2 emissions of the concrete structure

There are several environmental benefits that justify reuse before recycling practices (Bioregional, 2011):

- Although disposal is avoided for both options, reuse practices reduce to zero the amount of total waste to landfill, whereas recycling has an efficiency lower than 100 %.
- The embodied energy is saved, although recycled products have lower embodied energy than those from virgin materials.
- Recycling in construction leads to downgrading products quality. For instance, recycling of bricks means to crush them and produce a recycled aggregate, with a limited application and does not avoid the production of a new brick. Meanwhile, a reused brick has the same functionality and its use avoids the production of a new one.

Appropriate environmental indicators

It may be possible to control the amount of reused materials, i.e. the amount of reused materials in absolute units or the percentage of natural materials substituted with reused materials. But, in terms of overall waste management, the reuse of materials has a positive effect on the segregation rate and on the diversion from landfill rate, described in previous sections.

Cross-media effects

The main cross-media effect on the increase of reuse materials from deconstruction activities is the use of transport services on the logistics of reclaimed products. Local origin should be preferred when sourcing reclaimed products. BRE, 2008, calculated the maximum distance that a reclaimed material can be transported by road before exceeding the environmental impact of manufacturing new materials (Table 5.38)

Table 5.38: Maximum transport distances for reclaimed materials

Material	Distance, km
Reclaimed tile	161
Reclaimed slate	483
Reclaimed bricks	402
Reclaimed timber	1609
Reclaimed steel	4023

N.B. *Source*: BRE; 2008.

Operational data

One of the most important aspects is the logistics load of reused materials. Usually, quick wins are obtained from materials reuse performed in the same construction site, especially if construction works need to demolish existing buildings or structures. The benefit is doubled: first, free materials are prepared and used on-site and, second, waste management is avoided. Apart from this situation, reclaimed products trading is still not widespread enough. In the UK, a market for reclaimed products exists, especially for bricks, tiles and timber (WRAP, 2008). But, due to transport costs and environmental impact, local sourcing and local distribution of salvaged materials are always preferred. For auxiliary materials, there are more reuse opportunities on site and at other sites (from the same or different company). The local dimension allows a certain number of material flow streams to be established between manufacturers, distributors, sites and recycling plants. Figure 5.30 can be used as an example to illustrate this flow of materials. From this figure, it can be noticed that:

- Recycling materials flows is, comparatively, the most simple. The cycle can be closed partially, as wastes produced form construction and deconstruction sites are in a recycling plant, producing new materials able to be used again for construction. This is the simplest view of the closed cycle of construction products.
- Direct internal reuse (at the same site or at different site) produces quick wins and, most likely, less transportation costs.
- There are opportunities to establish take back systems or, even, reverse logistics schemes, allowing a significant reduction of transport costs. The presence of consolidation centres, as explained in section 5.6.2.2, would definitely be quite helpful for that.
- The involvement of manufacturers and suppliers of construction products, especially at a local level, is essential for achieving a high resource efficiency standard.

Usually, construction companies are quite efficient in the identification of reuse opportunities for auxiliary materials. There are already take back systems implemented for packaging materials, as pallets, which were successfully implemented because of the existence of fees per used pallet. Also, visits carried out during the development of this reference document showed that construction companies are reusing a significant amount of auxiliary and secondary materials. Table 5.39 shows some reuse examples.

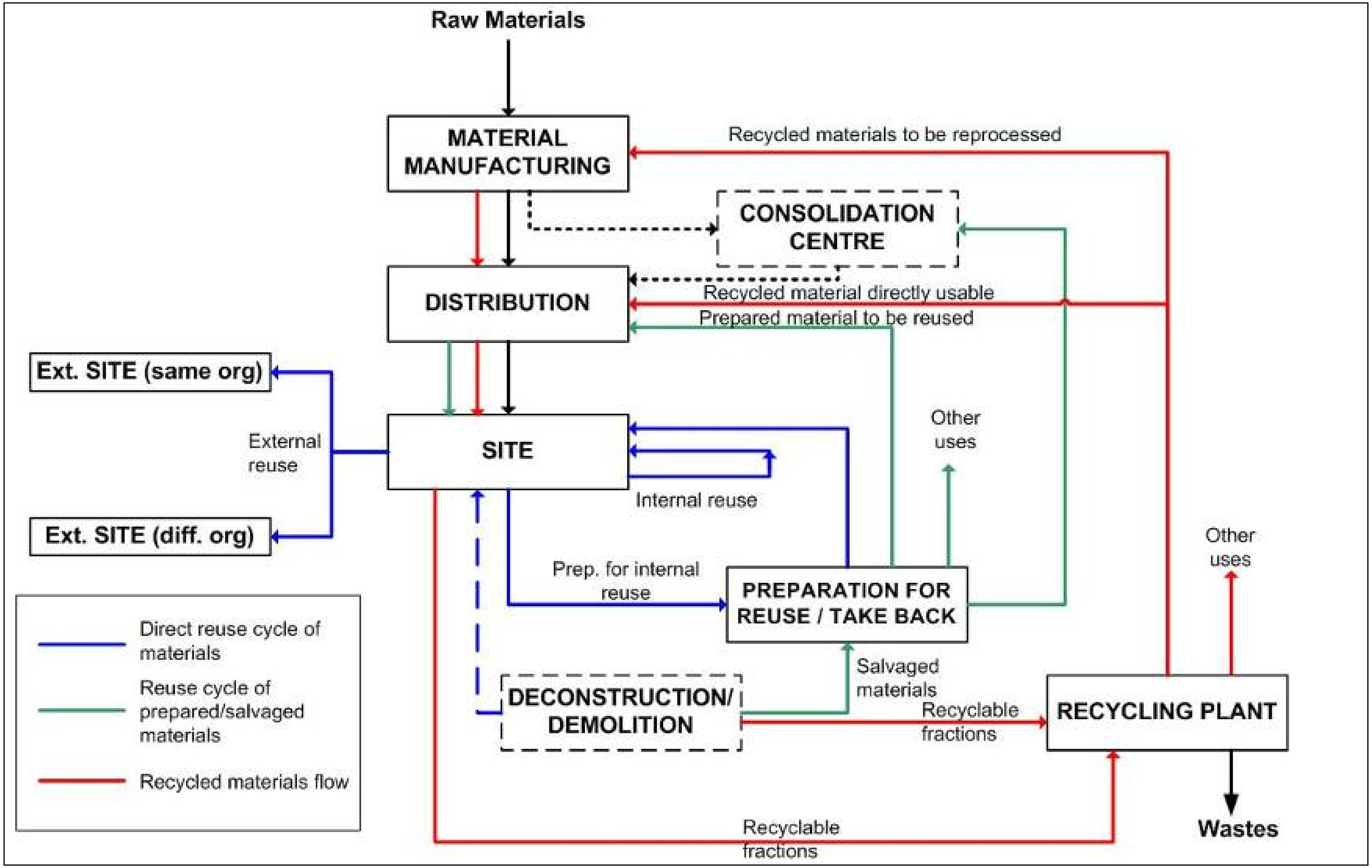


Figure 5.30: General overview of main reuse and recycle flows in construction sites

Table 5.39: Pictures and descriptions of some examples of the reuse of auxiliary materials

	Used pallets to be taken back by supplier.
	Reused mortar for site ground, e.g. in the entrance, to avoid site entrance dirtiness, mud during rain periods and dust.
	Wood from formworks reused for trees protection.
	Wood from formworks reused for temporary stairs.

Applicability

The only barrier for the applicability of reclaimed products reuse is the availability, which mainly depends on the existence of market acceptance. In countries such as the UK, there is a growing market for reusable products. Acceptability of designers, developers and clients is a key aspect on the use of reclaimed products, which fulfil exactly the same technical specifications, can be cheaper and can reduce considerably the life cycle environmental impact, reducing the extraction of raw materials. According to Bioregional, 2011, only by incorporating the fundamentals of reuse in designing practices, can the performance of the construction sector be made more sustainable.

Economics

While no construction company questions the acceptability of reusing packaging or auxiliary materials, which makes full economic sense, the use of reclaimed materials from deconstruction is quite rare. One main reason is the lack of deconstruction projects harvesting reusable materials. Nevertheless, WRAP published a guide on reclaimed products which showed that, even for manually separated bricks, the selling price is usually lower than for new products based on virgin materials. A comparison of costs for some reclaimed products is shown in Table 5.40.

Table 5.40: Cost comparison between reclaimed and new construction products

Product	Reclaimed	New	Comments
Clay brick	EUR 0.5 – 1.15/ brick	EUR 0.25 – 0.92/ brick	Cost Neutral. Cost premium for several high quality bricks
Structural steel	EUR 400 – 600/ tonne	EUR 920/ tonne	Important cost savings. Should fulfil specifications
Metal fencing	(free for site fencing), EUR 4 – 38 / m	EUR 6 – 44 / tonne	Cost saving depend on the required quality. Low cost fencing for construction sites may be free of charges
Roof slate	EUR 1 – 3 / slate	EUR 1 – 7 / tonne	Reclaimed products usually produce cost savings
Tiles	EUR 0.75 – 1 / tile (handmade) EUR 0.3 – 0.7 / tile (machine made)	EUR 0.75 / tonne (handmade) EUR 0.3 – 2 / tile (machine made)	Reuse of tiles is usually cost neutral.
Timber beams	EUR 1000 – 1400 / m^3	EUR 900 – 1300 / m^3	Costs can be higher or neutral
Timber joists	EUR 0.3 – 3 / m	EUR 2 – 4 / m	Usually, reuse of joists produce costs savings
Timber, common doors	Wide range: Free (on site) – EUR 690 /door	EUR 60 – 230 / door	Costs saving are usually produced for common doors

NB. Source: WRAP, 2008

Driving force for implementation

The reuse of materials saves costs and increases the economic performance of selective deconstruction. The enhanced environmental performance can improve the reputation of companies. Also, it would contribute to meeting future regulations on the recycling and reuse of construction waste.

Reference organisations

WRAP is the UK Waste Resources Action Programme. A lot of information could be obtained from their comprehensive knowledge database. WRAP commitment to resource efficiency and waste prevention is divided in seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient
- Recycling organic waste and recovering energy

- Increasing the reuse and recycling of priority products.

Salvo is an UK organisation that encourages and promotes stockholding dealers in architectural salvage, garden antiques, reclaimed materials, demolition salvage, etc.

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5.6.2.4 Use of recycled materials

Description

According to IHOBE, 2004, one essential condition for the use of recycled materials is the optimisation of the interaction among construction projects developers, contractors and suppliers. Generally, there is a lack of initiative, even from the designer, to introduce the use of recycled materials, even when the economic cost is not a barrier. Tiles, ceramics, bricks and concrete wastes are recyclable into secondary materials to be used as aggregates, but the economical feasibility of it is dependent on the separation rate with other materials and on the presence of other wastes in the fraction, such as wood, metal, plastic, etc. In this chapter, a strong attention is given to the use of recycled products from construction and demolition waste, as these close the cycle in the construction sector. Indeed, a especial focus is on the usability of crushed concrete aggregates (both as pure concrete or mixed). Nevertheless, there are a variety of products arising from industrial process with also a great potential for recycling, such as fly ashes, slags and others. Nevertheless, the amount of volume of construction waste is much higher (about 500 millions tonnes) than those so-called secondary aggregates from slags and ashes (up to 100 million tonnes). Also, the different management schemes (dispersed generation vs. localised generation) encouraged the European Commission to set a priority on construction wastes, where a clear benchmark was established in the Waste Framework Directive (70 % recycling rate). Nevertheless, most of the technical and environmental concepts used in this description can be applicable to other recycled aggregates material sources.

Table 5.42 shows some recyclable materials to be considered by the construction and deconstruction company (GASW, 2010). Waste management and recycling is also a significant issue for demolition companies, described in Chapter 6.

Table 5.41: Recyclable materials in construction and demolition wastes

asphalt
base coarse
carpet
cellulose insulation
ceiling tiles
ceramic/porcelain tiles
compost and soil amendments
concrete units
countertop
dock bumpers
drainage or backfill aggregate
ducts
fences
fibreboard
fibreglass insulation
fill materials
floor joist
floor mats
flooring
lumber
paint
pilings
plastic lumber
recycling containers
roofing
structural steel
underlayment
wallboard

Source: GASW, 2010

The choice of construction material types is usually performed by the designer and the structural engineer in the design phase, before the construction process starts. The environmental characteristics of materials can vary, for instance, depending on the location of the construction site, the assembly with different materials and on the application type, method and technique. Within those material selection processes carried out by the construction company (according to client, designer or own criteria), it would be desirable to consider the environmental impacts over the whole life cycle of a material. Therefore, Environmental Product Declarations (EPD) according to international standards offer basic information for a life cycle assessment (LCA) with respect to the application of the material (Dimoudi and Tompa, 2008; PE International, 2010).

Recycled-content materials can also be durable, have a high quality, usually similar prices as conventional materials and additionally help to protect natural resources such as timber and oil. The following table (Table 5.42) includes common recycled-content materials and products.

Table 5.42: Common products with recycled materials content

Building Materials		Site Work
Carpet Cellulose Insulation Ceiling Tile Ceramic/Porcelain Tile Concrete Masonry Units Countertop Dock Bumpers Ductwork Exterior Sheathing Fences/Posts Fiberboard Fiberglass Insulation	Floor Joists Floor Mats Flooring Lumber Paint Pilings Plastic Lumber Recycling Containers Roofing Structural Steel Underlayment Wallboard	Asphalt Base Coarse Compost and Soil Amendments Concrete Drainage or backfill aggregate Ecology Blocks Fill Material Ground colored glass pipe bedding Glassphalt Parking Stops

From waste to product

Construction and demolition waste, CDW, composition is highly variable. Waste generated at construction sites vary depending on many factors, especially the type of construction, the use of precast elements or the construction company practices. Recyclability of the inert elements of construction and demolition waste depends on the level of segregation at site. Low segregation levels lead to cost inefficient situations for waste recyclers, making the price for management much higher than for segregated waste. For segregation improving opportunities, see section 5.6.2.1.

The regional government of Madrid commissioned a study on the composition of construction waste (CEDEX, 2010). The results show that more than 93 % of wastes generated on site is recoverable, with achievable targets for demolition even higher than 95 %.

The most important part of construction waste is the inert fraction (concrete plus masonry). This is able to produce high quality aggregates products. A normalised classification of recycled aggregate from construction waste is proposed, among many other standards in Europe, by DIN (through the standard 4226-100 for recycled aggregates). Four types are distinguished, shown in Table 5.43.

Table 5.43: Classification of aggregates according to DIN 4226-100

DIN Classification	Type 1	Type 2	Type 3	Type 4
Recycled aggregates	Concrete and crusher sand	Mixed wastes plus crusher sand	Masonry plus crusher sand	Mixed plus crusher sand
Concrete and natural aggregates	≥ 90 %	≥ 70 %	≤ 20 %	≥ 80 %
Clinker, non-pored bricks	≤ 10 %	≤ 30 %	≥ 80 %	
Sand-lime bricks			≤ 5 %	
Other mineral materials	≤ 2 %	≤ 30 %	≤ 5 %	≤ 20 %
Asphalt	≤ 1 %	≤ 1 %	≤ 1 %	
Foreign substances	≤ 0.2 %	≤0.5 %	≤ 0.5 %	≤ 1 %
Density, kg/m^3	≥ 2000	≥ 2000	≥ 1800	≥ 1500

N.B. Source: Müller, 2006

Processing of CDW is usually similar across Europe, although the nature of final products may vary according to the existing market for these products. Under the Operational Data section of subchapter 7.3.3 a more detailed description can be found. Steps of one example of CDW recycling process are shown below:

1. Reception, weighing and visual inspection.
2. Manual preselection and rejecting to other treatments (depending on acceptability criteria, if original segregation is good enough, this step might not be useful).
3. Screening of large materials.
4. Magnetic separation (e.g. for reinforcement steel and metals) and screening for fine materials.
5. If segregation in origin is poor, manual separation of plastic, wood and other waste typologies may be needed.
6. Crushing (see section 7.3.3).
7. Screening and secondary crushing (depending on produced aggregates and marketing of products).

Recycling possibilities

There are a number of possibilities and routes for recycled products to be used. The main purpose of recycling should be to substitute natural materials without losing quality and removing any risk of environmental pollution when applying recycled products. The main final destination of recycled construction products is the substitution of materials as base materials in roads, as aggregates for concrete production and for filling material in earthworks. The characteristics of the final construction product should be considered when choosing the natural materials substitution rate. For example, high quality concrete for foundations and piles may accept less recycled products than mass concrete or light concrete, which are able to accept 100 % of recycled aggregates. Secondary uses for recycled materials may be as sand for cement production, but this application has a limited substitution rate because of the composition of crusher sand (even from concrete crushing) (Hauer,2007).

Table 5.44 shows applicable solutions for the two main products produced in recycling plants, i.e. concrete aggregates and mixed aggregates.

Table 5.44: Possibilities for recycled construction materials.

Material	Use	Applicability	Specifications/restrictions
Concrete Aggregates (e.g. minimum of 90 % concrete content)	Earthworks, filling and road sub bases	These aggregates are usually applicable to this kind of works. There may be restrictions on the physical properties because of water absorption, sulphate content (causing expansion and fragility) and water absorption. Usually, all countries ask for the same technical properties as for natural aggregates, plus some standards on concrete and impurities.	French NF P 11-30, Spanish PG-3 technical specifications for roads and bridges. Specific requirements for recycled aggregates in terms of strength (e.g. with Los Angeles test, or with the amount of small slaps or flagstone)
	Buildings and other civil works, for structural concrete	Coarse recycled aggregates may be applied for structural concrete (mass concrete or reinforced concrete) but water demand would be higher and may cause higher cement consumption for the same resistance as with natural aggregates. Compression resistance may be reduced (as a function of quality) and elasticity is lower.	Spanish recommendation of a maximum 20 % maximum substitution of natural coarse aggregates. Additional requirements are specified for recycled aggregates in order to keep structural properties. Dutch national standards allow for a replacement of 20 % of natural primary aggregates by mixed or concrete aggregates (without additional performance tests)
	Buildings and other civil works, for non-structural concrete		Up to 100 % of application if technical and environmental specifications are fulfilled
	Buildings and other civil works, for mortar	Fines and small particles may be used to produce mortar	Water demand is increased. CEDEX, 2010, recommends to use 25 % of recycled mortar in order to keep properties
	Buildings and other civil works, for cement	Fines from concrete sand crusher have similar properties to cement with natural sand.	First used in Japan. Price is less than conventional cement. Energy consumption reduction and saving of natural materials are main benefits, but the chemistry of the mixture does not allow using a substitution rate more than 10 % (Hauer, 2007). Nevertheless, 100 % substitution is allowed if technical specifications are met
Mixed Aggregates (e.g. minimum of 50 % concrete content)	Earthworks, filling and road sub bases	They can be applied but it is required gypsum content to be low. Main application is as filling material. Usually, not suitable for road pavement bases.	The cost for cleaning may be high. Same specifications as for other materials. Workability may be worse, as water absorption is higher and slower than for natural aggregates
	Buildings and other civil works, for non structural concrete	Adequate consistence and resistance properties are achievable for in-situ concrete for non structural concrete. Not usable for prefabricated concrete elements.	The low density of these aggregates may be optimal for the production of light concrete. Nevertheless, durability is lower than for other aggregates

Achieved environmental and health benefits

There is a large number of examples of construction waste recycling where a high rate of substitution of natural materials is achieved. According to UBA, 2008, countries achieving recycling rates over the 70 % objective of the waste framework directive are: Austria (76 %), Belgium (86 %), Denmark (93 %), Estonia (73 %), Germany (91 %), Netherlands (95 %) and UK (82 %).

Nevertheless, the most important factor to control for construction customers is the achievable rate of substitution. According to a report by BioIS, 2011, the achievable target for the use of recycled aggregates as bases for roads is about 75 % of total generated concrete waste, with a suitable 100 % of substitution rate (in the Netherlands 95 % of the stony fraction of construction and demolition waste has been reported).

For applications in structural concrete, it is not recommended to substitute more than 20 % of aggregates in concrete manufacturing. Substitution rates of 100 % are technically achievable for mass and light concrete, with no special requirements for high resistance. The application of best environmental management options should lead to technically feasible highest substitution rates.

For cement production, substitution rates of 10 % of crusher sand have been reported as feasible (Hauer, 2007). Masonry waste aggregates can be recycled in the production of bricks up to 30 %, when some technical properties are met. In fact, some positive effect have been reported because of the decrease of the shrinkage effect (Demir and Orhan, 2003).

For lower quality aggregates, e.g. those coming from mixed waste, only its use as filling material and some applications for road subbases are possible. Best option for ceramics and bricks is direct reuse from demolishing and deconstruction activities.

In terms of CO_2 and primary energy consumption, the use of recycled aggregate supposes a net reduction in the life cycle a CO_2 emissions and primary energy consumption, as the production and extraction of new raw material is avoided. Nevertheless, the large influence of transport for the performance of recycled aggregates may produce different results depending on local circumstances.

In general, recycling opportunities and the technical and environmental performance of the product should be analysed specifically for each product, as the nature of recycled construction products is highly diverse.

Appropriate environmental indicators

The use of recycled aggregates or recycled construction products can be monitored through several indicators:

- The amount of recycled materials used, in absolute units (e.g. tonnes) should be always controlled, as it will allow the setting of objectives for other related indicators
- The percentage of natural materials substituted by recycled aggregates, e.g. for concrete manufacturing.
- For public administrations, especially for local governments, a register on the amount of recycled materials sold from recycled plants, which may be related to the amount of total construction and demolition waste generated in the region. This register can be used to set objectives in terms of construction waste recycling.

Cross-media effects

Energy and water are consumed for crushing and washing concrete waste. However, the leaching of pollutants from concrete waste in landfills or other uses (road construction etc.) is reduced, as in recycled concrete these potential pollutants are bound. Recycled concrete might for some applications, lead to higher cement consumption.

For road construction, the balance of energy consumption is quite advantageous for recycled aggregates, especially if recycling is made in a portable plant. Table 5.45 shows a case study from WBSCD, 2009.

Table 5.45: Energy balance with and without recycling

Parameter	With recycling	Without recycling
Number of trips (to landfill and returns and to quarry and returns, recovery rate of 85 %)	4900	31600
Transport total energy, MJ (Energy consumption for transport: 1.22MJ per tonne and km, 44 tonnes per truck and trip)	1.05 10^{11}	3.61 10^{11}
Energy consumption for demolition and treatment, MJ	0.014 10^{11}	0.0132 10^{11}
Total Energy consumption, MJ	1.064 10^{11}	3.62 10^{11}

N.B. Source: WBCSD, 2009.

Operational data

Main environmental concerns when using recycled products

When recycling products are being used, it should be taken into account the huge amount of potentially hazardous materials contained in the original waste. Symonds, 1999, showed a full list of hazardous waste found in CDW (Table 5.46)

Table 5.46: Hazardous materials in construction and demolition waste

Product / Material	Potentially hazardous components	Hazardous properties
Concrete additives	Hydrocarbons, solvents	Flammable
Damp-proof materials	Solvents – bitumen	Flammable, toxic
Adhesives	Solvents, isocyanides	Flammable, toxic, irritant
Mastics, sealants	Solvents, bitumen	Flammable, toxic
Road surfacing	Tar-based emulsions	Toxic
Asbestos	Breathable fibre	Toxic, carcinogenic
Mineral fibres	Breathable fibre	Skin and lung irritants
Treated timber	Copper, arsenic, chrome, tar, pesticides, fungicides	Toxic, ecotoxic, flammable
Fire-resistant wasting	Halogenated compounds	Ecotoxic
Lighting	Sodium, mercury, PCBs	Ecotoxic
Air conditioning systems	CFCs	Ozone depleting
Firefighting systems	CFCs	Ozone depleting
Contaminated building fabric	Heavy metals, including cadmium and mercury	Toxic
Gas cylinders	Propane, butane, acetylene	Flammable
Resins/fillers, precursors	Isocyanides, anhydride	Toxic, irritant
Oils and fuels	Hydrocarbons	Ecotoxic, flammable
Plasterboard	Source of hydrogen sulphides	Flammable toxic
Road planning	Tar, asphalt, solvents	Flammable, toxic
Sub-base (ash/clinker)	Heavy metals including cadmium and mercury	Toxic
Insulation foams blown with ODS	Ozone depleting substances	Ozone depleting

In order to protect the environment, particular attention should be made all construction products on the release of dangerous products. This is the case with recycled aggregates, as they come from waste, whose composition is likely to contain some of the hazardous materials shown in Table 5.46, but also for those recycled products to be used for construction (e.g. slags, ashes, etc.). The Commission made a mandate to CEN for a harmonisation on the assessment of dangerous substances. As a response, a new TC, 351, was created 'Construction products: assessment of release of dangerous substances'. This committee should provide tools and assessment methods for the quantification of dangerous substances, which may be released from construction products to the environment into the soil, ground water, surface water and indoor air (Delgado, 2009).

Currently, there are not many approaches to limit the leachability of recycled aggregates. It is usually common that recycled aggregates coming from ashes, slags and other wastes are strongly regulated, while for recycled concrete and mixed aggregates some countries apply a set of different criteria. For instance, the Netherlands does not apply a waste regulation to recycled aggregates, but a common regulation is used for natural or recycled aggregates in terms of environmental criteria. In Germany, a regulation is being prepared and the leaching limit values are material specific and refer to specific applications. End-of-waste criteria may be issued in the future by the European Commission, as it has already been done in the UK for recycled aggregates.

As there are no harmonised standards and limit values in Europe, a good reference point is the leachability compared to the landfill directive leaching limit values. An assessment made by DHI, 2011, on the leachability of some aggregates, is shown in Table 5.47.

Table 5.47: Recycled aggregates leachability: elements close to, partially exceeding or consistently exceeding the EU leaching limit values for acceptance of waste at inter waste landfill

Product	**Close to the limit**	**Partially exceeding**	**Consistently exceeding**
Recycled concrete		Ba, Cr, Pb	
Recycled Brick		SO_4^-	
Recycled Glass		Cu, Pb	Sb
Mixed CDW		Cd, Cl, Pb	
Recycled asphalt			
Blast Furnace Slag		SO_4^-	
Basic Oxygen Furnace Slag			V
Electric Arc Furnace Slag			
Phosphorous slag		Mo, Pb, Sb, Se	
Coal Fly Ash		As, Ba, Cd, Cl, Cr, Mo, Ni, Pb, V, Zn	SO_4^-
Coal Bottom Ash	As	Cd, Cr, Mo, Ni	
Municipal Solid Waste Incinerator Fly Ash		As, Cr, Cu, Zn	Cd, Cl, Mo, Pb, SO_4^-
Municipal Solid Waste Incinerator Bottom Ash	Cd, Se, Zn	Cr, Mo, Ni, Pb, Sb, SO_4^-	Cl, Cu
Artificial Aggregates	Cd, Mo, Pb, SO_4, Zn	As, Cd, Mo, Se	
Natural aggregates	Cd, Ni, V		

N.B. Source: DHI, 2011

Technical and environmental criteria for recycled products

In order to keep the mechanical properties of structural concrete, CEDEX, 2010, recommends not using more than 20 % (w/w) of recycled aggregates in concrete. Other recommended restrictions are shown in Table 5.48.

Table 5.48: Technical specifications to fulfil mechanical properties of structural concrete

Parameter	Value
Particles <4 mm	<5 %
Clay lumps content	<0.6 % (for 20 % recycled aggregate)
Water absorption	<7 %
Ceramics content	<5 %
Light Particles	<1 %
Asphalt	<1 %
Other (glass, plastic, etc.)	<1 %

N.B. *Source:* CEDEX, 2010

Also, the use of mixed aggregates as filling materials for embankments is limited by its gypsum content (Table 5.49)

Table 5.49: Restrictions on the gypsum and soluble salt content for recycled aggregates

Gypsum content	Use
<0.2 %	Usable for any zone of embankment
0.2 %-2 %	Core of embankment
2 %-5 %	Core of embankment, with special materials in crowning point and screen walls
5 %-20 %	Core of embankment, with measures to avoid solution of sulphates.
>20 %	Not usable
Soluble salt	**Use**
<0.2 %	Usable for any zone of embankment
0.2 %-1 %	Core of embankment
>1 %	Not usable

N.B. *Source:* CEDEX, 2010

Table 5.50 shows some technical specifications for the mechanical properties for non-structural concrete, as shown by CEDEX, 2010.

Table 5.50: Proposed technical specifications to fulfil mechanical properties for non-structural concrete

Parameter	Value
Water absorption	< 12 %
Total S content	< 1 %
Sulphates (acid soluble)	< 1 %
Other materials (glass, plastic,…)	< 1 %
LA value	< 50 %
Fines content	< 4 %
Ceramics content	< 50 %
Gypsum content	< 2 %

N.B. *Source:* CEDEX, 2010

A voluntary quality requirement for construction and demolition waste recycled products has been established in the Baden Württemberg region in Germany (QRB, 2009). These requirements are mainly environmental and are especially focused on the leaching capacity of construction waste for certain pollutants. Three levels of quality are foreseen: quality Z 1 is for material lying under non water tight layer. Z 1.1., which is the more restrictive, is for layers of materials placed at least 1 m above the water table. Quality Z 1.2. is for layers above at least 2 m above the water table and over compact material. The less demanding quality is Z 2, which is place under water tight layers (concrete or asphalt) and above 1 m of the water table. These quality requirements, to be measured under leachability with water, DIN 38414, are shown in Table 5.51. These are requirements to add to those for any other aggregate.

Table 5.51: Extra quality requirements for recycled aggregates

Quality level	Z 1.1.	Z 1.2.	Z 2
Organic material, C_{10}-C_{22} (C_{10}-C_{40}), mg/kg	300(600)	300(600)	1000 (2000)
PAH, mg/kg (EPA method)	10	15	35
Extractable organic halogens, mg/kg	3	5	10
PCB_6, mg/kg	0.15	0.5	1
As, µg/L	15	30	60
Pb, µg/L	40	100	200
Cd, µg/L	2	5	6
Cr, µg/L	30	75	100
Cu, µg/L	50	150	200
Ni, µg/L	50	100	100
Hg, µg/L	0.5	1	2
Zn, µg/L	150	300	400
Phenols, µg/L	20	50	100
Chloride, µg/L	100	200	300
Sulphate, µg/L	250	400	600
pH	6.5-12.5	6-12.5	5.5-12.5
Conductivity, µS/cm	2500	3000	5000

N.B. Leachability with water tests made under DIN 38414

Apart from those examples shown above, some EU Member States have applied quality assurance schemes associated with recycled aggregates produced from construction and demolition waste (Delgado et al., 2009):

- The Austrian construction materials recycling association developed guidelines for recycled aggregates to be used in construction works. A quality mark is produced for recycled construction materials fulfilling some criteria where also environmental parameters are included.
- In the region of Flanders, Belgium, recycled aggregates can only leave the waste status if they meet specific requirements on chemical composition (both for solid content and leaching properties)
- In Finland, the SFS standard 5884 was developed, setting technical, production control and environmental classification of crushed concrete products
- In the UK, WRAP aggregates programme was established, with some quality specific protocols developed for recycled aggregates.

Plasterboard/Gypsum recycling

Plasterboards (also known as drywall, gypsum board, wallboard, etc.) are panels made of gypsum plaster pressed between two thick sheets of paper (or fibreglass to prevent mould), then kiln dried. The finished product consists of about 95 % gypsum and 5 % paper; the major constituents of gypsum are calcium (23 %) and sulphate (21 %). Drywall construction is used globally for the finish construction of interior walls and ceilings as a speedier alternative to using plaster based interior finish. Plasterboard waste accrues during construction and deconstruction. In the UK, several local authorities have introduced trial waste plasterboard collection at their Household Waste Recycling Centres to increase the quantity of plasterboard being diverted from landfill for recycling. In Denmark, already over 60 % of plasterboard waste is recycled (WRAP, 2006). Different recycling options exist for the recycled gypsum, besides the direct recycling within the plasterboard production process. These further options include the use as an additive to cement or the use in road foundations.

Since both the gypsum and paper is recycled from the waste plasterboard, it can be assumed that for every one tonne of waste plasterboard recovered one tonne of waste is diverted from landfill. For a low transport scenario (50 km to the recycling facility) compared to landfill, apply a recycling process such as that employed by New West Gypsum Recycling can save 47 kg of CO_2 for every tonne of plasterboard. (WRAP, 2009).

Plasterboard waste can be problematic in landfill conditions due to the sulphate content of gypsum. When mixed with biodegradable municipal waste in a landfill, it breaks down to form hydrogen sulphide, a toxic gas. In this way sulphate can have a long term negative impact upon the leachate generated within the landfill and can cause odour problems for communities close to landfills. Plasterboard recycling does not require significant changes to site practices. Plasterboard waste with up to 3 % contamination is accepted in most cases, whereas waste containing more than 3 % contamination is rejected. The main factor is availability of recycling sites at distances allowing economically reasonable transportation.

Table 5.52 gives an overview of quality parameters of recycled gypsum and flue-gas desulphurisation gypsum. It can be seen, that no major quality restrictions exist for recycled gypsum.

Table 5.52: Comparison of quality parameters of recycled and FGD (flue-gas desulphurisation) gypsum

Quality Parameter	Determined as	Unit	Quality criteria	
			FGD-Gypsum	Recycled Gypsum
Humidity	H_2O	Mass %	< 10	< 10
Calciumsulfat-Dihydrat	$CaSO_4 \cdot 2H_2O$	Mass %	> 95	> 80
Magnesium salts	Water soluble MgO	Mass %	< 0.10	< 0.02
Natrium salts	Water soluble Na_2O	Mass %	< 0.06	< 0.02
Potassium salts	Water soluble K_2O	Mass %		< 0.02
Chlorides	Cl	Mass %	< 0.01	< 0.01
Calcium sulfite-hemihydrate	$CaSO_3 \cdot ½ H_2O$	Mass %	< 0.50	< 0.50
pH	--	--	5-9	5-9
Colour		%	white	white
Smell	--	--	neutral	neutral
Toxic compounds	--	--	harmless	harmless
Grain size	--	mm	--	< 5

N.B. Source: LFU, 2007

Some recycling facilities for gypsum from the UK are described below:

- Roy Hatfield Ltd.: At the Roy Hatfield Ltd.'s recycling facility, waste plasterboard (all types of plasterboard waste, including waste generated from construction sources and from local authority collection) is taken from the stockpiles and fed into the processing plant which separates the gypsum from the linings. It is processed at a rate of 60 tonnes/hour. The site currently recycles around 500 tonnes of waste plasterboard per week, but has a capacity to accept up to 1000 tonnes per week. Both wet and dry plasterboard can be recycled. During the trial implementation, each load was largely free of contamination, which was consistently limited to wallpaper, which does not need to be removed prior to processing.
- New West Gypsum Recycling (NWGR): The recycling process is a bespoke system developed in Canada by NWGR. To date, NWGR have recycled over 2 million tonnes of plasterboard waste worldwide. The process involves shredding the waste plasterboard and mechanical separation of the gypsum from the paper. The process results in less than 1 % paper contamination in the gypsum, which is within acceptable tolerances for incorporation into new plasterboard. The recyclable gypsum is trucked back to drywall manufacturers, where it is combined with virgin rock or synthetic gypsum to make new

wallboard. NWGR studies have shown that new wallboard can include in excess of 25 per cent recycled gypsum. Also, recycled gypsum combined with synthetic gypsum produces desirable consistency levels in the manufacture of new gypsum-based products. The majority of paper is of sufficient quality for re-pulping and recycling, but composting is the favoured route since it can handle all the recovered paper. The working model adopted by NWGR is to enter into contract with plasterboard manufacturers and then to locate facilities to suit this arrangement. This ensures a ready market for its recycled gypsum.

- MID UK Recycling Ltd.: The plasterboard recycling facility has an operating capacity of 35 000 tonnes per year. Its high capacity and unique processing technology enables MID UK Recycling Ltd to recover and recycle nearly 100 % of all waste plasterboard they receive into a recycled gypsum product which can be used in a range of alternative applications. Most plasterboard waste is processed dry, but the facility is capable of processing plasterboard with a moisture content of up to 30 %. The facility uses a series of trommels, screens, shredders, magnets and gravity separators to separate contaminants, the paper layers, and the gypsum product. The recycled gypsum product is in the form of granules, 90 % of which are sold to a local cement manufacturer as a replacement for gypsum from conventional sources. The remaining 10 % is sold into a range of other markets. The cost of this product is lower than gypsum from conventional sources.

Applicability

The applicability of recycled aggregates can be summarised in a list of parameters to be controlled:

- heterogeneity
- impurities
- density
- absortion
- fines
- higher contents of chloride and sulphate.

Usually, there is no problem on the acceptance of recycled aggregates, as they usually fulfil the requirements to be applied (e.g. those for the C.E. marking). Also, some voluntary agreements and regulations in some European countries are required in order to check the environmental performance, to avoid any pollution derived from the waste origin. Some indications on the application of recycled aggregates are shown in the Description section. Generally, it is recommended to study on a case by case the applicability of a recycled product, especially when it comes to sensitive aspects.

Economics

Cost of recycled products

The cost of recycled aggregates is variable and depends on the manufacturer. Nevertheless, the final price is substantially not different from the natural aggregate cost and can even be lower. Selling price vary from EUR 3 to 12 and depends on many local circumstances, especially on transport costs (WBCSD, 2009) and quality.

Generally, the availability of low cost natural materials is a great disadvantage for the competitiveness of recycled aggregates. Production costs of natural aggregates are usually higher than for recycled aggregates, and logistics costs depend on the availability of quarries in the surroundings. Good segregation of construction waste would reduce the production cost of recycled aggregates and logistics prices are comparable to quarries. So, the cost of recycled aggregates should not be a main barrier for the uptake of recycled aggregates.

Main factors for the uptake of recycled aggregates are usually:

- The proximity and quantity of natural aggregates

- Reliability of supply and quality (in theoretical terms, quality homogeneity is better for natural materials)
- Incentives, subsidies and taxes for natural aggregates and landfills
- Standards and regulations for recycled aggregates
- Quality certification and green building systems
- Presence of illegal landfills.

During the development of this work, a visit to a Spanish construction and demolition waste facility was done. All of those problems shown above were taking place. Then, this inappropriate situation did not allow a good development of the market:

- There are many quarries in the surroundings with huge stockage, due to the building sector crisis in Spain. These quarries, which are not operating, have reduced a lot the price of natural aggregates to values lower than production costs (e.g. high quality sand is about EUR 4.5 per tonne)
- There is almost no segregation in origin, so higher costs have to be assumed in manual separation processes
- No incentives or subsidies are established for recycled aggregates and no label is available for them to indicate that it is a recycled product. Indeed, the Spanish objective for construction waste recycling is much lower than desirable: only 20 % of recycling rate for 2015.
- The application of green schemes application in Spain is lower than in other countries and ecolabels for recycled building materials do not exist (even, some green label schemes for buildings exclude the use of environmentally friendly materials for the Spanish case).
- Illegal landfill is not controlled properly and they have also to compete, in terms of price, with illegal landfilling prices. This means that they cannot encourage segregation at origin and, at the same time they have to lower their cost (e.g. EUR 3/m^3 of clean concrete, EUR 5.5/m^3 of mixed wastes).

Cost of gypsum recycling

Cost information on collecting and recycling waste plasterboard was analysed over a 7 week period at Stafford HWRC (UK). The gate fee costs for waste plasterboard were £25.00 per tonne (April 2008), which compares favourably against Staffordshire County Council's average alternative residual waste disposal charges of £47.00 (including Landfill Tax). Costs for the haulage were quite high compared to residual waste transportation to landfill, but reductions by compacting techniques are expected. Costs are summarised in the table below, it can be seen that recycling itself is cost efficient, only special collection and transportation requirements made it uneconomic in the case study (WRAP, 2008)

Table 5.53 gives some cost indications from one of the case studies described above. It can be seen that the transportation cost is the only reason for the lack of competitiveness of gypsum recycling in this case.

Table 5.53: Cost information from the Staffordshire case study (WRAP, 2008)

Costs	Plasterboard recycling	Landfill disposal
Average tonnage collected per load	6.5 tonnes	7 tonnes (avg. weight mixed residual waste container)
Gate fee per tonne	£25.00	£47.00
Haulage costs per load (incl. hire)	£300.00	£53
Total cost per load	£462.50	£382.00
Disposal cost per tonne	£71.15	£54.57

N.B. *Source*: WRAP, 2008.

Information from Denmark indicates, that with a country-wide system already collecting most of the plasterboard waste, the cost per tonne charged is lower than the cost of disposing of the waste to landfill (WRAP, 2006)

Driving force for implementation

The most important driving forces for implementation are:

- Environmental protection and raised awareness.
- Compliance with future regulations to avoid as much as possible the use of natural materials, as well as cost savings because of expected increase of natural materials prices and taxes.
- Increased reputation, also through environmental labels and green labels on the recycled content of construction products.

Reference organisations

There are many national organisations dealing with the applicability of recycled material products for new construction. Among the information available about recycled aggregates, some are remarkable, especially on the technical applicability of recycled aggregates:

European Commission, JRC-IPTS, is in charge of the development of the End-of-Waste criteria for aggregates. Many technical aspects of recycled aggregates from construction waste are well described at http://susproc.jrc.ec.europa.eu/activities/waste/, which gathers information on national approaches.

CEDEX. Spanish Institute for Civil Engineering, Building and Environment. Institution for the development of technical studies for construction.

World Business Council for Sustainable Development: Cement sustainable Initiative. Integrated by 24 major cement producers for a more sustainable cement production.

WRAP is the UK Waste Resources Action Programme. A lot of information could be obtained from their comprehensive knowledge database. WRAP's commitment to resource efficiency and waste prevention is divided into seven actions:

- Preventing food and drink waste
- Increasing the resource efficiency of products
- Increasing the resource efficiency of construction and refurbishment projects
- Improving the collection of materials for recycling and reuse
- Helping SMEs to become more resource efficient
- Recycling organic waste and recovering energy
- Increasing the reuse and recycling of priority products.

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5.6.2.5 Water Drainage Management and Erosion Control

Description

There are three main water drainage aspects for construction projects to be controlled, managed or planned properly regarding water and soil management:

- Water Drainage
- Soil Erosion
- Sedimentation and Water Pollution.

The **water drainage system** of the construction site should fit to the final design of the building site, so it should be one of the first elements to be built. Some design features may need to be installed at the end of the project development, so temporary drainage and treatment processes should be implemented on the site (e.g. sedimentation). Technical descriptions and details of environmentally-friendly designs of drainage systems are shown in 2.2.2 and 3.4.6.1. The construction (or temporary arrangement) of some low cost and low impact drainage elements (swales, basins and ponds) may reduce the costs of water management in construction sites, while, at the same time, reducing run-off volumes and helping to manage a huge amount of sediments.

During the pre-construction phase, the programming of construction activities should take into account water drainage, erosion and pollution control. A number of activities, proposed by Woods-Ballard et al., 2007, are shown below:

- Protect and identify areas with water drainage devices to be used during construction.
- Temporary protection for vegetation and a stabilised area to drive water run-off in construction accesses, construction entrances, roads and parkings. Protection of trees should be done around the branches drip line, and the roots zone should not be compacted.
- Set sedimentation basins and traps as soon as possible or when required. Also, run-off control measures (fences, conveyance systems, trenches, etc.) should be installed during first stages.
- Apply stabilisation measures to the surface, especially after clearing and grading.
- During building construction, soil exposed areas should be properly controlled and sedimentation practices implemented. Traps and pollution removal devices may also be required to prevent contamination of receiving streams.
- Final landscaping and stabilisation: removal of temporary systems and installation of final ones.
- Inspections and repairs, especially after rainfall events.

One of the main problems for soil during construction is **soil erosion**, which is the process where the land surface is worn away by the action of wind, water, ice, and gravity (Woods-Ballard et al., 2007). Although it is a natural phenomenon, construction activities are able to largely increase the rate of soil erosion when removing natural fist layers and vegetation and leaving bare, loose soil exposed to wind or water. Vegetation plays a key role in erosion control: roots bind soil particles, leaves and branches reduce the impact of drops on soil, this allows infiltration, reduces run-off and plants, generally, reduce wind speed at ground level. Erosion control procedures try to avoid the rate of erosion of disturbed areas caused by construction activities. These will not only affect water run-off, but its quality, sedimentation control procedures, dust generation, infiltration, groundwater recharge, cause site surroundings dirtiness, etc.

Procedures and best practices to avoid or minimise the impact of soil erosion are:

- Vegetation, which creates a binding root structure and reduces friction with water or wind.
- Geotextiles and other fabrics to avoid particle stripping.
- Reinforce grass, which is grown fast and can be used in temporary soil protection.

- Gravel trenches. Gravel particles are used to cover exposed land and help infiltration. They should be removed or cleaned after the construction project finalisation, as they accumulate heavy sediment loads.
- Flat sites, which reduces the run-off speed and, therefore, the speed of water.
- Water run-off should not be allowed to run over exposed land and it should be diverted to drainage systems.

Rainfall events can produce a significant amount of sediments, which in exposed lands are not carried away properly by waterways and may deposit, with associated environmental problems of water pollution and habitat alteration. So, sedimentation control is required in construction sites. According to USDA, 2007, a construction site without sediment or erosion control can produce between 5 to 50 kg per m^2 per year, ten to twenty times greater than soil losses on agricultural lands.

For large areas where significant amount of run-off flow is foreseen, sediment entrapment facilities should be taken, such as straw bale barriers, geotextile silt fences and sediment basins. Straw bale barriers are temporary and may work during a few weeks or months. Silt fences are made of a woven synthetic material (geotextile) and act as a filter. In general, straw bale barriers and silt fences are designed for small catchments. When larger areas have to be covered, conveyance to sediment basins should be installed.

Pollution of rainfall water is produced when water contacts with materials and fuels stored in the construction site, or when spills are produced. Therefore, after planning the site and deciding on the best management techniques for water drainage, it should be carefully considered the location of stockpiles, fuel stores, storage area, waste disposal areas, refuelling, wheel washing devices, etc. This should be included in the environmental management plan.

The main water pollution source at a construction site is suspended solids (Woods-Ballard et al., 2007), produced by the contact of water with excavated ground, stockpiles, wheel washing, site cleaning, haul roads, silty water from affected riverbed and from dewatering operations. Also, oils and hydrocarbons, from fuels and organic material used (paints, lubricants, varnishes, adhesives, etc) may represent a significant pollution load to waterways.

Main practices to prevent and minimise pollution are listed below:

- Use of sedimentation barriers and ponds.
- Stockpiles-water run-off should be diverted to a separate drainage system, away from a watercourse.
- Wheel-washing area should have a separate tank and should be treated separately (separate recycling system) and, if possible, fed to the sewerage. Wheel-washing effluent has a high hydrocarbon concentration, so it cannot be fed to any watercourse.
- Haul roads should have a minimum, optimal length. Unpaved roads should be sprayed to keep down dust, and frequently swept.
- Dewatering operations should be discharged slowly to promote settlement, using tanks or ponds to control the flow.
- If possible, machinery should be maintained off the site. This maintenance should check oil leaks.
- Storage facilities for waste, oil and fuels should be designed properly under a coverage, over an impermeable ground (made of concrete) with a temporary storage for spills.

Some best practice measures for soil erosion and sedimentation control measures are described in Table 5.54.

Table 5.54: Soil Erosion and Sedimentation Control Measures

Technique	Description	Limitations
Common techniques		
Planning	A water management plan with water drainage, run-off control and soil erosion and sediments control is performed. Protection issues are identified, best practices planned, reduces soil exposure and erosion hazard, decides on sediment entrapment of site perimeter.	-
Gabions	Free maintenance, permanent structure and long lifetime.	Expensive, labour intensive.
Straw Bale barrier	Relatively inexpensive if locally available.	Short service life, requires maintenance after heavy rain events.
Riparian zone preservation	Native vegetation acts as a filter and slows down run-off.	When creating new zones, a long period of time is required for them to be effective.
Slope texturing	Roughens slope to reduce erosion potential and sedimentation yield. Reduce velocity and increase infiltration rate.	Not suitable for silty and sandy soils, additional costs. Compacting.
Planning strategies	Minimise exposed soils. Operate during fisheries windows. Maximise favourable weather. Install BMPs at proper times. Avoid wet weather periods. Use existing drainage systems if appropriate. Control construction site traffic. Signs.	-
Sediment control measures		
Brush or Rock Filter Berm	Uses timber and materials salvaged from site clearing and may be adjustable to geotextile fabric envelope.	Temporary measure, not effective for run-off diversion, not suitable for high flows, more expensive than other measures.
Fibre rolls and wattles	Functions well in freeze-thaw conditions, it is a low cost biodegradable solution.	Labour intensive, only for slope surface with sheet flow.
Pumped silt control systems	Uses a filter bag, simple set up with different aperture opening sizes.	Expensive, require specific design, requires a pump and a power source, only usable in short periods.
Silt fence	Filters sediment economically from run-off. More effective than straw bale barriers. Settles down coarse particles.	Fail in heavy storm event. Limited to places where space is available to store temporarily run-off. Use life of 1 year, requires maintenance in case of high load of sediments.
Sediment basins	Reduces velocity of flow, reduces deposition of sediment.	Requires 250 m^3 per ha per ha of exposed soil. Requires large areas of land and maintenance periods with qualified personnel. Requires back-up control measures.
Erosion control, run-off control measures		
Slope drains	Directs surface water run-off into drain pipe instead of flowing over and eroding exposed soils of slope surface	Inlet/outlet can provoke erosion. Specific design required.
Energy dissipator	Rip rap or sandbags slow run-off velocity and dissipate energy to achieve a non erosive level.	Labour intensive. Specialised design for high flows.
Sedimentation **and** erosion control measures		

Table 5.54: Soil Erosion and Sedimentation Control Measures

Technique	Description	Limitations
Dams: rock check, aggregate filled sand bag, log check	Filtering capacity. Dissipation of energy, easily constructed. Reusable.	Expensive, may not be suitable for high flow storm events. Temporary.
Synthetic permeable barriers	Reusable and moveable, reduces flow velocities and dissipates energy.	Easily damaged during construction. Expensive.
Erosion control; surface protection		
Topsoiling	Placing topsoil provides an excellent medium for vegetation, e.g. by absorbing raindrop energy to minimise erosion potential.	Needs seeding. Need long time for establishing root structure. Not good for steep slopes. Dry topsoil may not be suitable due to higher erosion rates.
Seeding	Seeding will control naturally erosion as it will be more effective as vegetation develops.	Requires topsoiling, periodic reporting, season for vegetation development may not coincide with construction schedule
Mulching	To protect exposed areas for short periods, preserving soil mixture and protecting germination.	Specialised equipment required. May not be suitable for steep slopes.
Sodding	Immediate protection and buffer strip, suitable for steep slopes	Expensive, labour intensive, short lifetime
Riprap armouring	Channel lining with geotextile underlay, for high velocities, concentration and with scarce vegetation, easy to install.	Expensive, may require heavy equipment to transport rocks. Labour intensive.
Gravel blankets	Stabilise soil surface, minimising erosion, suitable as a permanent base construction of paved areas.	Requires specialised design, expensive, may require non-woven geotextile if groundwater table is high.
Rolled erosion control products	Protective covering when erosion protection is highly prioritised.	Requires site preparation, based on design particularities and risk assessment.
Cellular confinement system	Easily installed.	Expensive, installation is labour intensive.
Planting	Establishes a vegetative cover and a root net, reducing erosion, flow velocities, traps sediments	Expensive and labour intensive. Long time for stabilisation required.
Chemical stabilisation	Reduces soil moisture evaporation and increase soil cohesion.	Expensive, chemical pollution may prevent seeds germination.

Source: Adapted from AT, 2003.

Achieved environmental benefit

Avoiding sedimentation and the high input of suspended solids in waterways avoids a number of impacts: penetration needed for aquatic plants, reduced survival rates for fish eggs and affects, generally, threatened species and their habitats. Also, the impact on wetlands is avoided: a deposition of less than 1 cm can reduce by 60 to 90 % wetland seed germination.

NSW, 2007, determined the impact of three techniques to control soil run-off: compost blanket with binder, compost blanket without binder and hydromulch. Soil loss was reduced by 98 – 99 % in average, even improving the existing situation. Total suspended solids in water run-off were reduced by 96 – 99 %. In general, nutrients were washed off the compost blankets and, though to a lesser degree, from the hydromulch. Nevertheless, the concentrations measured were not high.

See Table 5.55.

Appropriate environmental indicator

There are several appropriate technical parameters that can be used to control the performance of water drainage and sedimentation and erosion controls. The main indicators are:

- For water drainage, **run-off control parameters, as shown in 3.4.6.1**.
- For soil erosion control, **soil loss**, %, can be easily checked.
- For sedimentation control, **total suspended solids (TSS)**, in terms of concentration and total load, can measure the effectiveness of sedimentation control and exposed soil protection measures.

For a single site, where those technical indicators are too costly to check, some qualitative indicators are also suitable to control the performance of sites:

- **Number of best practices** applied to control water drainage, soil exposure and sedimentation.
- **Water monitoring** system is implemented, y/n.
- **Ensuring a procedure for surroundings cleaning is implemented.**
- **Vegetation** barriers are used to control water infiltration and erosion, y/n.

Cross-media effects

The increase of infiltration rates in urbanised areas produces an undesired cross-media effect; namely groundwater contamination and soil pollution, especially if materials are exposed to rainfall events. Rainwater is usually polluted when it is in contact with the materials, increasing the concentration of heavy metals, taking away organic compounds as lubricating oils, and dragging suspended solids. Techniques based on vegetation have filtering capabilities that can, partially, mitigate the effect of drainage pollution.

Operational Data

Planning during pre-construction

Woods-Ballard et al., 2007, give some indications on the development of a site assessment during the preconstruction phase. Below, a summary list of the main issues shown:

- To determine the limits of clearing and grading, minimising the impact of land exposure and, if appropriate, maintaining some buffer zones of natural vegetation.
- Determine permanent drainage features (channels, surface sewers, etc.)
- Determine temporary diversions and drainage elements.
- Select sediment controls.
- Develop those points above according to the construction stage, applying more efficiently certain measures.
- Identify topsoil stockpiles.

- Identify location of temporary roads and other temporary facilities.
- Select erosion control for exposed land.

Performance of small construction sites during run-off events

As explained in the description, sedimentation is a severe problem for water streams, and soil exposure in construction sites constitute an erosion problem. Soil erosion is usually controlled on large construction sites, especially in the construction of civil works affecting waterways. Nevertheless, small construction sites are also responsible for a certain load of sediments, USGS, 2000, carried out a study on two small construction sites, one for a residential house and the other for a commercial building, and both showed that suspended solid concentration of run-off water during storm events was increased by 10-100 times the concentration of pre or post construction phases. As shown in Figure 5.31, the solids concentration during the construction stage was significantly increased, producing about 80-90 % of the total sediments load of the site. Therefore, soil erosion control is a significant environmental risk to be assessed and to be considered during construction.

The impact of these small sites is significant. It is shown in the figure below that almost 2 tonnes of contaminants is produced in the commercial building construction site (with about 7000 m^2 of surface, and a slope for water run-off of 8 %) with a rainfall water of 314 mm during the assessment period, so, in total, 439 m^3 of water were polluted with those 2000 kg of suspended solids (average concentration of 4500 mg/L of suspended solids). On the other hand, 43 kg of solids were collected in the residential house (1400 m^2 with a slope for water run-off of 4 %). Rainfall water was about 288mm, so 30.5 m^3 of water were collected, with a final average of 1400 mg/L.

In general, small construction sites do not have a sedimentation control plan or significant water drainage plan, especially if they are in an urban area. This has a significant impact:

- Water quality: leaving uncontrolled sites, sediments can migrate from construction sites with pollutants loading.
- The high dispersion of small construction sites within a city or within a region provokes a disperse contamination effect, much harder to control than for big construction sites.
- Equipment and vehicle movements per unit of area are much higher in small construction sites, causing soil compaction, reducing infiltration and increasing run-off volume. Also, mud and debris are transported to the surroundings and washed off during rainfall events.
- Topsoil is stockpiled with a higher slope, due to less available space, so the particle stripping rate is higher.

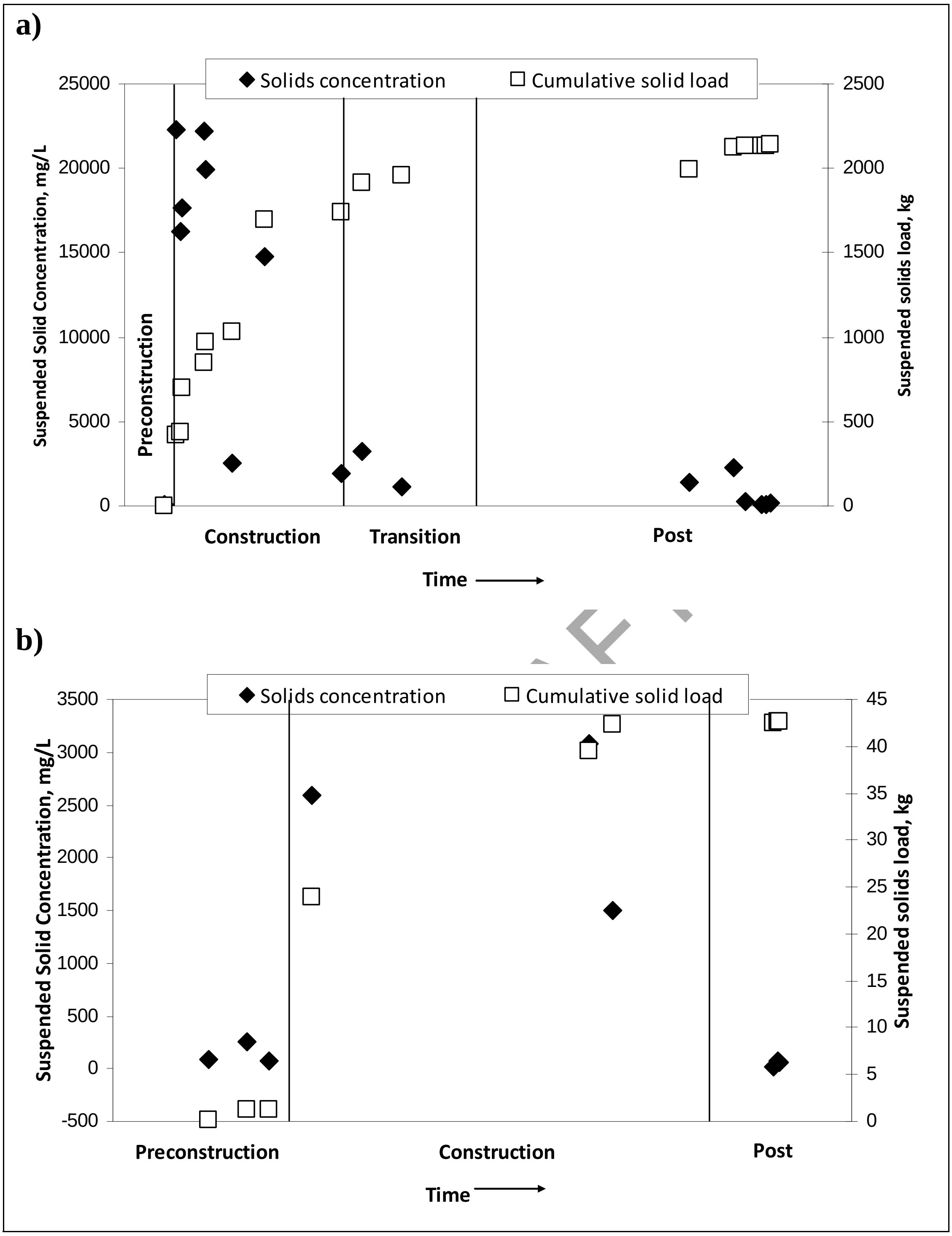

Figure 5.31: Suspended solids concentration and load in rainfall events for (a) a commercial building construction site and (b) a residential building site

Applicability

Water drainage measures, sedimentation and soil erosion control measures are applicable to any construction site. Nevertheless, a common rule for the design practice for every site does not exist and should be assessed and designed separately. The main factors to be considered for the applicability of the measures should be the slope; the existence of channels, waterways and ditches; the existence of flat surface areas; and the management of borrow and stockpile areas for materials and topsoil storage.

Economics

Details on costs for site water drainage are shown in section 3.4.6.1.

Best practices implemented to water drainage and soil erosion control have a significant economic impact, not only within the construction site, but in a broader sense: flooding risks are reduced, water treatment costs are reduced, dirtiness in the site surroundings are reduced and, within the construction site, less maintenance costs are foreseen as less maintenance of drainage channels, detention basins and overall cleaning practices are reduced (USDA, 2007). Regarding particular measures, Table 5.55 shows some performance data for erosion and sedimentation control practices.

Table 5.55: Quantitative and economic performance of some sedimentation and erosion control measures

Practice	Constraints	Removal of suspended solids	Lifetime, years	Costs
Sediment basin	Minimum area: 5 % of total drainage area	Observed: 55-100 %	2	EUR 15 per m^3 plus 25 % for annual maintenance
Sediment trap	-	Observed average: 60 %	1.5	EUR 15 per m^3 plus 20 % for annual maintenance
Silt Fence	150m of fence per ha.	Observed average: 60 %	0.5	EUR 8/m of fence plus 100 % for annual maintenance
Straw bale barrier	150m of fence per ha.	Observed average: 70 %	0.25	EUR 10.5/m of fence plus 100 % for annual maintenance
Vegetative strip	Must have a sheet flow	Observed average: 70 %	2	EUR 0 if comes from existing vegetation. EUR 20000/ha with sod.
Sodding	Protection of soil with high erosion potential	Observed average: 99 %	2	EUR 20000/ha plus 5 % annual maintenance
Seeding	-	Observed range: 50 – 100 %	2	EUR 800/ha plus 20 % annual maintenance
Mulch	Temporary stabilisation	Depends on material and slope. Up to 99 %.	0.25 – 0.33	EUR 3000 – 10000 / ha

Source: EPA, 2000

Regardless of the social benefits, soil erosion controls are always an investment with a long payback period and do not economically benefit contractors, who actually have to operate with higher running costs due to installation and maintenance.

Driving force for implementation

There are a number of drivers for the implementation of water drainage, erosion control and sedimentation control measures. These systems main benefits are:

- Reduction of water pollution, increase of infiltration and prevention against adverse effects of rain events.
- To fulfil regulations, national, regional or local, in line with the European Union Water Framework Directive.
- To prevent dirtiness in the site surroundings and to reduce downstream flooding and, therefore, preventing property damage.

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5.6.2.6 Dust prevention and control

Description

Dust is always present at construction sites and dust pollution is an unavoidable consequence of most of construction activities. The total amount of dust generated by construction sites is small if compared to other stationary sources of dust and particulate materials. Nevertheless, dust prevention and control is mandatory, not only to protect the environment but also to protect the health of workers.

Usually, worker protection laws define maximum dust concentrations at national levels. In Germany, the limit is 3 mg/m^3, which is allowed to be 6 mg/m^3 at several construction and demolition sites. Occupational exposure limits at construction sites are not higher than 10-15 mg /m^3 (ppm), while for crystalline silica, quartz or cristobalite, they are not higher than 0.05-0.10 mg / m^3. These compounds have been detected in some construction activities (Lumens and Spee, 2001). Environmental limits are usually much lower and should be controlled in sites where air quality controls are implemented, such as in urban environments, where limits are not higher than 0.05 mg/m^3 for particulate material (PM) under 10 µm. The contribution of construction sites should not be regarded as a source of PM for urban environments, but as an important local, temporal pollution hotspot.

In building sites, dust generation is mainly due to earthworks at the beginning of the works. Nevertheless, in open-air works, the dispersion of pollutants is very fast. In this case, health issues should be focused or closed environments, where demolition activity, construction of inner walls and recess milling can produce a significant amount of dust (Lumens and Spee, 2001).

The cutting of materials can produce actually a huge amount of dust. Thorpe et al., 1999, published the impact of using wet control of dust, assessing the impact of using two dust suppression systems with water (one with pressurized water) and other with local exhaust ventilation. These techniques are able to achieve dust suppression of more than 90 – 95 % suppression of dust. More data on dust generation from construction activities are given in the Operational Data section.

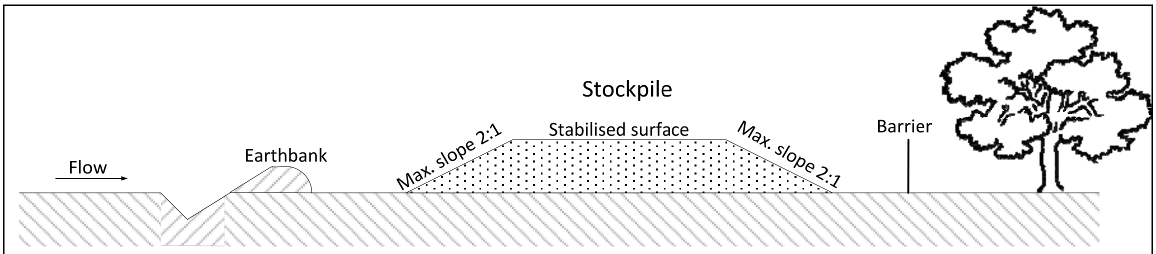
Dust suppression is required for unpaved roads and transport moves in construction or deconstruction sites. In this respect, dust control activities also include prevention, minimisation of soil disturbance and as the application of mulch, vegetation stabilisation, water spraying, surface roughening, applying polymers, and dust barriers. For the purpose of construction sites, dust control has a wider scope and the techniques applied in this sense should: reduce wind erosion and dust, minimise deposition of dust, and minimise low visibility conditions and reduce respiratory problems, not only to workers but also to the neighbourhood. Dust prevention measures regarding machinery are further explained in section 5.6.2.7. In general, there are several techniques or practices to avoid dust generation (NDNF, 1998):

- Prevention measures:
    - Dust management plan
    - Water spraying (wet suppression)
    - Limit of cleared areas
    - Traffic control
    - Soil compaction and early paving
    - Vegetable stabilisation
    - Chemical stabilisation
    - Pile configuration (Figure 5.32)
    - Limit transport and control site access and exit.
- Control measures:
    - Physical barriers
    - Monitoring.

A short description for some of these measures is given in Table 5.56.

Table 5.56: Some techniques to prevent dust generation at construction sites

Technique	Short description	Main benefit	Resources / Costs
Dust Management Plan	Addition to the environmental management plan, to be done in the pre-construction stages.	Constructor is aware of all the dust generating activities and has established mechanisms and adequate prevention measures	No additional effort if the environmental management plan is well implemented.
Wet suppression	It removes dust generation but it is short-term and should be complemented by other techniques. Dimensions can vary from single hand held hose to water trucks. Correct application of other measures can reduce water consumption.	It is a cost effective measure, but can significantly increase water consumption in dry seasons. Optimisation of water use through process oriented applications (e.g. wet cutting) can reduce overall water consumption.	Costs are associated to water consumption and extra equipment needed (trucks, nozzles, etc.).
Soil surface compaction	Usually, soil compaction occurs as a consequence of construction activities using heavy machinery. Soil compaction has a negative effect as it increases water run-off (affecting natural flows to groundwater) and biodiversity loss. Early paving of permanent roads can reduce risks associated with soil compaction by machinery.	This technique reduces dust generated from wind blows but, at the same time, it increases the risk of erosion if no barrier is applied.	Inexpensive measure but with extra difficulties in restabilising vegetation. Generally, provisional paving should not be regarded as a dust control mechanism.
Vegetative stabilisation	Best method is to retain existing plants and transplant plants from disturbed areas to land needing restoration. Vegetation should be native.	Soil compaction would not be needed and erosion should not affect soil. Dust will be avoided in areas with vegetation with a control efficiency of 99 %. Viability of soil is maintained (even increased).	Inexpensive for maintaining existing plants and high range of costs depending on the area to be restored.
Chemical stabilisation	Create an artificial crust by using polymeric binders, which are resistant to wind but not to traffic. It should be accompanied by wind barriers.	Avoids more dust in a longer term than other methods but can provide environmental problems and water run-off in the long term.	It can be expensive, depending of the amount of applications required.
Pile configuration	When stocking material, it should be located properly, in sheltered areas with stabilised surface and establish a pile size maximum, as shown in Figure 5.32.	Piles of material usually produce dust. Best practice should allow minimising dust and the cost of other management measures.	Costs are minimal if prevention on dust is already implemented in the environmental management plan of the site.
Site access and controls, traffic control	Site access should be hardened, maybe with leftovers from concrete preparation, or recycled gravel or crushed materials. Wheels' cleaning also avoids dirtiness at entrance. Paving or soil compaction should be done only if necessary.	Avoidance of dust emissions to site surroundings.	Some of the measures are inexpensive, but requires good monitoring of management practice.



***Source*: NDNF, 1998**

Figure 5.32: Pile configuration to avoid dust generation

Achieved environmental benefits

Controlled dust generation activities can avoid more than 90 % of the generated dust (NDNF, 1998). This would reduce the environmental impact of the site but there also would be fewer risks for workers' health. Depending on the technique, dust prevention has many cross-media effect (see Cross-Media Effects below).

Appropriate environmental indicators

The amount of dust, measured in kg per unit of area and period of time is a useful indicator to control the significance of dust generation in a construction site, although its impact actually depends on the design, the site selection and also on the sensitivity of the surroundings. Also, its concentration is regulated by law and should be measured in ppm (mg per m^3). Monitoring is preferred but involves associated costs to monitor dust, and the heterogeneity and complexity of dust generation can make monitoring very complex, involving many resources. Estimation through EPA's correlation (explained below) or any other scientifically based estimation method may be recommended instead.

An appropriate environmental indicator for dust control should reflect also the management practice, which can be controlled through checklists. Nevertheless, this would not control the performance of the implemented measures. The percentage of avoided dust emissions would be a good indicator for any site and any design, but applying comprehensive monitoring systems and estimating dust emissions should be performed in advance. Also, climatic conditions and soil composition are a limiting factor for the implementation of some measures. For instance, the watering of sites can be controlled with water consumption indicators, but not all soils have to be watered and raining would make this measure unnecessary.

Cross-media effects

Increased water consumption

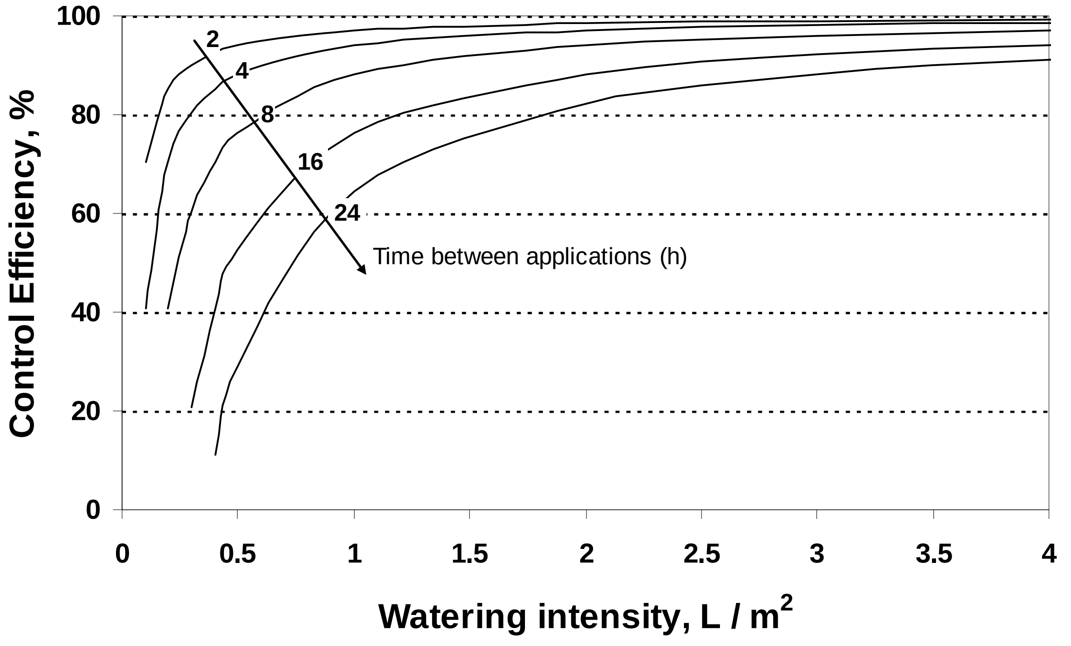
If dust is controlled through watering, water consumption will increase at the construction site. This becomes particularly important in construction sites in dry climates during dry seasons, where, as the dust amount increases, the water demand will increase exponentially while its availability in dry climates decreases, so the environmental impact of water use can become really significant. EPA published a report for the control of dust in construction sites (EPA, 1988), validated in 1998, where an estimation of dust removal efficiency in unpaved roads through watering is expressed by the equation below.

$$CE = 100 - \frac{0.8p \cdot d \cdot t}{i}$$

Where CE is the average control efficiency (%), p is the potential average hourly daytime evaporation rate, in mm/h, d is the average hourly daytime traffic rate (h^{-1}), i is the application intensity, measured in litres per m^2 and t is the time between applications.

Evaporation rate depends on many factors and some rough estimation can be done for some climatic conditions. Figure 5.33 shows the control efficiency calculated for a construction site with different water intensities and times between applications during summer. As seen, for a standard application rate of 1 L/m^2, a frequency of less than 8 hours would be needed to achieve

90 % dust removal efficiency. Although dust removal can be achieved effectively, dust concentrations can vary significantly, even from one application to another with similar achieved efficiency. For instance, 2 hours frequency application at 0.5 L/m^2 has the same efficiency as an 8 hours frequency at 2 L/m^2. Nevertheless, the concentration peak will be higher when the time between applications is higher. Health effects of dust concentration should also be considered as a cross-media effect and a key design factor for watering**.**



Source: EPA, 1998 and own elaboration

Figure 5.33: Dust control efficiency vs. watering intensity and time between applications

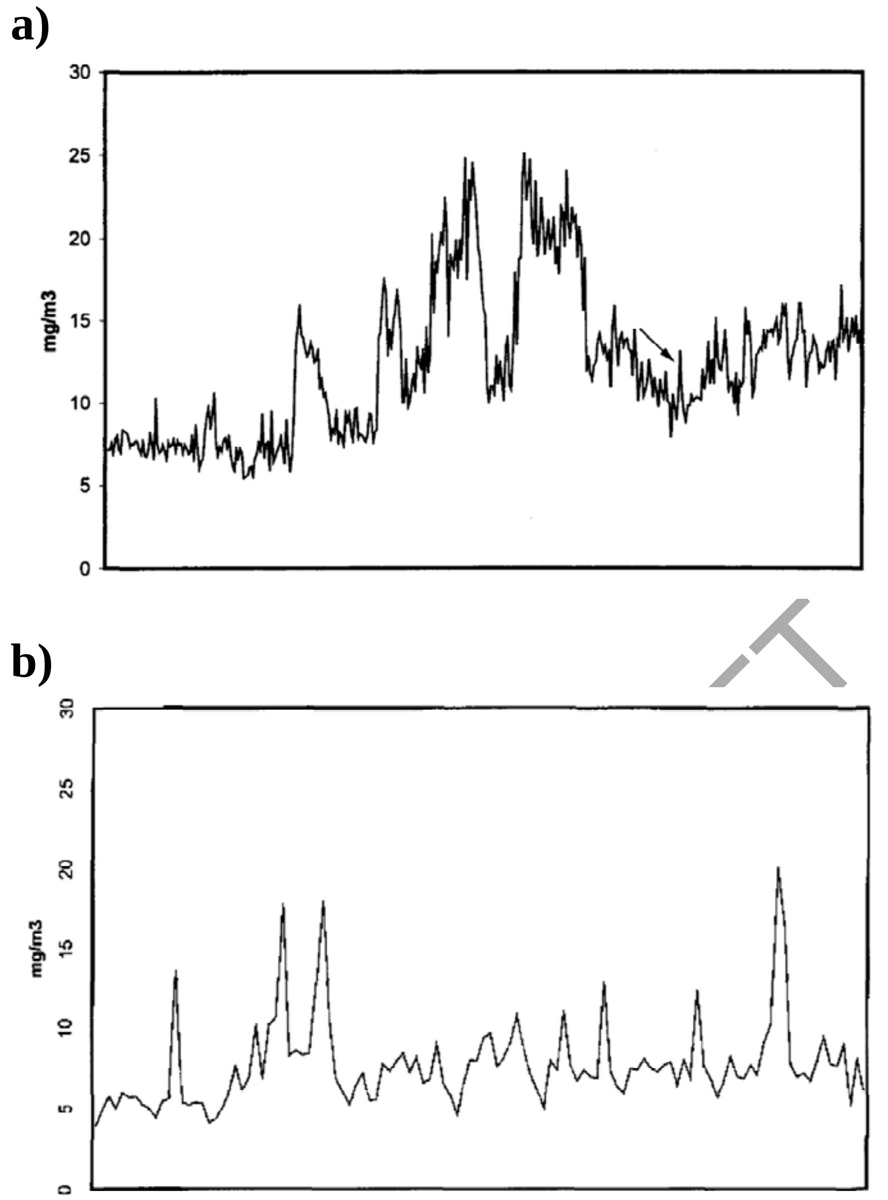
Use of chemicals

The use of binding agents, such as inorganic or organic surfactants, polymers or some chlorides (e.g. magnesium chlorides) can avoid the generation of dust, and have a very significant efficiency. However, the use of such agents can have important indirect effects on the environment:

- Water run-off and water table are affected, as soil drainage would be reduced. This effect is not only produced due to the chemicals but also to the increased soil compaction. (Goodrich et al., 2009b)
- Water quality. Some studies indicate that there is a risk of water pollution when using dust suppressing chemicals (Beighley et al., 2009)
- Biodiversity affectation. Chemical compounds can be absorbed by plants and can produce damages. For instance, magnesium chloride can produce foliar damage 98 m far from the road. (Goodrich et al., 2009a and 2009b)

Operational data

Dust in closed environments. For building construction sites, the most important dust generation activities are related to health aspects in closed environments. Demolition activities, cutting works and recess milling generate a significant amount of dust. Lumens and Spee, 2001 measured the concentration of these activities. Figure 5.34 shows the evolution of dust concentration over short periods of time.



Source: **Lumens and Spee, 2001**

Figure 5.34: Dust concentration in a closed room. Recess milling (a) and sawing (b)

In addition to the values shown in Figure 5.34, concentrations up to 300 ppm of dust were detected in demolition activities (Lumens and Spee, 2001). For cutting and sawing works, Thorpe et al., 1999, developed some measurements for assessing the impact of using water spraying in sawing machines with wet suppression. The results are shown in Figure 5.35. It can be observed that dust generation is reduced by a factor of 30-40.

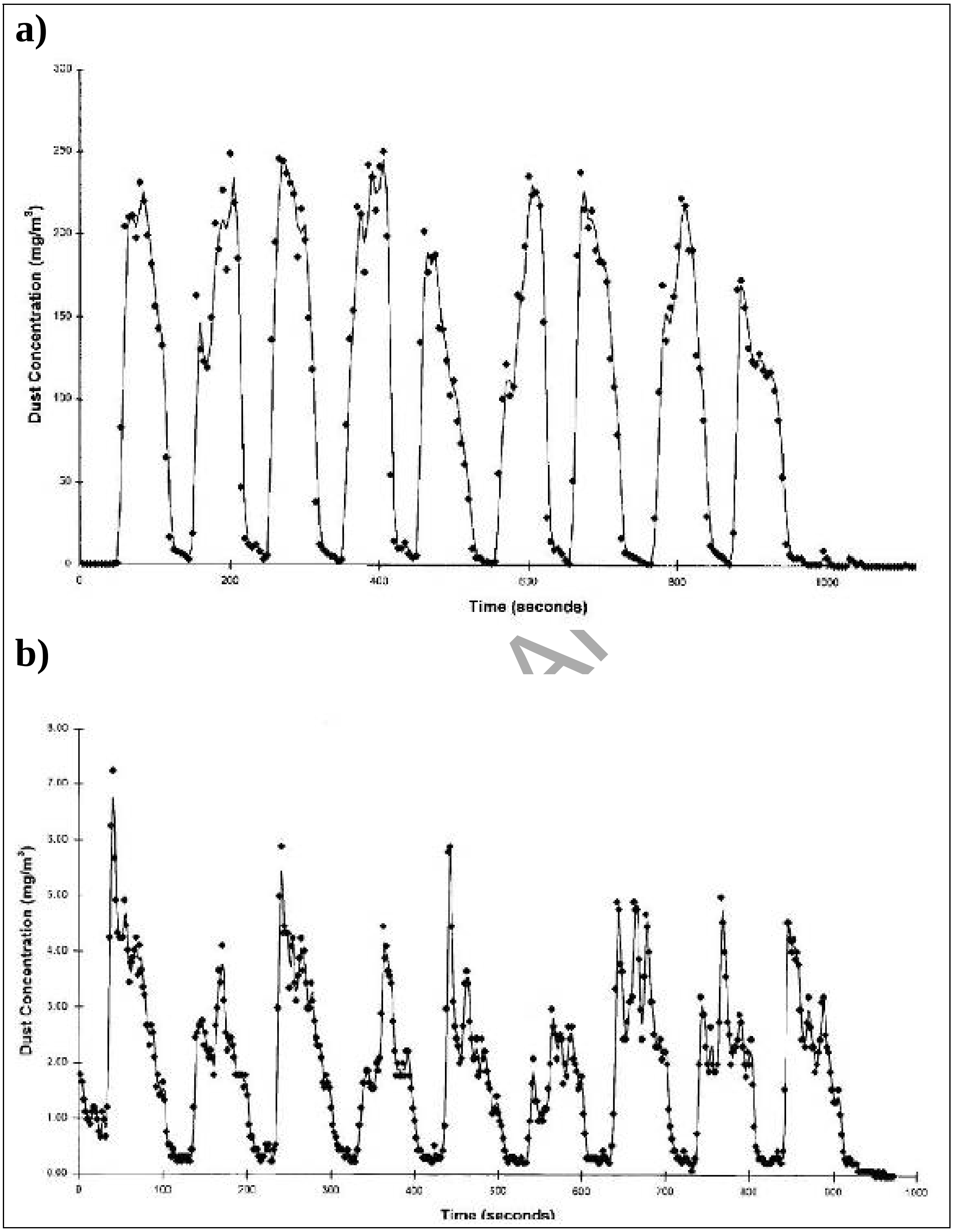


Figure 5.35: Dust concentration during cuts without water dust suppression and with water supplied using an electric pump to supply water at 0.5 L min^{-1}

<u>Measurement of dust emissions in roads and open spaces</u>

The United States Environmental Protection Agency, EPA, periodically publishes air emissions factors for industrial processes. The last revision was done in 2009 (EPA, 2009). Emission factors are used to make an estimation of the overall environmental impact. Usually, these factors are process oriented, although they can be used to estimate the overall activity using the following equation:

$$E = A \cdot EF \cdot (1 - ER/100)$$

where:

E = emissions;
A = activity rate;
EF = emission factor, and
ER =overall emission reduction efficiency, %.

Construction activities are seen as important contributors to dust and particulate materials pollution. EPA provides a general construction emission factor, 2690 kg per hectare per month, which is usually applicable to heavy construction sites, such as roads, and which can be valid for moderate climates in semi-arid regions.

Also, there are emission factors for singular construction processes, mainly related to earthwork activities and truck transport on unpaved roads. Table 5.57 shows the estimation procedures for emission factors for demolition and debris removal activities, Table 5.58 for site preparation activities and Table 5.59 for general construction activities
.

Table 5.57: Dust emission factors for several demolition and debris removal activities

Dust-generating activity	Emission factor	Comments
I. Demolition and debris removal		
I1Demolition of buildings or other obstacles		
I1a Mechanical dismemberment of existing structures	NA	
I1b Implosion of existing structures	NA	
I1c Drilling and blasting of soil	0.59 kg/hole	
I1d General land clearing	$PM_{30}(kg/h) = 2.6\frac{s^{1.2}}{M^{1.3}}$; $PM_{15}(kg/h) = 0.45\frac{s^{1.5}}{M^{1.4}}$; $PM_{10}(kg/h) = 0.75PM_{15}$; $PM_{2.5}(kg/h) = 0.105PM_{30}$	PM_x : amount of particulate material smaller than *x* µm; s: silt content (%), M: moisture content (%)
I2 Loading of Debris into trucks	$E = k \cdot 0.0016\frac{\left(U/2.2\right)^{1.3}}{\left(M/2\right)^{1.4}}$	E: emission factor (kg/tonne), k: dimensionless particle size multiplier: 0.74 (≤30 µm), 0.45 (≤15 µm), 0.35 (≤10µm), 0.053 (≤2.5 µm); U : wind speed, m/s (range from 0.6 to 6.7 m/s), moisture content range from 0.2 to 47.8 %, silt content from 0.44 to 19 %
I3 Truck transport of debris	Unpaved road: $E = 0.281k\frac{(s/12)^a (S/30)^d}{(M/0.5)^c} - C$	E: emission factor, kg per VKT (vehicle kilometre travelled); S: mean vehicle speed (miles per hour), range 10 TO 55 (16-88 km/h), C: emission factor for 1980's vehicle fleet exhaust, brake wear and tyre wear, $1.01 \cdot 10^{-4}$ kg / VKT (vehicle km travelled) for $PM_{2.5}$, $1.01 \cdot 10^{-4}$ kg / VKT for PM_{10} and PM_{30}; *a* = 1; *c*=0.2 (0.3 for PM_{30}) and *d*=0.5 (0.3 for PM_{30})
I4 Truck unloading of debris	See I2	

***Source*: EPA, 2009**

Table 5.58: Dust emission factors for several site preparation activities

Dust-generating activity	Emission factor	Comments
II Site preparation		
II1 Bulldozing	See I1d	
II2 Scrapers unloading topsoil	0.02 kg/tonne	
II3 Scrapers in travel	See I3	
II4 Scrapers removing topsoil	5.7 kg/VKT	
II5 Loading of excavated material into trucks	See I2	
II6 Truck dumping of fill material, road base or other materials	See I2	
II7 Compacting	See I1d	
II8 Motor grading	$PM_{30}(kg/VKT) = 0.0034S^{2.5}$; $PM_{15}(kg/VKT) = 0.0053S^{2.0}$; $PM_{10}(kg/VKT) = 0.60PM_{15}$; $PM_{2.5}(kg/VKT) = 0.031PM_{30}$	S: mean vehicle speed (km/h)

***Source*: EPA, 2009**

Table 5.59: Dust emission factors for several general construction activities

Dust-generating activity	Emission factor
III General Construction	
III1 Vehicular traffic	See I3
III2 Portable plants	
III2a Crushing	In kg per tonne: Tertiary crushing: $2.7\cdot10^{-3}$ (total), $1.2\cdot10^{-3}$ (10μm), $5\cdot10^{-5}$(2.5 μm) Tertiary crushing (controlled): $0.6\cdot10^{-3}$ (total), $0.27\cdot10^{-3}$ (10μm) Fines crushing: $19.5\cdot10^{-3}$ (total), $7.5\cdot10^{-3}$ (10μm), $3.5\cdot10^{-5}$(2.5 μm) Fines crushing (controlled): $1.5\cdot10^{-3}$ (total), $0.6\cdot10^{-3}$ (10μm)
III2b Screening	In kg per tonne: Screening: $12.5\cdot10^{-3}$ (total), $4.3\cdot10^{-3}$ (10μm) Screening (controlled): $1.1\cdot10^{-3}$ (total), $0.37\cdot10^{-3}$ (10μm) Fines screening: $15\cdot10^{-3}$ (total), $3.6\cdot10^{-3}$ (10μm) Fines screening (controlled): $1.8\cdot10^{-3}$ (total), $0.11\cdot10^{-3}$ (10μm)
III2c Material transfers	See I2
III3 Other operations	NA

Source: EPA, 2009

Applicability

There is an important difference between dust management and prevention for large construction sites for civil works and that for buildings. Water spraying is the main, most common technique in road construction in dry regions. For small buildings, dust generation is maybe not so significant compared with other relevant environmental impacts. Nevertheless, all techniques described are applicable at any construction site and may be necessary to avoid adverse health effects.

Economics

Trucks for watering need an initial investment for the truck purchase and other devices. Operational and maintenance costs are usually even higher than the cost of a single watering truck for heavy construction sites, and include fuel water, truck maintenance, operator labour and others. The number of trucks depends on the surface and the required frequency for watering. Normal operation in dry conditions consumes about 1 L/m^2 per truck at a rate of 16000 m^2 per hour (EPA, 1988).

Driving force for implementation

The main driving forces for the implementation of these practices are:

- legal compliance
- reduction of risks in the quality, environmental or health and safety management plans
- better environmental performance through the application of best practices
- enhanced environmental credentials for public administration and customers

Reference organisations

An important reference organisation for dust control is the United States Environmental Protection Agency (EPA), which has published sectoral emissions factors for dust generation, not only for construction but for many other sectors where dust generation is also a relevant environmental aspect.

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5.6.2.7 Disturbance management

Description

In this description, the main environmental aspects related to disturbance management are described. In general, disturbance is a term reflecting the nuisance and irregularities caused to employees, to the surrounding environment and to the people living in the surroundings. In this section, the administrative, organisational, planning and technical activities oriented to reduce the impact of main health nuisance sources will be described:

- Noise and vibration
- Lighting
- Odours

Note: other impacts (dust, biodiversity, waterways, soil erosion and pollution, etc.) are described in other sections of the document.

This section is almost fully dedicated to noise and vibration, although some indicative best practices on lighting, odours and complaint management are given below.

Noise and vibration

According to the Directive 2002/49, environmental noise is all unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activities. There are strict controls in place for traffic noise (road, train or airplanes) and no specific regulation is being implemented for temporary sites, for instance regarding to construction activities

Vibration is the mechanical oscillation of an object or a device and reflects the undesirable energy wasting of engines or electric motors. Usually, noise and vibration are quite interrelated, as vibration is the main cause of noise, as it causes pressure waves from structures or objects to the air. When the vibration is transferred to other solid media, it usually causes low frequency vibration, which is also a main cause of disturbance.

For this document, more relevant construction activities creating noise and vibration in urban environments are road construction, replacement of pipes (requiring frequent cutting), structural modification of existing buildings and the construction of tracks. Pavement breaking and pile driving operations are the operations generating more noise. Earthmoving creates both noise and dust nuisance (Gilchrist et al., 2003).

During construction planning, at preconstruction or even during the design phase, the implementation of a noise control plan can be considered as a best environmental management practice. This plan would include:

- identification of sensitive noise receptors
- background noise levels for each noise receptor
- predictive analysis of the expected construction noise
- comparison expected noise levels with noise limits
- decisions on the mitigation measures to reduce the duration and the impact of construction noise. Include these measures in the consents and contracts
- use of prefabricated elements, which would reduce noisy activities
- communication plan of noise measurements, monitoring and strategies for complaints management.

Noise mitigation techniques are divided into prevention and control measures:

- Prevention or source control strategies:
    - Synchronise timing of noisy operations, as the total vibration level will not be significantly higher than if these operations are done separately
    - Use modern equipment with better engine insulation

  - For sensitive areas, modern methods for construction should be preferred in order to prevent noise: i.e. concrete bored piles, slurry-wall construction, prefabricated elements, etc.
  - Storage areas, with high transit of vehicles, should be placed away from residential or high sensitive areas
  - Restrict traffic and construction activities during silent times (night)
  - Maintain haul roads properly.
- Control measures: consist of the utilisation of physical barriers, which are able to absorb the sound.
  - Enclose noisy activities or stationary equipment, providing a reduction of 10 to 20 dBA noise level reduction
  - Erect noise barriers for the absorption or reflection of noise
  - Place the noise generator as far as possible from the receptor
  - Use innovative active noise controls. Use silencers to reduce noise of pipes
  - Reduce the drop height when unloading

A third strategy is receptor control. This is easy to perform with employees, but it can be costly and even unacceptable for the people living at the surroundings of the construction site (Gilchrist et al., 2003).

Although vibration is prevented when noise is also mitigated, it may require other measures. For instance, when a building is deconstructed, it may be necessary to break concrete by bending instead of by percussion. If possible, rotary drills and bursters actuated by hydraulic or electrical power should be used for excavation (CIRIA, 2005).

Lighting

Some construction works may be required to be performed at night. Illumination is therefore necessary, as enough light is required to ensure proper working conditions and allow safe movements. Nevertheless, it can create a disturbance for the surrounding community. The best environmental management practice to avoid lighting nuisance should (EA, 2010):

- Reduce the need for lighting, through effective programming of works, e.g. to avoid night time scheduling
- Put screens in place
- Introduce directional lighting devices
- Use sensors for presence detection and dimmers to control light intensity.

Odours and air emissions

During construction, odours and emissions will likely be generated. The main emission to air is dust (see 5.6.2.6). Other air emissions come from burning fuels on site for the machinery, fuel and chemical evaporation, from the storage of waste and from waste water generation. In general, it is not a sensitive issue in well managed construction sites. CIRIA, 2005, gives some measures to prevent undesired odours and air emissions:

- Keep machinery and vehicles well maintained and fulfilling legal requirements
- Coordinate deliveries to site to avoid vehicle queuing
- Switch off any equipment which is not in use
- Establish a perimeter for refuelling. The fuel tank should be not exposed to sunlight and far from fire risks. A detention mechanism for fuel spillage should be installed
- Fires should not be made on construction sites
- Frequently remove wastes, which can generate undesired odours (e.g. organic waste)
- Chemicals, paints and varnishes should always be kept in a closed storage

In general, good housekeeping is required in a construction site. A tidy site is not only safer, but no wind-blown litter or debris would happen. Lightweight materials should be properly covered and haul roads, entrances and transit zones cleaned properly and regularly.

Complaints management
As construction activities will likely create nuisance to the surroundings and affected people might complain. Construction site managers should have identified the potential nuisances before starting the work, e.g. in the environmental management plan. Also, local restrictions for noise and working hours should be identified. To minimise the number of complaints, control measures should be implemented on-site. Neighbours should have been advised about the scope of the construction project. Foremen, subcontractors and all workers on-site should also be informed about nuisance restrictions. A procedure for dealing with complaints has to be implemented.

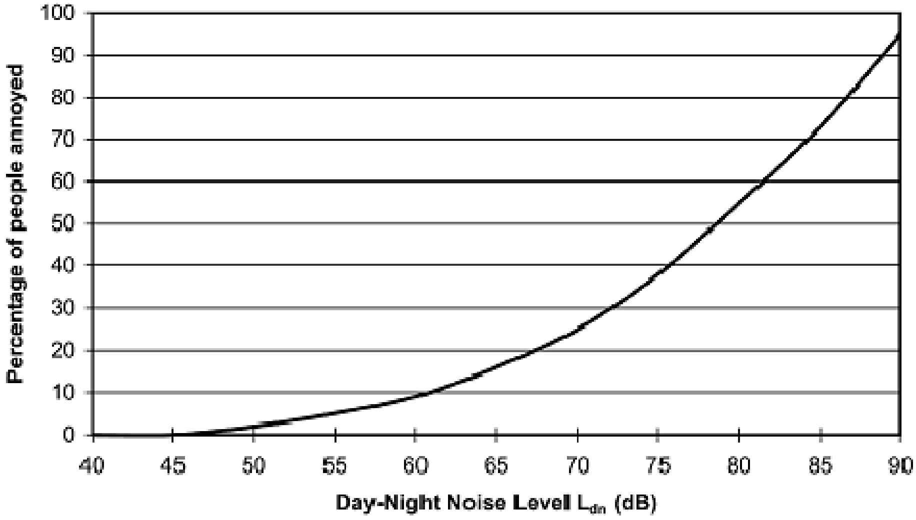
Achieved environmental benefit
Average environment noise during construction is around 65-75 dBA. The installation of control measures, such as barriers, is able to reduce the noise level in the surroundings by up to 20 dBA for specific processes.

The implementation of appropriate contingency plans for nuisance management is able to reduce significantly the amount of complains. For instance, the construction of the new European Central Bank premises in Frankfurt had almost zero complaints, despite it is being quite close to sensitive areas.

Appropriate environmental indicator

Noise levels heard by humans are measured with a logarithmic scale named the decibel A scale (dBA). Sounds heard by humans are in the range of 10 to 140 dBA, being 130 dBA the threshold for physical pain. Environmental noise produced by a construction site fluctuates at high frequencies with time. Thus, for the purpose of analysis of environmental noise, the equivalent sound level, L_{eq}, is defined as the average acoustic intensity over time, or the equivalent noise energy level of a steady, unvarying tone (Burge, 2000).

Another important indicator suitable for checking the performance of the noise prevention and control plan is the number of complaints. There is a direct relationship between the number of complaints, and, thereof, the number of people annoyed and the environmental noise. This is called the Shultz curve (Figure 5.36). Therefore, the effectiveness of the noise control can be related directly to the number of complaints received about the effects of construction noise.



Source: Gilchrist et al., 2003

Figure 5.36: Shultz curve: relationship between environmental noise and the percentage of people annoyed

Cross-media effects

No cross media effect is expected from the management of nuisance aspects at construction sites.

Operational Data

Noisy equipment

Pneumatic equipment and alarms are the main noise generators. Milling, grinding, earthmoving, crushers, demolition, pavers, etc. create excessive noise levels. Also, equipment becomes noisier when inappropriate maintenance is being performed. In Table 5.60, the noise generated by several items of equipment as delivered by the manufacturer or used is shown.

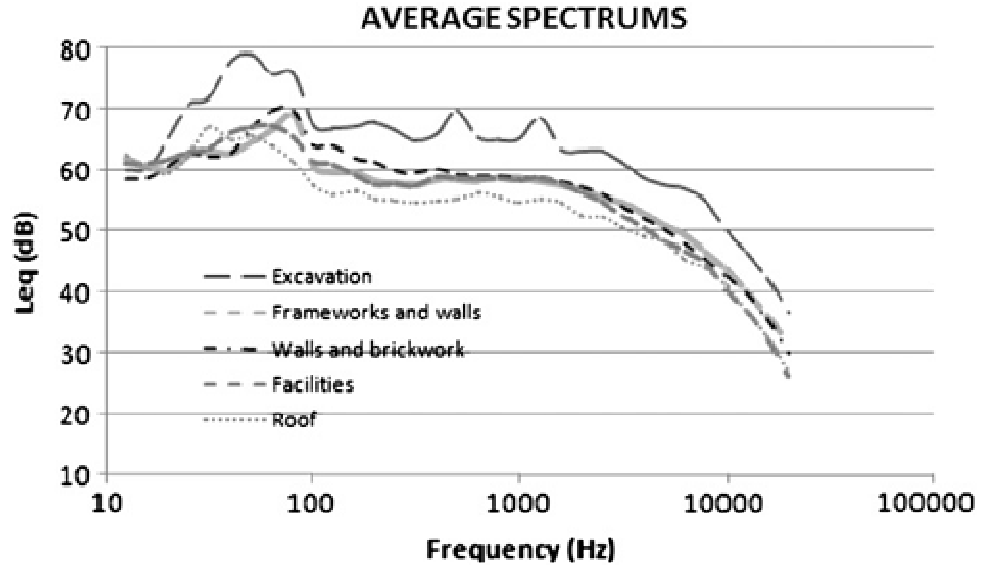
Table 5.60: Noise levels generated by construction equipment

Equipment	Noise level, dBA, new	Noise level, dBA, used
Compressor	73	76 – 800
Backhoe	75 – 80	83 – 88
Concrete mixer	75	85 – 87
Concrete pump	75	82 – 85
Concrete saw	90	–
Concrete vibrator	75	76 – 80
Crane	75	85 – 90
Bulldozer	75	83 – 88
Dump truck	84	85 – 88
Excavator	83	85 – 87
Grader	72 – 75	85 – 90
Jackhammer	75 – 80	85 – 90
Loader	80 – 85	92 – 95
Paver	80 – 85	95 – 101
Rock drill	80 – 85	95 – 98
Roller	80	88 – 90
Scrapers	78 – 83	96 – 98
Tractor	75	85 – 90
Trencher	83 – 88	–
Vibratory pile driver	95	–

Source: Gilchrist et al., 2003

Noisy activities

Ballesteros et al., 2010, performed an analysis on the environmental noise produced by several construction sites and disclosed it per process or construction stage (see Figure 5.37). According to their findings, the excavation stage depends on heavy construction machinery and produces a more constant noise than other activities. Frameworks and walls stages have a variable and disperse working time, with higher nuisance. The presence of enclosures in the building may influence the generation of noise of other activities: piping, brickworks, etc. The noise generated by roof construction is not significant.



Source: Ballesteros et al., 2010.

Figure 5.37: Average spectrum of noise in construction sites

Acoustical Barriers

These items reduce noise by 15 – 20 dBA. The effectiveness of an acoustical barrier is limited by the sound energy that is able to travel over and around it. As stated by Gilchrist et al., 2003, an acoustical barrier should be used when a reduction of about 10 dB is required. In the other hand, if a barrier is not able to reduce 10 dB, it is usually not justified. There are two main properties which characterise the effectiveness of an acoustical barrier: mass and stiffness. A barrier is able to provide protection through three mechanisms: (i) some of the sound energy is transmitted through the barrier, (ii) some of the energy is absorbed, and (iii) some of the energy is reflected back.

The effectiveness of a barrier can be enhanced by:

- Gap sealing between different barriers
- The length of the barrier being twice the distance from the source to the barrier (approx.)
- The barrier being placed as close to the source as possible.

Descriptions of several noise barriers are shown below.

Table 5.61: Description of noise barriers

Type of barrier	Description
Berm	Long lifespan, cost effective. It has space constraints and needs to be higher than other barriers.
Wood panel	Low cost, easy to build, needs supporting beams of steel or concrete. High sound transmission.
Metal	Perforated metal containing wool or other noise-absorbing material.
Concrete	Low or high density, reinforced, containing noise-absorbing material.
Glass, acrylic and polycarbonate.	Transparent, with less visual impact.
Curtains	Less effectiveness. Used to enclose specific work operations. They are used to protect stationary equipment, as power generators, reducing, therefore, erection costs.

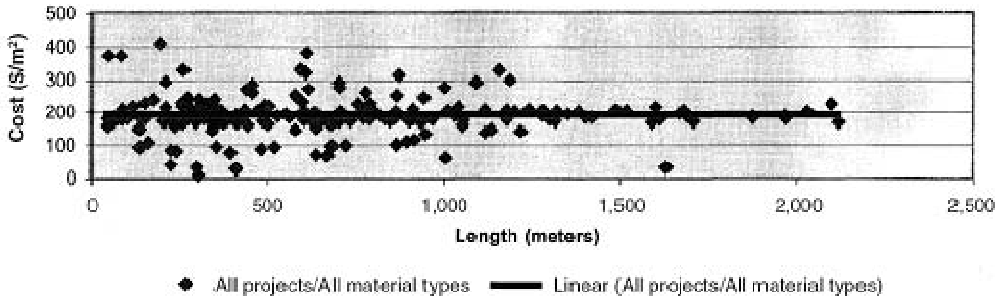
Applicability

No restriction on the applicability exists. Some control measures are avoidable when building out of urban environments, although other impacts should be then carefully assessed.

Economics

Disturbance prevention measures, such as organisational, scheduling and communication are low costs when properly implemented, as compared to mitigation measures.

The costs of barriers for environmental noise has been analysed by Polcack, 2003, for several types of highways and for all construction materials. Figure 5.38 shows that the average cost is around USD 200 (about EUR 177 in 2003, in actualised price EUR 230) per square metre of barrier. A construction project needing more than e.g. 120 m of barrier (2 m high) would need more than EUR 55 000 for noise control (this investment may be shared with other future construction works if sound barriers are reusable).



Source: Polcack, 2003

Figure 5.38: Costs of noise barriers in motorways

The implementation of noise barriers for specific equipment, such as a generator, also has a significant associated costs. For instance, the acoustic protection of the generator of Figure 5.39 costs about EUR 11 500.

Figure 5.39: Soundproof electricity generator

Driving force for implementation

The main driving forces for the implementation of these practices are:

- legal compliance
- reduction of risks in the quality, environmental or health and safety management plans
- enhanced environmental credentials for public administration and customers
- in general, reduced costs when applying prevention rather than correction measures.

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5.6.2.8 Improving energy efficiency and reducing pollution from engines

Description

In this section, several energy efficient machinery technologies are shortly described for lifting, piling and other special machinery and also for the transport and handling of materials. This is not an exhaustive list of energy efficiency measures on site. The relevance of energy consumption impacts during the construction phase is not as significant as other aspects (e.g. wastes) or as during the operational phase (i.e. buildings use). Hence, several examples for improving energy efficiency are given without detailing a systematic, exhaustive approach.

Lifting and piling machinery

On construction sites, the transport of materials and lifting activities are energy-intensive processes, needing special machinery and techniques, such as hydraulic cylinders. These hydraulic techniques generate power by a piston connected to a piston rod moving back and forth inside a cylinder barrel, compressing a hydraulic fluid, such as oil. The oil is pumped into the cylinder in a regular flow by a hydraulic pump. Hence the cylinder is the actuator, transforming the power into a linear force. This technique is implemented for lifting purposes in hydraulic excavators. One of the best available techniques for the energy efficiency of these lifting systems is the storage of a part of this energy in a separate gas cylinder when the equipment is lowered by compression of the gas in the storage cylinder. The stored energy in the separate gas cylinder is directly transferred to the two heave cylinder when material is lifted again, so the energy demand is reduced (Liebherr, 2010). In general, there are many opportunities for energy saving in hydraulic actuators. Hydraulic accumulators or batteries storing regenerated energy, both for hybrid or non-hybrid systems, have a huge potential for increasing the efficiency of many operations (Rydberg, 2009).

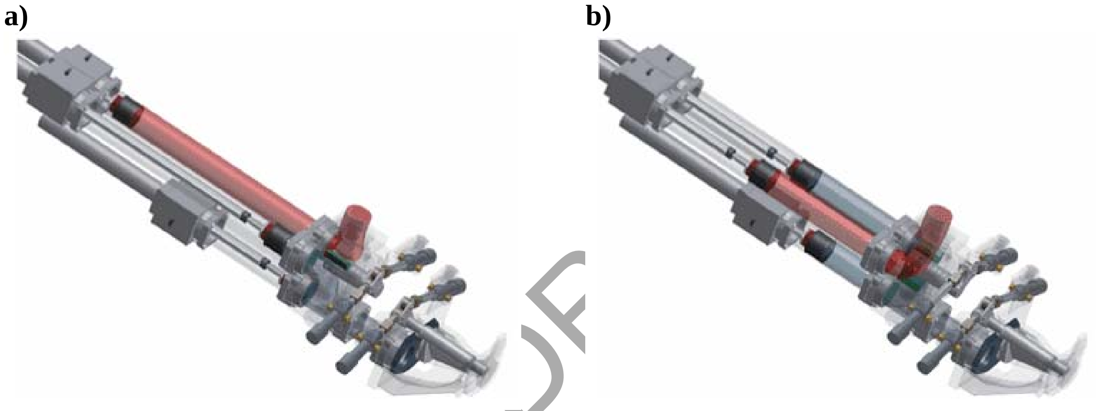
Forklifts are common lifting equipment on construction sites for lifting and transporting material and elements. Conventional forklifts are generally equipped with diesel engines. The combustion of the fuel-hot-air-mixture within the combustion chamber of the diesel engine causes air emissions, such as carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (HC) and particles. To reduce the impact, the amount of gasoil consumption and the amount of ejected emissions should be limited. Hybrid forklifts including diesel engine coupled with a nickel-metal hydride cell battery and an electric motor can reduce fuel consumption as well as emissions by 50 % as compared to conventional forklifts with normal diesel engines.

Piling is a main activity in civil and underground engineering. There, the use of vibrators, applied on a cable or hydraulic excavator, employed to sheet piles, casings and beams already reduce noise by 15 dB in contrast to impact piling. Usually the static moment of these vibrators is fixed. The use of a vibrator with a variable/adaptable static moment between 0 and 100 % increases efficiency of the vibrators piling technique, as the complete offered power of the vibrator can be used and, additionally, a higher drive frequency can be driven. Hence the vibrator becomes applicable for diverse site conditions and a wide range of diverse piling activities (ABI, 2010).

Transport of materials

A significant contribution to the environmental impact of construction products is made by transport needs. The mode is the most important determinant of specific transport efficiency on a per tkm basis. Transportation to construction sites is usually performed by trucks and its impact is usually attributed to the activities of the supplier. Construction companies are usually responsible for the procurement of materials and may reduce transport demand by sourcing locally or at the closest supplier. Also, construction companies can manage a large number of trucks, especially for earth movement and waste management. In this case, techniques such as reverse logistics, avoiding empty trucks, can significantly reduce the energy demand and GHG emissions from transport. Usually, construction companies want to reduce their transport needs or use reverse logistics because it produces important cost- savings, as the local sourcing for construction materials often costs less and wastes reuse saves costs associated with new purchases and waste treatment. Some other techniques are easily applicable, such as increasing the load factor. Transport of materials over long distances from production mills should also be considered an issue around green sourcing of materials.

At construction sites, concrete pumping is extensively used, and it is quite energy intensive, as it is usually driven by diesel engines, with a requested power up to 500 kW. A continuous flow pumping system can be used to reduce the energy demand by 30-40 %, without affecting the properties of the pumped concrete. The system consists of three cylinders (Figure 5.40): a suction cylinder and charger for loading, while the other cylinder is conveying. Then, the charger fills the suction cylinder and compacts concrete with a 100 % filling ratio. During the shifting cycle, the charger bridges the shifting gap by maintaining the pressure and transport in the conveying line. The procedure starts over again when the other cylinder is loading. This system allows the reduction of peaks, allows increased outputs and increases the efficiency of pumping (REICH, 2010).



Source: **Reich, 2010**

Figure 5.40: Pumping of concrete with continous flow: a) first cylinder laoding phase b) second cylinder loading phase

Selection of machinery

The use of machinery for the development of building construction projects is essential. Most of the machinery usually runs with diesel engines. These engines generate a series of impacts due to dust and particulate materials and, also, due to the carbon emissions associated with fuel combustion. A best environmental management practice on the selection of new machinery is to use environmentally friendly criteria. The main criteria, apart from energy efficiency and carbon emissions, should be the particulate materials generated by the machine, the optimisation of the work load, emissions beyond regulations (i.e. Directive 97/68 and its amendments), lubricant oil consumption and optimal maintenance cycles.

Heavy hydraulic machines require a significant amount of lubricant oil. To minimise oil use, machines with enhanced lubrication system and optimal maintenance cycles are regarded as best available techniques. In fact, the use of predictive analysis, predictive maintenance and preventive maintenance can reduce oil use to a large extent.

Regarding exhaust emissions, the Swiss approach seems to be noteworthy as, apart from fulfilling the requirements of Directive 97/68 and the EURO5 and EURO6 standards, they established a new limit: construction machinery should not exceed the particle count of 10^{12} per kWh for solid particles with a diameter greater than 23 nm. This achievement is only possible when an appropriate particle filter system is installed, even for existing machinery. These particle systems are able to reduce 97 % of solid particles and have the potential also to considerably reduce the soot emissions from construction machinery (FOEN, 2012).

Cabins

Construction site cabins are temporary construction facilities that provide additional space to site managers and site workers during the project additional indoor space for office (direction and managing tasks at site, carrying out meetings with suppliers, training courses, official office accommodation, etc.) and also provide labourers with useful space as a canteen, dressing room or common areas. Cabins are a common asset at construction sites. When cabins are extensively used (see Figure 5.41), energy consumption for heating (space heating or domestic hot water preparation) and electricity (for office equipment) becomes relevant. Consumption in several sites of up to 50 % of the total site energy demand has been reported for cabins. Also, environmental considerations come into plan for these temporary offices: i.e. water consumption, paper, printers, energy efficiency, wastes, etc.

Cabins suppliers usually offer energy efficient equipment in cabins. Konstructa, 2012, suppliers cabins with 30 % lower lighting energy consumption and efficient toilets with 40 % reduced water consumption. The main environmental techniques used in these cabins are foam insulation, with a thermal conductivity of 0.025W/mK; timers on convector heaters; sensors; dimmers and timers for lighting; low volume dual flush WC and controlled urinal cistern for reduced water usage; double glazed windows; underfloor insulation, etc.

In general, the best environmental management practices regarding cabins include submonitoring of the cabins energy and water demand, minimisation of that demand and the implementation of energy efficient and water saving measures.

Figure 5.41: Construction site cabins

Achieved environmental benefit

Table 5.62 shows the environmental benefit of some of the described techniques. The benefit of using energy-efficient equipment and machinery is difficult to quantify at the overall performance level of construction works, since construction projects differ significantly and the resources demand vary even for similar products. So, the benefit of energy efficient machinery should be regarded at the process level. The same happens for other indicators.

Using energy efficient cabins can reduce the overall energy demand of the site by up to 30 %. Engines with closed filter systems are able to reduce by 97 % the emission of particles, and NO_x emissions by 90 %.

Appropriate environmental indicators

Energy consumption per m^2 of construction site or building or per km of linear work (roads, bridges, etc.) is a recommended indicator, although improvement of the company's performance cannot be measured with this indicator, since it depends on the design. Nevertheless, primary energy consumption per m^2 in buildings and per year can be a good indicator to establish comparisons with the life cycle performance of a building. For instance, an office building consumes about 100-200 kWh of primary energy per m^2 during a year, while it can consume about 30 kWh/m^2 during one year of construction. Process oriented indicators may be preferred to measure the efficiency of energy saving techniques. For instance, the volume of fuel per cubic metre of transported material, per tonne kilometre for transport, used energy per m^3 of excavated material, energy consumed per lifted material and per metre, etc.

Table 5.62: Energy efficiency measures environmental benefit

Equipment/process	Purpose	Environmental benefits	Comments
Energy storage in machinery using cylinders, especially for excavators	Excavation/lifting	Reduce energy demand, reduce noise and reduced air emissions	The exact figure on savings depends on the process and in the activity intensity. This technique can produce cost savings.
Improved logistics, change transport modes and better trucks	Transport of materials	Reduce total fuel consumption for transport, better management and, improved materials use efficiency can be an indirect impact of this technique.	
Concrete pumping on site with continuous flow systems	Transport of material	Reduction of energy consumption up to 40 – 60 %, reduce of CO_2 emissions	Payback time is long. Energy consumption for pumping concrete varies from 2.5. kWh/m^3 in conventional systems down to 1 kWh/m^2

For cabins and auxiliary processes, other indicators may be suitable. For office cabins, water and energy performance per square metre of cabin are appropriate indicators.

Particle emissions, in kg/kWh and in number per kWh, are also a suitable indicator for the pollution control of construction machinery.

Cross-media effects

The reduction of energy consumption has a direct impact on costs. No new impacts on environment are expected from the use of energy-saving techniques. Synergies may be expected from better transport and logistics, which can have also impact the logistics of wastes or materials to be reused.

Operational data

Energy consumption at construction sites

Figure 5.42 shows the cumulative distribution of the primary energy consumption of about 40 construction sites. The energy consumption data shown in that figure is the total consumption per m^2, normalised per year of construction. These data show that energy consumption in the construction phase can be much smaller than from one year of building operation and is negligible compared to the fun life cycle of the building, as most of them are in the range from 10 to 30 kWh/m^{2}yr. Also, data from Figure 5.42 cannot produce any benchmark, since if accumulates gathering the energy consumption from all processes. The final energy demand, during the construction phase, depends on the design of the final product, and construction companies will only be influenced if they can see and increased efficiency in their activities.

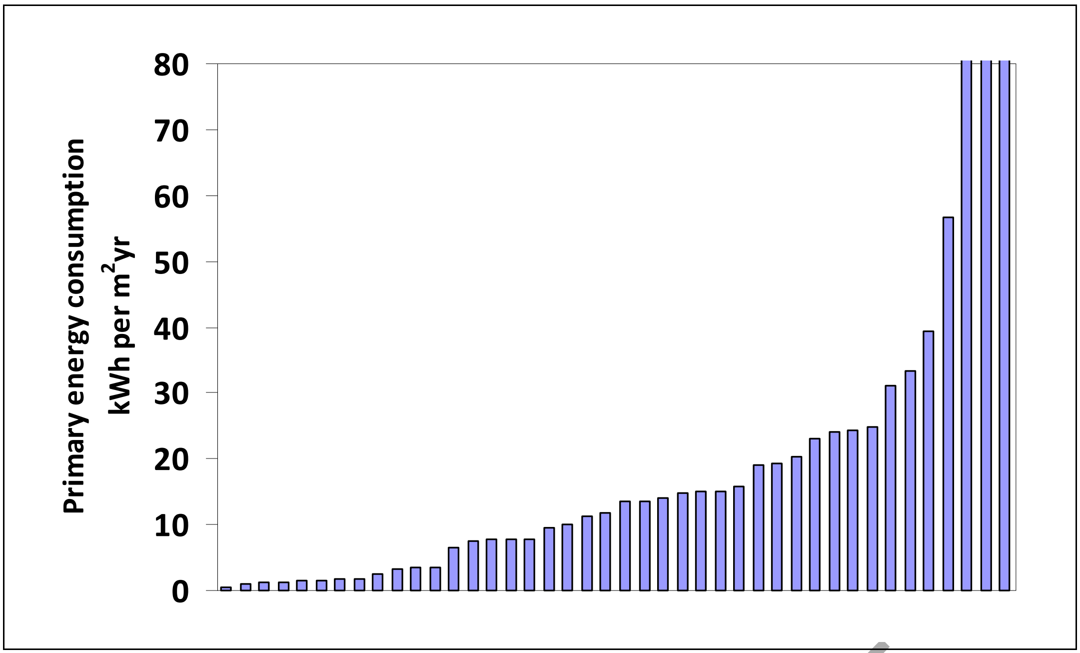
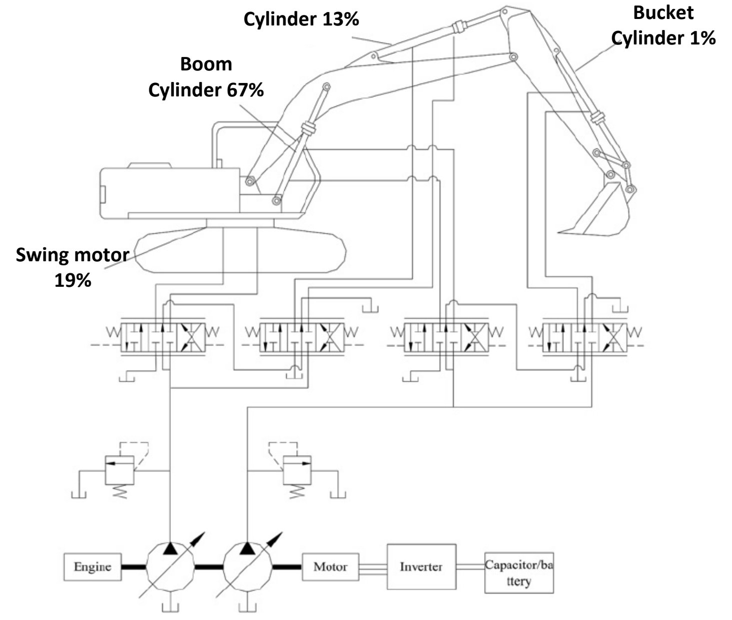


Figure 5.42: Cumulative frequency distribution of the energy performance of several construction sites

Energy efficient measures

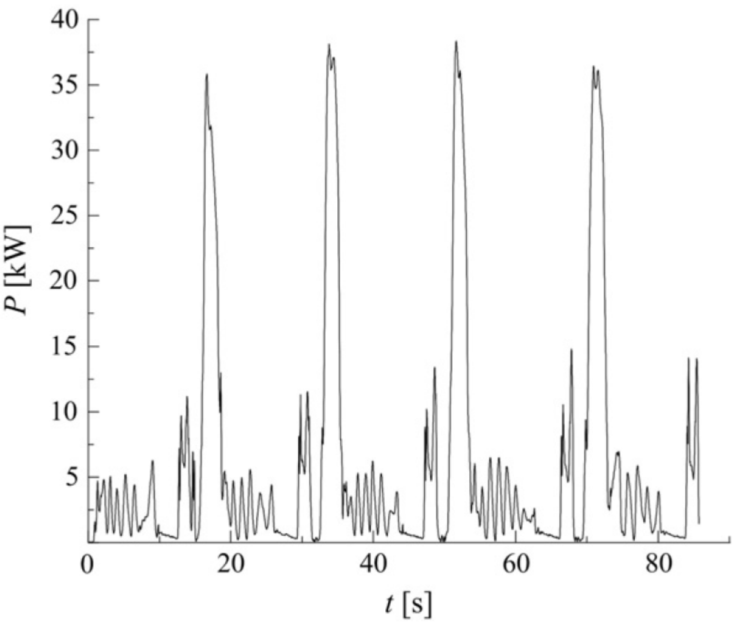
An example of the implementation of an energy efficient measure is the use of energy recovery systems (ERS) and more efficient machinery, for instance, hybrid diesel electric excavators. Figure 5.43, Lin et al., 2010, identifies the opportunities for energy regeneration in the cylinders of a mechanical earth excavator.



Source: Lin et al., 2010

Figure 5.43: Structure of a hydraulic excavator and the regeneration potential of energy in an hybrid system

As observed, the main recovery opportunities are in the boom cylinder. The availability of energy is high (more than 67 % of the total energy, with 39 % coming from the transformation of potential energy into linear displacement). Nevertheless, when assessing excavation processes, regeneration systems are usually limited due to their short regeneration times. For instance, Figure 5.44 shows the potential power to be recovered from the boom. The peaks represent the lowering of the boom and where the highest recovery efficiency is achieved. The duration of these peaks is about 2 to 3 seconds, while the normal process of excavation (in the shown example) is about ten times longer.



Source: Lin et al., 2010

Figure 5.44: Regenerative power peaks of the boom cylinder for several consecutive digging works

Applicability

No restrictions are observed on the applicability of the described techniques.

Economics

The economic balance of energy saving measures in transport modes, lifting, piling and other machinery is usually positive, as the reduction of fuel or electricity demand ensures pays back. It is not possible to propose a range of payback periods since it depends on the technology and on the activity to be performed.

Driving force for implementation

Main driving forces for the implementation of these practices are:

- legal compliance
- costs savings
- better knowledge of company performance
- identification of opportunities for wastes and materials logistics
- reduction of risks in the quality, environmental or health and safety management plans
- better environmental performance through the application of best practices
- enhanced environmental credentials for public administration and customers.

Reference organisations

Many suppliers of construction equipment are available. For the development of this section, some of them have been referenced:

- Liebherr: www.liebherr.com
- Reich Baumaschinen GmbH, Concrete Efficient Pumping
- ABI GmbH. Civil engineering equipment

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6 BUILDING OPERATION AND MAINTENANCE

6.1 Scope

This section concerns the operational and utilisation phase of a building, and the use and the management of its facilities, as well as its maintenance operation. Current schemes for environmentally friendly construction usually concentrate more on new buildings. Nevertheless, existing buildings account for the greatest share of total building energy consumption. Thus, this section addresses both existing buildings, and buildings under planning and design phases that can be designed environmentally better in order to optimise their environmental impact during their operation phase.

6.2 Introduction

Building operation refers to the use and operation of a building, including the running of its facilities and services. The operation phase is the real purpose of a building and the longest phase of a building's life cycle (typically 50 – 100 years).

Building maintenance is the combination of all the technical and associated administrative actions carried out during the service life to retain a structure in a state in which it can perform its required functions over its lifetime. Maintenance is an essential aspect of the environmental performance of a building. The long-lasting effectiveness of the techniques implemented during the building design stage depends on proper maintenance and care activities, such as cleaning, control, troubleshooting, repair, or the replacement of components.

The concept of facilities Management is 'an integrated approach to operating, maintaining, improving and adapting the buildings and infrastructure of an organisation in order to create an environment that strongly supports the primary objectives of that organisation' (Atkins and Brooks, 2009).

Building maintenance
Maintenance covers 'all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required functions'([26]). Maintenance management aims to verify that all technical equipment is functioning efficiently, and can restore to a good condition any part of a building that is in any way defective. Usually, maintenance includes technical actions as well as administrative, managerial and supervisory actions.

In the European building sector, maintenance and repair activities can account for up to 40 to 60 % of the building construction costs. This reveals the need for improvement in durability during the building design (see Chapter 3).

Inspection, maintenance and operation involve significant expenditures. Several examples of costs from 1998 are given by the Guideline for Sustainable Building released by the German Ministry of Transport, Building and Housing:

- Electricity/cooling: 15 - 40 EUR/m^2 yr ([27])
- Cleaning: 15 - 35 EUR/m^2 yr
- Inspection and maintenance: 5 - 35 EUR/m^2 yr
- Value-conserving building maintenance: 5 - 15 EUR/m^2 yr
- Heating: 5 - 15 EUR/m^2 yr.

The building technical equipment and systems covered by building maintenance are mainly:

([26]) Definition by the European Federation of National Maintenance Societies.

([27]) These results were calculated for the main used areas (including habitable and living rooms, offices, technical rooms, storage rooms, etc.).

- HVAC (Heating, Ventilating, and Air Conditioning)
- Plumbing equipment
- Electrical, instrumentation and controls
- Security and communication systems
- Gas, smoke, and fire-alarm systems
- Laboratory and clean-room systems
- Elevators
- Media systems.

Facilities management

In commercial or institutional buildings, the integrated management of all activities and services supporting the operation and maintenance of a building and its facilities can be regrouped under the term Facilities Management.

Facilities management goes beyond just building maintenance and involves the totality of services and utilities supporting the operation of a commercial or institutional building, such as the procurement of equipment and materials or the purchase of land. These services generally do not belong to the core activity of the owner, who often chooses to outsource them to an external organisation specialised in Facilities Management.

Facilities management covers three main areas of activity (Hellerforth, 2006):

- Technical facilities management or 'maintenance management' covers the maintenance of facilities and equipment: heating, air-conditioning, electricity, etc. This is the part which is most relevant for sustainable building, since it is directly related to energy and resources consumption.
- Infrastructural facilities management includes all services to the building users: cleaning services, mail services, reception service, lock up service, sweeping snow and ice control, relocation management, operating washroom and shower facilities, etc.
- Commercial facilities management embraces the commercial services related to the building property: utilities billing, life cycle-cost accounting, space management, property management, procurement management, marketing and rental facilities, delegated project contracting, etc

The main objective of facilities management is to improve the services provided in terms of cost efficiency and quality, taking into account a number of criteria including cost efficiency and other requirements regarding safety, security, health, environment, comfort and end-user satisfaction. Total facilities management is not only cost-efficient but also presents a great potential to reduce the environmental impact of buildings, while extending their lifetime.

Facilities management is a continuous process, covering the whole lifetime of a building (design, planning, construction, operation, refurbishment, and deconstruction). The focus here is however on the operation phase, which lasts the longest (usually several decades) and which is the most important in terms of costs. Related activities dealing with continuous improvement are monitoring, evaluation and anticipation, and these are especially linked to building management systems.

Facilities Management is a continuous process, seeking continuous improvement, based on monitoring, evaluation, and anticipation (forecasting the buildings' future requirements). Facilities management makes available all information and data related to building management. In recent years, facilities management has evolved and is now increasingly performed under IT support through the web-based or LAN-based environment. This so-called Computer Aided Facilities Management (CAFM) is closely linked to the concept of intelligent buildings.

CAFM allows the automation of all functional processes of a building according to pre-adjusted values or parameters. This implies integration within a network that comprises sensors, control elements, user parameters and other technical devices.

CAFM tools concern all aspects of facilities management. In the context of intelligent buildings, the advantages of CAFM are:

- Better monitoring and control of electrical and mechanical equipment
- Better data collection on performance and energy use
- ‘Real time’ data synchronisation
- Accurate reporting for data managers
- Improved access to operations and maintenance manuals, health and safety information drawings
- Enhanced productivity of users and employees by reducing double-entry data submission
- Reduction of energy consumption, maintenance and repair costs.

References

Atkin, B. and Brooks, A., 2009: Total Facilities Management. 3rd edition, Wiley-Blackwell, Oxford and New York

Hellerforth, 2006. Handbuch Facility Management für Immobilienunternehmen, Michaela Hellerforth, Springer

6.3 Environmental aspects during the operation of buildings

The utilisation phase of the building is the longest phase of its life cycle, generally lasting many decades, and produces significant environmental impacts, accounting for the greatest part of a building's energy use. The building operation requires the consumption of electricity and water resources. Besides, a great number of pollutants are emitted, a large volume of natural resources are consumed, and a huge amount of wastes are produced in building facilities.

6.3.1 Energy demand

Environmental impacts of energy consumption

The main environmental impact of building operation is from electricity generation, as buildings are great consumers of electrical energy. A great amount of fossil resources are therefore consumed, emitting a large volume of greenhouse gases and other pollutants such as sulphur dioxide and nitrogen oxide. A significant share of electricity comes from nuclear energy, so the production of radioactive waste is also a significant environmental pressure from energy consumption in buildings. The main building processes demanding energy are space heating, heating of drinking water, electricity for lighting, ventilation cooling, as well as air conditioning systems.

Although great savings are achievable by the use of efficient technologies, the most efficient measures can only be accomplished through the optimised design for new buildings or major renovation of existing ones. For that reason, the best options for building management systems are summarised in this chapter. Building automation through energy or building management systems enables the integrated control and monitoring of all automated components (e.g. boilers, cooling plants, ventilators, pumps, single-room control systems, lighting control systems, etc). The use of on-site generated energy should also be considered as an important aspect in relation to the operation of the building. The preferred option (with lowest impact) is the use of renewable sources such as solar energy for heating, and wind or water energy for energy accumulation. Several techniques for the production of renewable energy can be implemented during the building design. In the context of procurement, it is also possible for facilities managers to purchase green electricity from the market.

6.3.2 Indoor environmental quality

Indoor environmental conditions are a major factor in user comfort. They also influence living quality and the work productivity of inhabitants. They are directly related to health aspects. The most important aspects, therefore carrying strong requirements in building code regulations, are:

- **Acoustics.** In buildings with poor acoustic insulation, users might be disturbed by different types of noise such as airborne noises, impact noises (through shocks or machines) or various outdoor noises (transport, passersby, construction works, etc). In certain cases, these noises can even be accompanied by vibrations. These disturbances due to noise and vibration can degrade users' comfort and have an influence on their quality of work, on their sleep, and even on their health. Buildings therefore have to guarantee acoustic comfort by avoiding any acoustic disturbances through the use of proper design features (e.g. sound-insulated windows), whilst allowing users to hear important features of the interior, and also the exterior, environment. Acoustic comfort also depends on local conditions, on the adjustment of rooms and on the characteristics of the building itself. Some buildings and constructions host activities which are a major source of noise, and poor noise insulation or poor location can induce conflicts with neighbouring land uses due to noise emissions.

- **Odour emissions.** During the operational phase of a building, users can be disturbed by odour emissions coming either from the direct environment or by the construction products used in the building itself. These are often associated with chemical pollution emissions, and also have negative impacts on the users' comfort and health. Some buildings and constructions host activities which are a major source of odour, and poor insulation or poor location can induce conflicts with neighbouring land uses due to these emissions.

- **Indoor air quality.** Air quality on the premises is a factor affecting users' health. Through the use of cleaning products or paint, containing hazardous or toxic chemicals, the building operation can potentially be harmful to users' health. Poor air ventilation can induce health risks, such as respiratory diseases and allergies.

- **Thermal comfort.** Human thermal comfort depends on environmental and personal factors. The environmental factors are air temperature, airflow (wind), air humidity, and radiation from the sun or other nearby hot surfaces. Thermal sensitivity is also affected by personal factors such as the clothing being worn and the person's level of physical activity. Another factor is acclimatisation: for example, people living in hot climates are usually more comfortable at higher temperatures than those living in cooler climates. Independently from these factors, thermal comfort usually requires conditions to be within the following ranges:

  - Temperature: 19 to 24 °C.
  - Air humidity rate: 30 to 70 % RH (relative humidity)
  - Air velocity: 0.2 m/s.

  These values can be measured with appropriate devices (respectively a thermometer, hygrometer, and anemometer). These comfort parameters can be regulated through the use of a building management system.

- **Lighting quality.** User comfort also depends on lighting systems. A deficit of natural light can have negative effects on human comfort and trigger diseases such as depression. The optimisation of lighting systems also offers great potential in terms of energy efficiency (see Section 3.4.4).

6.3.3 Water use

Regarding water use, please refer to Section 3.4.6.

6.3.4 Waste production

Large quantities of waste are produced during the operational phase of a building, from the various activities performed by occupants in the building and on the premises. These activities can be related to the operation (office waste, residential waste, waste water, food, etc.), or the maintenance, or the refurbishment of the building.

Waste trashing contributes to the pollution of air, water and soils. Waste disposal is also associated with indirect aspects such as energy consumption and the emission of pollutants in transportation and manufacturing processes. To reduce these impacts, the objectives of waste management are, on the one hand, to prevent or at least minimise waste production and, on the other hand, to reuse or recycle waste. It is therefore necessary to collect and separate office and domestic recyclable waste (paper, plastic, glass).

6.3.5 Cleaning activities

The environmental impact of cleaning agents is relevant during the use phase of a building The consumption of natural resources, especially water and electricity, during cleaning work is a major environmental impact of cleaning activities. Water pollution is also a major issue. Some cleaning agents contain chemicals that contribute to air pollution, ozone formation, bioaccumulation or even hazardous effects in aquatic organisms. However, cleaning activities are a determinant of cleanliness and hygiene, and for the health of building users. Nevertheless, the cleaning agents used might contain hazardous or toxic chemicals which can be harmful to users' health. Cleaning services also give rise to waste, especially from packaging of used cleaning products. Finally, cleaning activities can lead to noise and dust generation. Cleaning activities and products may impact on the performance and well being of cleaning staff.

To reduce the environmental impact of cleaning activities, it is possible to design the building in a way that facilitates cleaning, and/or to purchase green cleaning services.

6.4 Background information

It is possible to minimise the environmental impact resulting from the operational phase during the building design phase, e.g. by specifying energy efficient facilities. But even environmentally friendly design and construction of buildings does not guarantee optimal environmental performance during the operational phase. Approximately 20 % of 'green buildings' fail to meet their planned target values and partly even the minimum requirement([28]). Once an environmental building is constructed and the operational phase begins, it is still necessary to check the quality of its use in order to optimise its environmental performance, e.g. through monitoring and control. Therefore, maintenance and facilities management are critical aspects of building sustainability, guaranteeing the long-lasting environmental performance of buildings and the effectiveness of the environmental techniques implemented during the building design phase.

For a building to be environmentally efficient, it has to be operated and maintained properly by its users. Studies have shown that in many buildings, the introduction of environmental and energy-saving measures during operational management can reduce the building electricity and heat consumption by 10 to 20 %.

6.4.1 Building design

In order to optimise building operation, facilities management takes into account the whole design of the building, starting with the design stage.

Design for maintenance: Maintenance activities can be made easier when considered during the design stage of the building, e.g. by designing the building so as to guarantee good accessibility for cleaning, inspection, maintenance, and repair activities. On one hand, the effectiveness of maintenance activities and, consequently, the environmental performance of the building, depend on many characteristics such as:

- The positioning of technical equipment and systems (production systems, regulation systems, terminals, etc.)
- The dimensions and accessibility of technical rooms
- The accessibility of technical equipment and systems
- The dimensions of technical components
- The dimensions of the work area
- The presence and configuration of lighting
- The presence and positioning of power outlets.

On the other hand, design for maintenance can help reduce user disturbance in case of failure or maintenance intervention. This implies designing building systems simply, in order to enable quick interventions and quick replacement of components.

Also, building design can enable a certain anticipation of maintenance activities by involving building owners, drawing on their experience and expectations within the design process.

Design for cleaning. In the context of design for maintenance, cleaning can also be taken into account during the design stages of buildings in order to facilitate the cleaning work during building operation, and to minimise the cleaning effort, for example:

- By providing smooth surfaces and largely uniform materials, and avoiding construction features which can be an obstacle, such as construction details, difficult-to-access areas or edges, as well as interior installations (e.g. toilet bowls) which can hinder cleaning when not positioned correctly. As an example, stairways should be designed with lateral

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([28]) According to an evaluation of buildings certified after green building standard LEED.

waterproofing or gutters. In order to facilitate cleaning, supports for banisters and head railings should be fixed to the outside edges of the stairs rather than on the stair treads themselves.
- By choosing appropriate materials and colours for surfaces and floor coverings (for example, the use of glass materials leads to higher cleaning costs, bright colours increase the cleaning frequency).

Finally, the design and location of sanitary objects, cleaning rooms, water taps and sockets should take into account the optimisation of the cleaning process. Cleaning rooms should provide sufficient space for the storage of cleaning products and equipment. Further techniques can be implemented during the design of the building in order to optimise the cleaning process, such as:

- The installation of devices such as dust catchers and floor mats in the entrance area, or the roofing of the entrance area, to reduce dust and wetness entering into the building.
- Self cleaning facades, roofs or windows, e.g. made of self-cleaning glass.

Design for energy efficient operations. In order to optimise the environmental performance of a building during the operational phase, it is necessary to take into account facility management as soon as possible in the design phase of the construction process. Characteristics such as energy and thermal demand of a building can be agreed upon at an early stage, for example through building simulation. Facilities environmental management should consider all relevant aspects.

In addition, each investment should be assessed by taking into account the functionality and life cycle costs of a building, and not just construction costs. Building operating costs are heavily dependent on design choices, such as the type of building envelope, the applied lighting systems, windows, doors, bathrooms, HVAC systems etc. Through an integrated planning and design approach, it is possible to plan and optimise future tasks of the building operation. For example, a highly insulated façade with integrated sun protection can be installed in order to reduce the number of interior heating and cooling systems needed. The main instrument for integral planning is building simulation.

6.4.2 Maintenance management

In the context of the environmental management of buildings, the role of maintenance is to ensure that all environmental performance criteria specified within the design are realised throughout the operational phase. From this perspective, specific activities of building maintenance include:

- Cleaning, control, troubleshooting, repair, or the replacement of components of building equipment and systems
- Control and monitoring of building consumption
- Control and monitoring of building environmental performance.

Based on this definition, the HQE approach identifies the following objectives for sustainable building maintenance:

- To facilitate cleaning and maintenance activities through the building systems and architectural design.
- To enable control and monitoring of the building consumption and environmental performance during the operational phase.

Definition of a maintenance strategy. There are generally 3 possible types of maintenance strategies: corrective maintenance, preventive maintenance and predictive maintenance (Horner et al., 1997)

Corrective maintenance covers the actions taken to restore a failed system to operational status. This usually involves the repair or replacement of the component responsible for the failure of the overall system. Since component failure times are unknown, corrective maintenance is performed at unpredictable intervals. The objective of corrective maintenance is to restore the system to satisfactory operation within the shortest possible time.

Corrective maintenance typically involves three steps:

- problem diagnosis (localisation of the failed parts and determination of the failure cause)
- repair and/or replacement of defective component(s)
- verification of the repair action (verification that the system operates correctly again).

Since corrective maintenance only occurs when a components fails, this strategy can be very expensive. The failure of components might cause consequential damage to other elements of the building or disturb building users and interfere with activities.

Preventive maintenance consists of planning maintenance actions to prevent the breakdown or failure of equipment and facilities, and replacing worn components before they actually fail. This includes equipment checks, partial or complete repair at specified periods, components changes, etc. The main objective of preventive maintenance is to reduce the risk of breakdowns, increase reliability and equipment lifetime. The schedule for preventive maintenance is based on the knowledge acquired through monitoring of the system, for example regarding mechanisms and rates of component wear. Since preventive maintenance is performed before a failure occurs, consequential damage and risk to users well-being is minimised. Preventive maintenance is performed at regular intervals, and can be scheduled at a time which is convenient for building users. However, preventive maintenance involves a large number of unnecessary tasks since all building components are inspected even if they are in a good operating condition. This strategy is therefore very demanding in terms of labour and spare parts.

Predictive maintenance (or condition-based maintenance) consists of continuously monitoring, testing and inspecting the building's systems in order to forecast component degradations and perform planned maintenance prior to equipment failure. Maintenance is performed when a change in condition and/or performance of an item is detected. The planning of maintenance tasks is based on detailed monitoring of building envelopes (walls, roofs, floors) and building systems (HVAC systems, lighting, plumbing systems, etc.). Monitoring helps identify which components require maintenance before they fail, based on the condition or the performance of the items. Predictive maintenance and monitoring play an increasing role in building maintenance management.

Preventive and predictive maintenance are proactive strategies, which offer many environmental benefits such as:

- The extension of building equipment and material lifetimes
- The reduction of solid and hazardous waste generation
- The continuous energy-efficient operation of systems
- The avoidance of negative effects on occupant health by preventing disruptive failures (e.g. of HVAC systems since they are a determinant of air quality).

Preventive and predictive maintenance are therefore the best maintenance strategies with respect to overall environmental performance. Therefore, the challenge for facility managers is to define the best strategy for each part of the building and to plan maintenance activities efficiently. This implies the implementation of an appropriate operating and maintenance plan.

References

CRTE, 2009. Centre de Ressources des Technologies pour l'Environnement. Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

Horner, R.M., El-Haram, M.A., Munns, A., 1997. Building maintenance strategy: a new management approach, International Journal of Quality in Maintenance, Vol. 3 No.4.

Maintenance planning. To enable the realisation of optimal efficiency and continuous improvement, maintenance and repair activities must be planned, documented and monitored. This requires the implementation of an appropriate operating and maintenance plan (O&M plan).

For efficient building operation and maintenance, the planning and monitoring of maintenance activities is crucial. As soon as a building enters its utilisation phase, planning is established in relation to small, medium or large maintenance interventions required in the future. This planning is based on the experience and knowledge of facilities' individual durability and maintenance requirements.

The O&M Plan should contain a schedule of all preventive and predictive maintenance activities for all building equipment (lighting, HVAC equipment, plumbing systems). Preventive maintenance activities such as plumbing, carpentry, painting, and renovation, have to be scheduled at regular intervals, preferably during unoccupied periods to avoid disturbing users. Regarding maintenance planning, the HQE Association requires the establishment of a preventative maintenance and care plan during the design stage of energy efficient buildings, to help building owners or facility managers to maintain building operation and detect or predict equipment wear. This plan should include a list of all interventions to be performed at specified frequencies, and must ensure compliance with criteria regarding health and safety (e.g. fire safety).

O&M planning is based on the continuous monitoring of building equipment performance. In association with alarm signals, monitoring enables the early detection of defects or failures and helps to plan predictive or preventive maintenance activities in order to repair defective components before system failure arises.

Checking building operating efficiency also implies redefining maintenance to include operating activities. For this purpose, additional controlling procedures are undertaken to check operating efficiency instead of only focusing on maintenance. In order to check the building energy-performance, the O&M plan integrates procedures to continuously verify indoor environmental quality (IEQ), energy efficiency and water efficiency. This includes actions such as:

- Review of HVAC and lighting schedules, temperature set points
- Diagnosis of user/tenant requirements to perform demand-oriented management and ensure that equipment runs only when needed.

The O&M plan must be adaptable to changing user needs and allow the modification of HVAC, lighting, electrical, telecommunications, safety, housekeeping, and building automation control systems. Like maintenance tasks, controlling strategies should be reviewed and adjusted seasonally, depending on whether it is the cooling or heating season.

Maintenance management is based on documentation of maintenance activities and equipment. The documents included are e.g. operating manuals and specifications for all equipment, the history of all maintenance actions, monitoring information on all building systems, preventive maintenance charts for each piece of equipment. The monitoring of maintenance interventions allows the identification of successful interventions and assessment of all actions undertaken. Maintenance monitoring is an integral component of effective preventive maintenance. Maintenance actions and equipment deterioration are monitored in order to identify future needs for maintenance, replacement or repair of worn parts before they cause system failure. This contributes to reinforce the knowledge on building maintenance, which can be useful for future interventions. Maintenance planning also requires regular training of maintenance and facilities management staff in order to correctly perform and document maintenance activities.

Besides maintenance and repair activities, O&M planning should also include procedures and recommendations regarding waste management and cleaning activities.

6.4.3 Operations monitoring

Monitoring building resource consumption. The monitoring of the building resource consumption (water, energy) helps to avoid uncontrolled consumption of resources and reduce the rate of resource depletion.

Different metering systems may be installed to monitor building consumption of water and energy. Traditionally, each type of energy is measured by a specific meter, differentiating: electricity; heat sources such as gas, oil, district heating; energy for cooling such as district cooling. More sophisticated metering systems allow sub-metering by substantial uses such as cooling, lighting, water heating, space heating, ventilation, etc. by systems (meter 1, meter 2, etc.), or by area (electricity 1st floor, electricity 2nd floor, etc.). Advanced metering systems even allow two levels of sub-metering, allowing the specific monitoring of energy consumption per area and/or use and/or system. For example, the sub-meter ‘electricity R offices area’ could be subdivided according to the area (meter 1st floor, meter 2nd floor, meter 3rd floor, etc.) or according to the function (meter lighting, meter ventilation, meter computers, etc.).

Monitoring of the building environmental performance. Monitoring the environmental performance, when applied to detect improvement options and reduce operation costs, is considered as a best practice. During the operational phase, it is particularly important to monitor the consumption of resources (energy, water) and operating costs, in order to allow the ecological assessment of the building.

All production systems of the building must comply with regulations regarding the programming of comfort parameters (temperatures, air flow rates, etc.) and the operating periods of different equipment. More advanced systems allow the monitoring and control of comfort parameters for each sector (or even for each room) of the building by optimising the operation of building systems according to occupation of each area. This optimisation can be implemented for the following systems:

- Heating / cooling (via temperature monitoring and control)
- Ventilation (via flow rate monitoring and control and optimisation of ventilator operating time)
- Lighting (via lighting systems monitoring and control).

When monitoring and controlling building systems, the objective is to enable the optimisation of systems during the building operating phase and the detection of component failure. Monitoring enables the detection of failures and activates alarm notification for all systems in case of any defect or major deviations in the consumption. Automatic alarm notification is possible via a BMS (Building Management System) or EMS (Energy Management System). Another possibility offered by monitoring is the detection of leaks for water systems (see section 6.5.2.2). Advanced systems also allow the adjustment of HVAC systems, the monitoring of equipment operation (visualisation, overview), or the management/optimisation of energy supply contracts.

- Heating and cooling systems, for example:
  - Control several parameters (temperature, occupancy, etc).
  - Include filter pressure drop indicators (prevention of plugging in case of air filtration).

  - Monitor and control hygrometry.
  - Enable users to adjust room conditions (thermostats, timing systems, etc.).
- Ventilation systems, for example:
  - Include filter pressure drop indicators (prevention of plugging in case of air filtration).
  - Include measuring systems for air velocity, ventilation operating mode, air quality (CO_2 sensors, etc.).
  - Include ventilation flow management (to adjust the extraction volume in accordance with real-time requirements related to humidity and temperature).
  - Control for several parameters (occupancy and hygrometry, ventilator controlled by heating systems, etc.).
- Lighting systems, for example:
  - Manage light grade depending on desired ambiance.
  - Include optional measurement of lighting.
  - Manage solar protection according to interior lighting.
  - Control for several parameters (brightness, occupation, etc.).
  - Include lighting control from any location.
  - Include automatic grading systems controlled by brightness.
- Water management systems, for example:
  - For temperature control of the whole hot water circulation network: include a system for surveillance and automatic management of the cold water network coupled with a system for repatriation and treatment of data.

6.5 Best environmental management practice for building operation and maintenance

6.5.1 Practices related to building design

6.5.1.1 Simulation based building design

Description

Building design is increasingly based on dynamic simulations of buildings and their facilities. With consideration of dynamic conditions such as wind, temperature, radiation, operating and use conditions, it is possible to use models to study and to optimise different construction measures with respect to energy demand and user comfort. Energy simulation systems usually consist of software systems with modular structures that allow the detailed modelling of specific energy efficiency solutions at different implementation levels (household, building, neighbourhood, and district). During the design stage of a construction project, these energy simulation systems can be used by architects and designers to evaluate the different design choices taking energy efficiency criteria into account in the design process.

Although this practice addresses the design phase, simulation of indoor conditions and user behaviour is highly important. Simulation models may also be used to determine improvement options during operation, maintenance, reparations or refurbishment, as well as to determine retrofitting requirements in relation to future standards. Best environmental management practice for building simulation models incorporates all of the above.

Through the analysis of different building configurations, different occupancy scenarios and thermal behaviour under dynamic conditions, energy simulation systems can help take into account energy efficiency during building operation at an early design stage and help to reduce considerably the energy needs of the planned building.

Achieved environmental benefit

This is an overarching practice, dealing with other environmentally friendly techniques, already described in Section 3.

Appropriate environmental indicators

The use of simulation based design is a practice which can have an impact on all the indicators developed to control the environmental performance of a building life cycle, especially those explained in the design section.

Cross-media effects

No cross-media effect is observed. Nevertheless, building simulation can be used to control and monitor potential cross-media effects that may arise from implementation of other techniques.

Operational data

Energy simulation systems contain simulation software which allows users to create and visualise a 3D model of the planned building (or alternatively residential area, household, etc.). A first simulation evaluates quite precisely the future heating and hot water needs of the building, given the current insulation level, materials used, type and position of the external openings for each building. Based on this evaluation, different design choices are tested in order to reduce the building's energy needs, such as increasing the insulation thickness of the walls, changing the type of glazing, applying technical corrections to the major thermal bridges, considering different ventilation and heating strategies, etc.

As an example, for the renovation of an office building, ALLP Renovation used the advanced energy simulation software TRNSys during the definition stage of the project. Using advanced energy simulation, the engineering team evaluated and chose the best solutions in terms of HVAC systems, lighting equipment, control strategies for a heat pump and a gas boiler, and blinds. This method enabled a reduction of the annual consumption of the building from about 250 kWh/m²yr to 60 kWh/m²yr.

Applicability

No special restriction is observed on the applicability of simulation based design.

Economics

Significant energy savings can be achieved through optimal energy consumption, simulation, optimisation and configuration of new buildings and refurbished existing buildings. Simulation based design helps architects and building owners calculate exactly how much energy may be saved by implementing particular energy efficiency solutions, and enables full comparison of different design choices in terms of energy efficiency and costs.

Driving force for implementation

The main driving forces are legal requirements concerning the energy efficiency of buildings, better economical performance, and better preparaedness for increased energy tariffs and more restrictive legal requirements for environmental performance. In addition, improved reputation through better design performance and a reduction of greenhouse gas emissions is an important driving force.

Reference organisations

Detailed information can be found on the download webpage of REEB for the following case studies:

- Cenifer Centre. ICT-s and architectonical solutions applied to renovation
- TRNSYS-powered positive energy building design
- EnergyPlus energy simulation software.

6.5.2 Practices related to building management systems

Best available techniques regarding building operation and maintenance are often based on Information and Communication Technologies (ICT): they imply the use of computing equipment and software, internet, telecom or GPS technologies.

ICT equipment includes end user devices such as computers & peripherals, digital data recorder-storage-player devices, modems, phones and multimedia mobiles, fax machines, set top boxes and TV & peripherals. ICT infrastructure covers hardware equipment and software elements such as server and data centres, wired core telecom networks, cellular phone networks, Wireless Local Area Networks, Radio/TV broadcast equipment and micro systems.

ICT is closely linked to the concept of an Intelligent Building, i.e. 'one that incorporates the best available concepts, materials, systems and technologies integrating these to achieve a building which meets or exceeds the performance requirements of the building stakeholders, which include the owners, managers and users, as well as the local and global community'([29]).

6.5.2.1 Building management systems

Description

Building management systems (BMS), also called 'building automation systems' (BAS) or energy management systems (EnMS) are the central tools of an intelligent building. BMS are central computerised systems for managing and operating various equipment within a building. They aim to optimise the operational phase of a building, through the monitoring and control of building mechanical and electrical systems. Energy optimisation is one of the main functions of a BMS, with the objective to achieve an optimal level of control of occupant comfort while minimising energy and resource consumption.

In an 'intelligent building', the BMS can be compared to the nerve system of the building since it registers all information and reacts to it. The main functions of BMS are computer-based monitoring and control, as well as building automation.

The monitoring function of a BMS allows it to collect, handle and analyse user data, and alarms the building manager in case of failure or disturbance. In new buildings where energy efficient technologies have been implemented, for example, the BMS helps to verify if building users are using the facilities in an efficient way. The energy monitoring function of a BMS has many advantageous functions for the building tenants/facilities managers:

- Provides a rapid overview of the consumption of water, electricity, heat and gas
- Identifies problem areas and sources of error
- Supplies comparative data for consultation by the energy manager
- Optimises proposals for the operation and use of the building
- Determines the cost-effectiveness of planned measures by simulating the targeted situation.

A BMS also usually includes automation functionalities, such as control of heating, cooling, ventilation, lighting, energy production and storage, maintenance management, security, access and fire systems. A basic example of an energy efficiency solution based on building automation is lighting based on occupancy.

A BMS can provide different levels of control, from the basic sensor-activated light control and programmable thermostats to the more advanced models of BMS which control all equipment in the building (pumps, fans, valves, dampers, compressors, lighting etc.).

([29]) European Intelligent Building Group.

Fundamental control systems include technical functions such as:

- The control of HVAC and lighting systems based on occupancy sensors
- The scheduling of HVAC and lighting systems per zone
- The scheduling of HVAC and lighting systems according to presence hours, seasons, calendar, etc.
- The controlling and resetting of temperatures.

Advanced BMS cover much more complex control functions:

- Control of lighting schedules of outdoor facilities (parking lots, signs, etc) depending on sunrise and sunset throughout the year
- Lighting control based on daylight levels detected by photocells
- Control of HVAC systems depending on outside air and inside temperatures
- Regulation of ventilation according to CO_2 levels or humidity in rooms
- Optimum start/stop: definition of the optimal time to gradually start up or shut down HVAC systems before occupants arrive or after they leave
- Load shedding of HVAC systems: monitoring and control of electrical demand to avoid peak utility charges
- Optimisation of chilled water loop temperatures
- Optimisation of cooling tower temperatures
- Optimisation of hot water system temperatures based on outside air temperature, decreasing heat losses in supply piping as well as localised heating due to excessively hot pipes
- Control of building energy production and storage systems (photovoltaic panels, combined heat and power generators, batteries, etc.)
- Remote data access: possibility to retrieve real-time data from the internet (e.g. weather forecasts) for monitoring, control, facility management or analysis.

Within a BMS, all facilities are optimised as a whole (such as heating and indoor air systems, sanitary facilities, electronic devices, information systems, security and supply systems). As a result, the different systems work together with each other and with the building technology.

BMS also have different levels of integration between the systems they control. State-of-the-art BMS enable superior integration between systems, including information technology (IT), sophisticated security systems, and ongoing energy cost savings. In an office building, integrated BMS not only deal with energy management but also integrate video surveillance and alarm systems, access control, audio-visual and entertainment systems, staff time and attendance control and reporting. Environmental systems are able to communicate with security and emergency systems, e.g. through emergency-response procedures (automatic shut-down based on preset specifications).

Integrated BMS are an advanced solution for total facilities management, and integrate all functions of building facilities management with one common user interface (see Figure 6.1). They combine facilities management and IT through a common IP network, avoiding the duplication of multiple networks and operating environments. These systems allow centralised monitoring and synchronisation with environmental, emergency, and security systems, enabling facilities managers to monitor and control the whole building from a single interface, either on-site or remotely over the Internet.

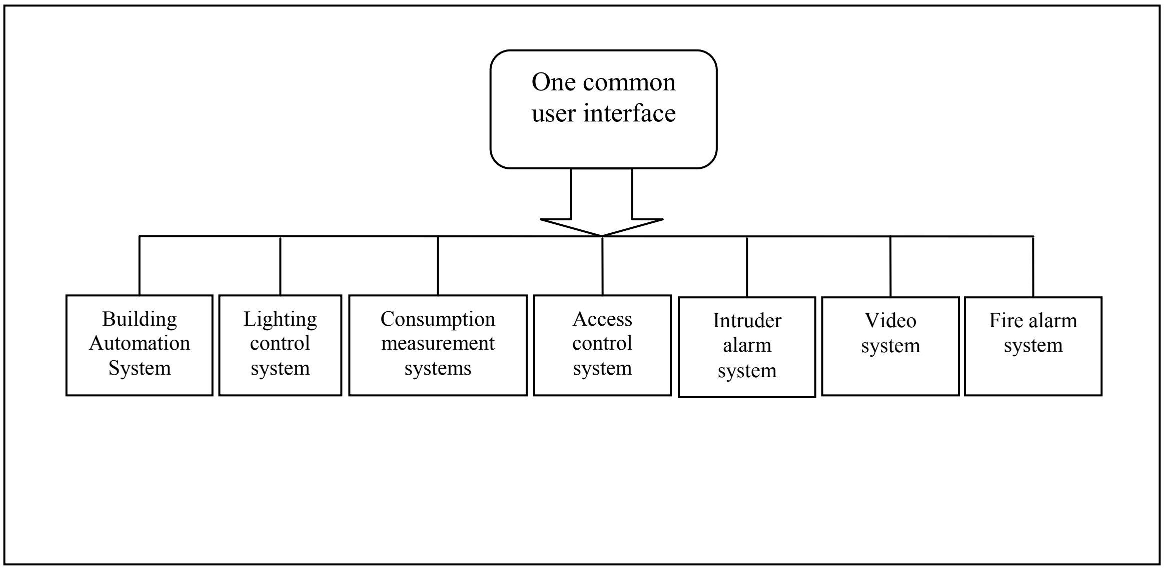

Figure 6.1: Integrated building management system

Home automation systems

Home automation systems, also called domotics or smart homes, are a type of building automation system designed for use in residential dwellings and households. Like BMS, they are centralised computerised systems enabling the management of building equipment, but they are less complex than BMS and offer a more basic level of control, usually involving the automation of household appliances. The core feature of home automation is the full integration of lighting and heating/cooling control systems. However home automation systems generally integrate all electrical devices within a household with each other. The users of these systems are the building occupants and homeowners, therefore home automation systems focus on user friendliness. The main functionalities of home automation systems include:

- Control of HVAC systems to optimise temperature and humidity control (remotely controlled thermostat through the internet)
- Control of household electric lights
- Natural lighting (control of window shades, LCD shades, blinds, etc.)
- Audio and video systems
- Communications systems
- Security systems, etc.

Achieved environmental benefits

Energy efficiency is one of the primary objectives and can be achieved through energy optimisation of the building and all its technical facilities. Through the identification of problem areas and sources of error, BMS allow considerable energy savings as well as increased levels of comfort within the living environment. By optimising comfort for users, BMS have positive effects on user comfort and health. In office buildings, improving worker health can contribute to raising productivity in office building.

Environmental indicators

The specific energy consumption, expressed as energy consumption per square metre and year (e.g. kWh/m^{2}yr), as described in Chapter 3, seems to be a useful indicator to evaluate the benefits from the implementation of a building management system.

Cross-media effects

BMS are the most advanced solutions in terms of energy management. When a BMS is installed in the building, techniques like centralised control or ventilation have to be integrated in the BMS (via smart circuit breakers) and do not need to be implemented separately.

Operational data

In practice, the BMS can be connected to building mechanical and electrical systems such as fans, pumps, mixing boxes, thermostats. Some integrated subsystems of a BMS are:

- HVAC systems
- Lighting systems
- Fire protection systems
- Elevators
- Security systems
- Communication systems.

The architecture of the BMS is made of the following major components:

1. A data collection system for data gathering and dissemination. This consists of a variety of sensors installed throughout the building. These sensors can either be wired or wireless, and track various data such as occupancy, movement, light, internal solar radiations, indoor/outdoor humidity, temperature, pressure, flow rate, power or even air quality, lighting level and fire or smoke.

2. A direct digital control system for the data collection, administration and evaluation, and system control, which includes two major hardware components:

- Controllers, which confront the raw data received from the sensors with a desired value, deduce the required controlling action and send the controlled device the relevant signal.
- Controlled devices, or terminal devices, which respond to the signal for action. Typically, these devices can be air dampers, mixing boxes, control valves, or fans, pumps or motors.

3. A user interface for the data analysis, which can contain different software modules for energy management and maintenance, and planning software to simulate, calculate and optimise the energy consumption of planned construction measures. A basic example of a user interface is the illustration of different energy efficiency classes in the form of traffic lights on the operative's screen.

Home automation systems have a similar architecture, with main elements comprising hardware controllers or software controllers, sensors and actuators. The system can either be centralised with one controller receiving information from all sensors and controlling all actuators, or distributed with distributed intelligent modules connected to all sensors and actuators. Mixed architecture is also possible with decentralisation of small controlling devices.

Applicability

BMS can be used in office and institutional buildings as well as large residential buildings. Home automation systems can be installed in residential dwellings and households.

Whether in homes or larger buildings, the implementation of a BAS requires the installation of external sensor systems. They are mostly integrated during the design process, but it is also possible to integrate BMS into existing buildings, even though this requires the installation of an additional infrastructure for data collection (sensor systems), which is more expensive. Moreover, when installed in existing buildings, the optimisation of the energy systems cannot begin during the planning phase, but during the inventory and audit phase. Integrated BMS solutions are designed for larger office buildings within the framework of total facilities management. Some advanced control applications can be added to the BMS through software modifications or updates, without the need for additional sensor installation. BMS require the implementation of technical provisions that enable the communication between different technical components and functions, including a multitude of products from different manufacturers.

Economics

For a BMS with fundamental control, the data collection devices are usually inexpensive, and despite difficult-to-estimate installation costs, BMS have relatively short amortisation periods. Simple BMS can enable considerable energy savings. Depending on the building, on the chosen configuration, level of control and integration of the BMS, the implementation of a BMS in a building can lead to energy savings of between 10 **%** and 40 %, in addition to maintenance cost savings of between 10 % and 30 %. The most challenging task for maintenance is the calibration of sensors, which requires a concrete maintenance programme. Even though they are difficult to detect through a simple maintenance inspection, calibration errors can induce massive energy waste, since all parameters are based on the data measured by the sensors. All EnMS rely on sensors for proper feedback to adjust to efficient conditions. Therefore calibration activities play a key role in EnMS maintenance. Integrated BMS are designed to be flexible and can support additions and changes to commercial office layouts or usage patterns through software update and without additional investment in the system. The same network architecture may be used for all systems (BMS, security and fire alarm systems), reducing installation costs. Integrated BMS have a lifetime of over 30 years and allow a reduction in building operating costs of up to 35 % annually. Additional cost-savings can be realised through increased employee productivity.

Driving force for implementation

Reduction of energy demand and the reduction of building and infrastructural costs through the optimisation of all operational functions are the main drivers for the implementation of BMS. Environmental performance is also improved through better integration of energy using services and comfort and time savings for the users.

Reference organisations

Some examples of BMS suppliers are :

- Ennovatis GmbH (http://www.ennovatis.de)
- Ecovert (http://www.ecovertfm.co.uk)
- Siemens Building technologies (http://www.buildingtechnologies.siemens.com)
- Advantech (http://www.advantech.com)
- Intelligent building group (http://www.ibgroup.org.uk)

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6.5.2.2 Water monitoring, maintenance and management optimisation

Description

Leaking water pipes and appliances can increase water consumption considerably, and in the process incur significant costs. A leaking toilet can waste up to 750 litres of water per day (ITP, 2008), compared with 30 litres per day required for five full flushes of a low-flush toilet.

Commercial buildings managed by companies usually are able to control water wasted through leakage thorugh an effective monitoring and maintenance programme that involves the following.

- Daily checks and reporting procedure by housekeeping staff to detect obvious leaks, such as leaking taps or toilets.
- Detailed periodic inspections to detect hidden leaks, including inspection of pipe joints, appliances, and heat-exchanger units. On large premises, technicians may perform detailed testing that may include use of leak-detection cables and portable clamp-on flow-meters.

Monitoring and benchmarking of water consumption is the first step to improve water use efficiency. Monitoring of water use can be performed at varying levels of detail depending on resources available and the size of premises. For commercial buildings, annual or monthly water consumption may be recorded and compared with similar periods of recent years in order to evaluate improvement potential and establish benchmarks. . An audit of water-using equipment in all areas can be used to identify possible measures to reduce consumption – for example through targeted implementation of the techniques described in section 3.4.6. For larger buildings, sub-metering of different areas is likely required in order to monitor, evaluate and benchmark water consuming processes (kitchens, swimming pools, cooling towers, heating circuit, domestic hot water preparation, etc.). Sub-meters may be connected to a central automatic recording system, or Bullding Management System (BMS), that continuously records consumption and provides detailed data on water use patterns throughout the premises (section 6.5.2.1)

Residential buildings managers may have less management resources for controlling, monitoring and benchmarking, as it would depend on many user behavioural issues. In this document, influencing user behaviour best practices are not covered.

Domestic hot water (DHW) heating accounts for a significant portion of energy used, especially for buildings with intensive use of hot water (residential, sports halls, schools, etc.). Effective system monitoring and implementation of identified water reduction measures can significantly reduce energy use for water heating. Further, monitoring can be used to accurately control water heating so that hot water production matches demand, in terms of quantity, timing and temperature. DHW is often heated to more than 80 ºC on accommodation premises, compared with a requirement of only around 45 ºC to supply most needs (Lamei, 2009) – although at least periodic heating to 60 ºC may be required to minimise the risk of legionnella bacteria colonising the system. Effective pipe insulation reduces water consumption by: (i) reducing the time required for hot water to arrive at opened faucets; (ii) by reducing heat loss from hot water moving through the pipes. These two factors enable less water to be heated to a lower temperature, thus significantly reducing water consumption and considerably reducing energy consumption.

In Table 6.1, measures for the maintenance and control of water systems in buildings are summarised.

Table 6.1: Monitoring and control of water supply systems in buildings.

Measure	Description	Applicability
Water audit and benchmarking	Assess water use on a seasonal basis and draw up inventory of main water using equipment. Calculate water performance, e.g. in litres per person per day. Identify priority measures to reduce water consumption.	Commercial, non-residential, buildings
Periodic monitoring	Record water consumption periodically (daily, weakly, monthly), and check consumption during quiet times (e.g. early hours of the morning) to detect leaks.	Commercial buildings. Multi-family buildings with the help of public administration
Sub-metering	Divide premises into zones, install sub-meters and periodically monitor water consumption.	Large commercial, non-residential, buildings
Continuous monitoring	Install complete continuous monitoring system, with automatic recording of flow at all sub-meter locations.	Large commercial, non-residential, buildings
System inspection and maintenance	Regularly inspect equipment. Housekeeping inspection of taps, toilets and drain plugs. Technician inspection of valves, pipes, pipe-insulation, aerators, and equipment such as heat-exchangers. Repair or replace damaged equipment.	Large commercial, non-residential, buildings
Avoid excessive pressure	Install pressure reducers at relevant points and adjust to the minimum pressure sufficient to supply the maximum flow rate required at those points.	All buildings
Water conditioning	Install an electronic water conditioning system to 'soften' hard water by removing excess calcium and magnesium ions.	All buildings
Adequate insulation	Make sure that all water pipes are adequately insulated to minimise heat transfer heating and cooling energy requirements.	Commercial, non-residential buildings

Achieved environmental benefit

Leak avoidance

Even small individual leaks with barely perceptible flow rates can result in significant water wastage over a year. Modest leaks that may be undetectable in large buildings, but they can result in hundreds of m^3 of water per year (Table 6.2). A number of small leaks can contribute substantially to total water consumption, and easily result in cumulative wastage of thousands of m^3 per year in larger buildings. Analysis of data from a water monitoring study of eight rooms in one hotel led to the discovery of a leaking cistern in one room losing 380 litres per day that had gone undetected for at least the 90 days of the study. Consequently, the avoidance of leaks through monitoring, inspection and maintenance can reduce water consumption dramatically.

Table 6.2: Water flow rates and daily/annual wastage from different types of leak

Leak description	Flow rate		Daily water loss	Annual water loss	Annual cost
	L/min	L/hour	L	m^3	EUR
One drip per second	0.003	0.17	4	1.5	2.92
Drips break to stream	0.063	3.8	90	33	65.70
1.5 mm diam. stream	0.22	13.3	320	117	232.36
3 mm diam. stream	0.68	41	985	360	719.06
6 mm diam. stream	2.43	146	3500	1 278	2 555.00

Source: Derived from data in Cridge (2000).

Water management plans

Monitoring and reporting of water consumption is an integral component of water management plans with defined targets that can achieve substantial reductions in water consumption over time. Sector specific approaches are needed, as there could be very different needs from one sector to the rest, e.g. management of swimming pools, sports centre, etc. One of the best examples is the establishment of water management plans in large hotel chains (EC, 2012)For example, Accor have set a target to reduce water consumption by 10 % per occupied room between 2006 and 2010 in owned and leased hotels (Accor, 2011). Meanwhile, Scandic have been monitoring specific water consumption across hotels since 1996, and can consequently report that average water consumption per guest-night decreased by 25 % between 1996 and 2010.

Energy savings

For every m^3 reduction in hot water consumption, approximately 52 kWh of energy is saved, assuming water is heated by 45 ºC. Meanwhile, 20 mm of insulation can reduce heat loss by almost 400 kWh per year for every metre of large diameter (5 cm) piping .

Appropriate environmental indicator

Water performance indicators should be able to establish trends and establish benchmarks on the use of water and on the control of water management, maintenance and optimisation best practices. However, different types of buildings lead to different behavioural aspects, which are, definitely, influencing the kind of indicator to be used. Table 6.3 shows some examples of usable indicators per type of building.

Table 6.3: Usable water performance indicators per type of building.

Building type	Unit
Residential	L / person per day
Offices	L / person per day L per m^2 per year
Hotels	L/guest night
Hospitals	m^3/m^2yr
Museum	L/m^2yr L / visitor per day
Library	L/m^2yr
Industrial	L/ position day
Airports	L / passenger day

No benchmark for water use will be established in this document. As mentioned, it should be assessed in a sectoral approach, including different typologies of building users.

In addition to the above performance indicators, management indicators of best practice may include:

- regular monitoring and recording of consumption;

- installation of water sub-metering for major water-using areas and processes, which can be considered, as well, as a benchmark of excellence;
- establishment of an action plan to reduce water use, with measurable and scheduled; targets;
- all pipes carrying heated or chilled water are insulated;
- regular inspections are carried out to check for leaks, also to be considered as a benchmark of excellence.
- staff training to reduce water use.

Cross-media effects

There are no significant cross-media effects associated with this technique. Reducing water consumption leads to a reduction in the quantities of chemicals and energy required to treat and pump water. Reducing hot water consumption leads to a considerable reduction in energy use for water heating.

Operational data

Monitoring and leak detection

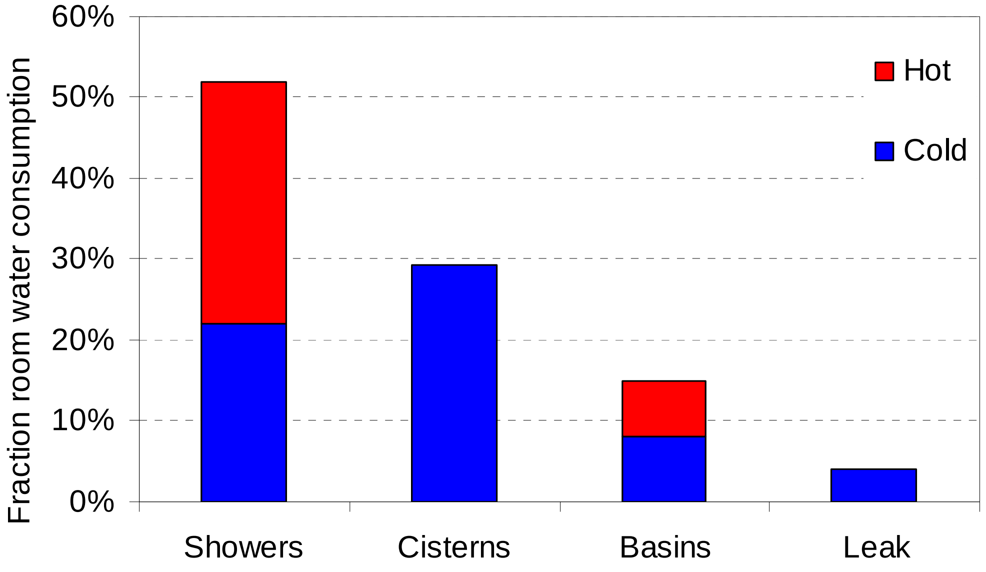
Managers in all types of buildings may perform a basic audit of water using equipment to compare with water consumption data in order to draft a water balance. For the water inflow, annual water consumption can be taken from water bills (actual rather than estimated readings should be used). Flow rates from taps and showers can be easily measured according to the following procedure: (i) turn on the tap or shower to full flow; (ii) place a container of known volume (e.g. 5 litres) under the flow; (iii) time how many seconds it takes to fill the container to the indicated volume mark; (iv) calculate the flow rate dividing the volume of the container by the time (in seconds or minutes).

This process can be performed for the different types of fittings throughout the premises and can be multiplied up by the number of such fittings and estimated use rates (average frequencies and durations of use). Water consumption for processes occurring in large equipment such as washing machines and dishwashers can be estimated from technical information and estimates of usage rates. The information obtained from this procedure can be tabulated or inserted into a flow-chart, and compared with best practice water consumption for different fittings and processes in order to identify priority measures to reduce consumption. For small buildings, inspections may be performed by residents (in case of residential buildings) or should be in charge of management staff (for commercial buildings). Leaking toilets (e.g. flapper valves) are common but difficult to detect. Food colouring may be added to the cistern water to identify slow leaks into the toilet bowl. Water meters can also be checked late at night (~00:00) and early in the morning (~05:00) to identify unexpected water consumption during low water use periods that may indicate leakage.

For large buildings and to detect leaks, sub-metering is required. Inexpensive mechanical water meters can be fitted at fixed positions within the distribution system and require periodic replacement. Ultrasonic meters are relatively expensive, but may be clamped on to the outside of pipes and moved to different positions in order to audit consumption in different zones or to check for leaks. Flow meters should be installed or clamped at the inflow points to different zones and preferably attached to electronic recorders in order to provide information on daily patterns of water consumption that help to isolate the effect of different processes or leaks.

Records of water consumption should be analysed monthly to identify any irregular patterns. In addition, priority zones should be installed. Priority sections may vary for different types of buildings. Uusally, kitchens, laundries, toilets, public showers and swimming pools should be monitored separately. For buildings using water as main heating or cooling fluid, special checks to avoid leaks should also be performed..

As an example of the results for large premises, Figure 6.2 presents results of an intensive sub-metering study of eight guest rooms in one hotel performed by engineers from the Polytechnic University of Valencia, in Spain (EC, 2012). Ultrasonic meters were clamped to all feeder pipes in the eight bathrooms in order to monitor hot and cold water consumption across all fittings. Data were logged automatically, providing insight into the frequency, duration and intensity of water consumption across different fittings, and demonstrating water savings achievable from the installation of low-flow fittings.



NB: Aerators fitted to showers and basin taps.
Source: EC, 2012

Figure 6.2: Breakdown of water consumption across eight rooms in a hotel obtained from a study employing sub-metering of flow rates through pipes to individual fittings

Automatic leak detection systems based on detector cables, or 'water fuses' that cut-off water when unexpected flows occur, may also be installed alongside water piping during construction or extensive renovation of large premises. Water fuses can detect low continuous flows down to two litres per hour (Environment Agency, 2007).

Other measures that can improve overall system efficiency and reduce leaks are explained under section 3.4.6.

Applicability

Monitoring and maintenance is applicable as a best practice technique for all types and sizes of buildings. In small organisations (SMEs), monitoring may simply involve recording total water consumption at (at least) monthly intervals based on meter readings.

Economics

A mechanical flow meter costs in the region of EUR 300[30] whilst a portable ultrasonic flow meter can cost approximately EUR 2000[31], whilst flow monitors cost approximately EUR 400[30]. These investments may be recouped within a few years where monitoring helps to reduce excessive water consumption and avoid leaks.

At a water supply and disposal price of EUR 2.50 per m^3, a single leaking toilet wasting 750 litres per day could cost over EUR 684 per year.

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[30] http://www.kimray.com/LinkClick.aspx?fileticket=qOCSQItnW7U %3D&tabid=192&mid=749

[31] http://www.globalw.com/catalog.html

Cost savings from reductions in hot water consumption are considerably higher for buildings with a high demand of hot water: hotels, sports halls, etc. The cost of water use, and value of water savings, can be calculated from the following equation (elaborated in Table 6.4) :

$$C_T = V_T \text{ x } (C_S + C_D) + V_H \text{ x } (\Delta T \text{ x } SC_W \text{ x } (1/E_{EN}) \text{ x } C_{EN})$$

Table 6.4: Elaboration of terms in the water cost equation

Term	Abbrev	Unit	Typical values
Total cost	C_T	EUR	
Total volume consumed	V_T	m^3	
Supply cost	C_S	EUR/m^3	EUR 2 – 4 (EU average EUR 2) combined supply and disposal cost (EC, 2009)
Disposal cost	C_D	EUR/m^3	
Volume heated	V_H	m^3	
Heating temperature increase	ΔT	ºC	30-80 ºC
Specific heat capacity water	SC_W	$kWh/m^3/ºC$	1.16
Heating efficiency	E_{EN}	Fraction	0.85 (oil boiler) to 0.99 (electric heater)
Cost of energy	C_{EN}	EUR/kWh	EUR 0.06/kWh for gas up to EUR 0.22/kWh for electricity (Energy.EU, 2011)

Driving force for implementation

The main driving force for implementation of monitoring and maintenance is to identify water use efficiency options and to detect and prevent leaks, thereby reducing costs associated with excessive water consumption and wastage, and reducing costs associated with water heating (see 'economics' section). In addition, it is becoming common for many organisations to report their specific consumption in annual sustainability reports, which requires monitoring.

National, regional or local governments may provide incentives in the form of subsidies or tax breaks to encourage installation of water efficient fittings. For example, in the UK, the Enhanced Capital Allowance scheme allows business to deduct the capital cost of water-saving equipment from taxable profit in the year of purchase (http://etl.decc.gov.uk/). Equipment covered by the scheme relevant to this technique includes:

- flow controllers
- meters
- leakage detection
- pipe work insulation.

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6.5.3 Practices related to cleaning services

6.5.3.1 Self-cleaning coating

Description
A self-cleaning coating is a new technology for the design of facades, roofs or windows, using a special coating film, which is applied to the surface during the manufacturing process. This reduces the need for cleaning and extends the lifetime of the façade by raising optical quality and scratch resistance.

Achieved environmental benefit
Self-cleaning coating avoids the consumption of water for cleaning, as well as the use of cleaning agents that can contain environmentally harmful chemicals.

Appropriate environmental indicators
Water consumption per day and per user, position or worker is an appropriate indicator for this technique. There is no proposed indicator for the avoidance of chemicals, although reduced consumption could be checked using records of the amount of cleaning agents purchased per year.

Cross-media effects
No data available.

Operational data
There are currently two different types of coatings on the market: hydrophobic coatings or hydrophilic coatings. Hydrophobic coatings are dirt- and water-repellent. They contain nanoparticles, which produce the so called 'Lotus Effect': they prevent water drops from drying on the glass pane and leaving stains. However, current hydrophobic coating techniques do not demonstrate enough hydrophobicity to provide a total self cleaning effect([32]). Hydrophilic coatings, on the contrary, are water attracting, making water drops spread out evenly across the surface of the glass and forming a thin sheet that washes away and dries off more quickly without leaving stains. Hydrophilic coatings are mechanically much more stable.

The best technique available regarding self-cleaning coatings is applying photocatalytic coating, a type of hydrophilic coating containing titanium dioxide (TiO_2) nanoparticles. These nanoparticles initiate photocatalysis, a process by which dirt is broken down by exposure to the sun's ultraviolet rays and washed away by rain. Volatile organic compounds are oxidised into carbon dioxide and water. Today's self-cleaning surfaces are made by applying a thin nanocoating film, and painting a nanocoating on, or integrating nanoparticles into the surface layer of a substrate material.

Applicability
Self-cleaning coatings are currently developed and commercialised by most major window manufacturers, as well as facade paintings manufacturers. Therefore, there is no applicability restriction.

Economics
By reducing water consumption for cleaning pruposes, as well as maintenance costs, self cleaning coatings can help achieve considerable savings.

As an example, photocatalytic coatings were used for the facade of the Jubilee Church in Rome. The panel system's manufacturer, Italcementi Group, even tested TiO_2 on road surfaces and found it reduced nitrogen oxide levels by up to 60 per cent. At present, their self-cleaning facade system costs 30 to 40 per cent more than regular concrete, but they believe that self-cleaning materials will save costs in the long term([33]).

([32]) Ivan P. Parkin and Robert G. Palgrave, Self-Cleaning Coatings, Journal of Materials Chemistry, 2005.
([33]) Nanotechnology for Green Building, Green Technology Forum, 2007.

Driving force for implementation

Self coating reduces costs through less maintenance and less water consumption. Water pollution is reduced, since no cleaning agents are used, which can also lead to a great advantage for the indoor environment.

Reference organisations

These are some examples of suppliers:

- Self-cleaning glass: Pilkington Activ self-cleaning glass (http://www.pilkington.com)
- Painting: Herbol Symbiotec by Akzo Nobel (http://www.herbol.de/)
- Hydrophobic Nano-Coatings for Glass (http://www.ferro.com)

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6.5.3.2 Green cleaning services

Description

Green cleaning services imply the use of cleaning agents containing no harmful substances on the one hand, and a reorganisation of cleaning management on the other hand.

Cleaning products used for general cleaning and maintenance of buildings cover: all-purpose cleaners, cleaners for plastic or metal surfaces, sanitary and toilet cleaners, restroom and bathroom cleaners, dishwashing detergents, laundry detergents, softeners, glass and alcohol cleaners, carpet cleaners, floor strippers and floor care products. Green cleaning services involve the use of green cleaning products, which do not contain substances or ingredients classified as hazardous by EC Directive 1999/45/EC and Council Directive 67/548/EEC. The European Commission recommends public procurers to purchase cleaning products meeting with ecological and packaging requirements for the EU Ecolabel([34]).

Different categories of cleaning product must comply with relevant EU Legislation, including:

- All purpose cleaners and cleaners for sanitary facilities (Commission Decision 2005/344/EC)
- Laundry detergents (Commission Decision 2003/200/EC)
- Hand dishwashing detergents (Commission Decision 2005/342/EC)
- Detergents for dishwashers (Commission Decision 2003/31/EC).

Cleaning products should be appropriately labelled according to the regulatory labelling of dangerous substances and preparations. Especially if cleaning products are transferred to other, mainly smaller containers or bottles, the label must be systematically reproduced on the new container.

Reorganisation of cleaning management: Beside the purchase of green products, it is possible to optimise the whole organisation of cleaning work, e.g. by making staff aware of instructions and dosage devices, in order to avoid using more cleaning product than necessary. The reorganisation of green cleaning services includes the following aspects:

- Appropriate dosage of products: Using cleaning agents in appropriate quantities can considerably reduce the quantity of product consumed and associated environmental impacts. Therefore, dosage instructions or suitable dosage recommendations for every cleaning agent used should be defined in a cleaning plan. These measures can be supported by monitoring the consumption of products.
- Use of modern cleaning techniques: Green cleaning management includes the use of modern cleaning techniques and methods, such as speed rotary floor machines, mopping systems and cleaning trolleys and fibre cloths – including microfibre cloths, synthetic fibre cloths or cellulose fibre cloths. These techniques facilitate the work of the cleaning staff, support ergonomic cleaning, increase productivity and can reduce the quantities of cleaning agents and water required.
- Demand oriented cleaning: Demand oriented cleaning aims at determining the best way to organise cleaning (frequencies and methods used) so that it matches user demand for cleanliness while reducing environmental impacts. This implies redefining user requirements for cleanliness: cleanliness standards for each room, the needs of the main users of the rooms, the frequency and type of cleaning desired.
- Training of cleaning staff: Satff training plays a central role in cleaning management. Cleaning staff are usually trained in aspects such as security, including extensive introductory training for new staff and periodic training (e.g. once a year) for permanent staff. Information on green cleaning can be added to the topics covered during training, e.g. regarding new techniques and alternative cleaning methods, new and environmentally

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([34]) http://ec.europa.eu/environment/ecolabel/index_en.htm sound cleaning products, use of cleaning products in an ecologically sound manner, ecological and health risks associated with active ingredients contained in detergents, dosage instructions and the use of dosage devices, awareness raising for the use of protective equipment. Instructions and information should be translated into appropriate foreign languages when foreign personnel are employed.

For the health of staff, cleaning should be performed with the appropriate protective equipment such as working clothes and gloves. Protective gloves and skin care products must be made available for staff and their use mandated.

Achieved environmental and health benefits

Green cleaning can have positive effects on the occupational health of the cleaning staff and the health of building occupants. Besides this, green cleaning can help to reduce water resources and reduce emissions of pollutants.

Appropriate environmental Indicators

Indicators based on consumption, such as water or energy consumption, may be suitable to control the implementation of this technique, but it is likely that the effect of green purchasing is diluted among other best practices implemented silmutaneously. Then, the consumption of ecolabelled (with third party verified labels, ISO type I) products can be considered as an indicator of best practice in green cleaning.

Cross-media effects

Cleaning activities contribute significantly to building water and energy consumption. Green cleaning can contribute to a reduction in energy and water consumption during the building operating phase.

Applicability

There are no limitations regarding green cleaning services, but in hygiene sensitive areas (e.g. hospitals, areas of food preparation) additional cleaning e.g. with anti-bacterial or antiviral cleaning products and techniques is necessary. When cleaning services are performed by an external company, any organisation can purchase these services from a company offering green cleaning services. Public organisations should insert green criteria into their public tender; guidance on this topic is available by the European Commission's website on green public procurement.

Economics

An important element of cleaning costs is the cost of labour (between 92 % and 97 % of the money spent on cleaning). Cleaning costs do not include the consumption of electricity and water, since the cleaning companies use the existing infrastructure. Nonetheless, these savings will be realised by building managers.

The use of cleaning agents takes on a special significance. Even though their environmental benefit can be significant, the cost difference for the purchase of green cleaning products is small in relation to cleaning budgets. The price premium for green cleaning products is generally small and depends on the market for green cleaning products in individual countries. In the Nordic countries where the market is developed, green cleaning products are cheaper than their non-green version(35). On the other hand, behavioural changes of the cleaning staff may result in a reduced need for cleaning products and consequent cost savings.

Driving force for implementation

Better environmental performance and better reputation through the application of best practice and the purchase of environmentally friendly products are driving forces.

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(35) European Commission study on the Costs & Benefits of GPP, 2007.

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7 BUILDING END-OF-LIFE

7.1 Scope

This building end-of-life chapter describes best environmental management practices for conventional demolition and selective deconstruction of buildings at the end of their life cycle. It is important to clarify that this section comprises best environmental management practices that follow the use phase of the building. Before building demolition or deconstruction, the reuse of buildings should always be a preference because it:

- avoids the construction of new buildings, and so the consumption of resources
- avoids the huge environmental impact, especially at local level, produced by a demolition project
- reduces risks due to hazardous materials handling, accidents, etc.
- often, old towers and other buildings are important habitats for protected species

Nevertheless, demolition may be a necessary requirement if the conditions of the existing building are far from optimal due to, for example, risk of collapse, the presence of dangerous substances for health, after fires or earthquakes, etc.

All the techniques described for construction sites in Chapter 5 are applicable to deconstruction or demolition sites, as the management is usually very similar and the environmental aspects are the same, although the impact magnitude is different. The main scope of the best practices described in this chapter is the minimisation of waste through selective deconstruction and demolition waste recycling measures. Waste management techniques, shown in Section 5.6.2.1, are applicable to demolition or deconstruction projects. In addition, for this kind of project, transport needs may be higher than for construction projects, so optimised planning of deconstruction waste routes, recycling and upgrading should be also considered in detail for demolition projects. Air emissions, noise and nuisance and soil contamination are also relevant for deconstruction sites, but best management practice is similar to techniques described in Section 5.6.2.7.

7.2 Introduction

Designers should consider all aspects related to waste generated during construction and deconstruction, with an aim to facilitate recyclability and the reuse of materials from the beginning of demolition or deconstruction projects (see chapter 3.4.7.2).

Deconstruction is the selective dismantlement of building components, intended to enable direct reuse and recycling, generally through mono-fractional separating of waste at source. Deconstruction focuses on giving the parts and materials within a building a new life by applying a ‘construction in reverse’ process. Conventional demolition in contrast aims at the efficient removal of a building without special regard to the reuse or recycling of materials.

The main products of demolition through conventional methods or through selective deconstruction are wastes to be treated, materials to be re-processed and a brownfield to be recovered as a green area or as a new building. Apart from these, other direct local impacts of deconstruction and demolition are quite important (Lippok and Korth, 2004):

- **Dust.** During most deconstruction/demolition activities, the creation of dust is an unavoidable local nuisance that can be harmful to health and can damage property. Dust emissions arise mainly from the break-up of mineral construction materials, and should be minimised by binding or aspiration. Dust suppression before demolition is mainly done by removing existing dust and by wetting, the latter is less efficient for reinforced-concrete buildings than for masonry buildings. Dust suppression during demolition is mainly done using water. The amount of water can be minimised by e.g. the creation of ultra-fine water droplets (high-pressure nozzles, air-assisted atomising). Worker protection laws define maximum dust concentrations at national levels; example values for Germany are 3 mg/m³ (exceptional level for certain construction and demolishing activities 6 mg/m³) (see section 5.6.2.5).

- **Splinters and debris.** Splinters, debris and dirtiness are created when breaking materials and are a problem for small areas around the demolition site. They can be a particular problem for high-rise buildings and nearby roads; in these cases, a fenced enclosure of the demolition is recommendable.
- **Noise.** Most demolition activities create high levels of noise. Several regulations concerning workplace safety and maximum noise generation must be respected. Noise can be reduced by the selection of appropriate demolition methods, acoustic shielding (mainly for permanent sources of noise), use of low-noise machines (for example certified by an ecolabel like the Blue Angel for low-noise devices) and organisational measures.
- **Vibrations** are created by explosions, machinery, falling construction parts and transferred though the ground to surrounding structures. They can mainly be reduced by avoiding particular demolition methods (explosives, jack hammers, demolition hammer).

Deconstruction is a real alternative to conventional demolition around the world. Whereas demolition of a building often leads to the mixing of all materials and contamination of non-hazardous components, deconstruction aims at separating materials at source. The separation of building materials for recycling can alternatively be achieved by sorting techniques at recycling facilities, but the most efficient way to produce mono-fractional material streams is the selective dismantling of buildings. Due to the fact that, in theory, every single building element can be separated, the achievable separation of the building materials is extremely high. On the other hand, extensive dismantling leads to high operating costs, especially labour costs. Depending on the prices for disposal and recycling, labour costs may offset savings caused by less expensive disposal (Schultman, 2005). Selective deconstruction is described in more detail in Section 7.3.1.

The conventional demolition of buildings produces large amounts of debris that often results in a significant portion of the total waste stream. While it is not the best option concerning recyclability of waste, demolishing may still be the preferable option in cases of buildings in danger of collapsing (e.g. after fires or earthquakes), when time is limited or when requirements concerning quality of material streams are low. Conventional demolition and selective deconstruction are not mutually exclusive concepts. Both techniques can be used to set up a strategy designed to achieve optimal operating times, recovery rates and economical results for demolition projects.

Elaboration of recycling and reuse plans in deconstruction projects

The objective of recycling planning is the design of optimal recycling techniques for processing dismantled materials and building components into reusable and recyclable materials. Depending on the stage of dismantling, the feed can be either a single material or a mix of all building materials. For certain individual materials such as metals, glass and minerals or plastics, recycling techniques are already commonly available. In this case, recycling planning is based on simple coordination. Several projects carried out in practice and analysed so far have shown a potential for further improvement concerning cost reduction as well as environmental benefit. Based on these results, application of computer aided systems appears to offer potential for deconstruction optimisation.

For example, a guideline and computer tool for deconstruction planning can be found at http://www.lubw.baden-wuerttemberg.de/servlet/is/13512/. Due to the fact that buildings and building elements can contain many different harmful substances, the guideline informs about building elements, which could contain such substances. Furthermore, advice is given about which procedure should be undertaken before the demolition of buildings containing the mentioned building elements. The guideline provides a decision support for the choice of the adequate demolition techniques. Advantages and disadvantages of the different demolition techniques are analysed according to economic, environmental and other aspects. The guideline lists different tools for disposal to support this decision: a flowchart showing the procedure of planning, permission and contracting of building deconstruction, a calculation sheet for the determination of costs for demolition and recycling/disposal and a computer tool. The computer tool allows the user a quick survey of the material composition of the building as well as the costs for demolition and recycling/disposal of the demolition waste arising. The program contains a database, which supports the data input supplying information concerning the costs of dismantling and recycling. The calculation can be performed using two different calculation methods (Schultmann, 2005):

- A rough estimation of costs and material composition of the building on the basis of the type and the volume of the building.
- A detailed determination of the building masses including mineral building structure as well as the internal finish. For each building element, data concerning dismantling and recycling can be determined by the user or can be found in the database.

In the UK, a so-called demolition protocol has been developed by the Institute of Civil Engineers (ICE, 2008) with the aim to provide a pragmatic set of methodologies to achieve resource efficiency in construction, demolition and refurbishment projects. The Protocol shows how the production of demolition material can be linked to its specification and procurement as a high value material in new works and how resource efficiency can be driven through the planning process.

Recycling is difficult when materials are mixed, when composite materials occur or when pollutants like hydrocarbons or asbestos are present, e.g. in chimneys. In order to obtain materials in an optimal composition for recycling facilities, the available recycling techniques, as well as the location of processing facilities, have to be considered during dismantling planning. Direct reuse of elements can be a promising alternative if dismantling is well planned (Schultmann, 2005). More information on this can be found in the construction section of the document (section 5.5).

If selective deconstruction is not an option and a building is to be demolished then the demolition process should aim for the reuse and recycling, at the highest possible level, of the materials released by the demolition activities. A structured approach using a demolition plan is essential for minimising environmental impacts and diverting waste from landfill. Although developing such a plan is time consuming and requires resource re-allocation, it will reduce waste management costs, as the budget of a demolition project usually includes the cost of demolition (increased by planning) but also the cost of landfilling (decreased by planning) minus the revenues from salvaged parts and materials (which may be increased by planning). Some factors determining how a building will be deconstructed or demolished are: location, type of building, its design, construction method, materials used and the presence of any hazardous substances (Dorsthorst and Kowalczyk, 2005).

Deconstruction process

The process of demolition and selective deconstruction are quite similar and the main difference is the timing and resources allocated to reuse and recycling schemes. First, buildings are checked for hazardous materials like asbestos (in which case a specialist has to be engaged to remove them, as asbestos stripping in particular requires extensive safety measures) or PAH (polycyclic aromatic hydrocarbons). Then, valuable parts that can be reused (boilers, precious woods or sanitary ware) are removed carefully. After these, floor coverings and ceilings are removed, as well as windows, building servicing installations and all other non-structural parts. Depending on the type of building, the remaining building fabric is taken down floor by floor using appropriate deconstruction equipment (see Sections 7.3.1 and 7.3.2). Finally foundations are broken up and removed by diggers or pulled out of the ground (Dorsthorst and Kowalczyk, 2005).

Demolition contractors can choose from a range of methods to demolish buildings and civil engineering structures, ranging from manual demolition to the use of explosives. These techniques are described in more detail in Section 7.3.2. A common point between building deconstruction and conventional demolition is the initial stripping of buildings for reuse and recycling before demolition. However, for selective deconstruction this phase can become more important than the final demolition of the remaining structure itself. The first steps of stripping and reusing or recycling salvaged parts and materials are often performed manually or using light machinery that can operate on the building floors. For the final step of deconstruction, which involves dismantling the building fabric, similar methods are applied as in conventional demolition.

The amount of waste generated in construction sites is about 100-180 kg per m^2 of built area, while demolition projects can generate up to 1500 kg/m^2 of demolished area. Reducing the amount of deconstruction waste is not only an issue for deconstruction companies, but for the whole construction sector, as indicated by these six core strategies for construction waste minimisaiton (Scheibengraf and Reisinger, 2006):

- avoid new construction (reuse buildings as much as possible)
- use low-waste construction techniques
- use buildings efficiently
- use selective deconstruction
- collect mono-fractional waste streams
- recycle waste in high-grade applications.

Demolition waste comprises bricks and stones, concrete or mortar, wood, steel and other metals (rebar, electrical wiring), and plastics. It also may contain lead, asbestos or different hazardous materials. The list of construction and demolition waste is shown in Table 5.10. The composition of deconstruction waste strongly depends on factors like the type of project (renovation, deconstruction, demolition), the type of building (residential, non-residential, special purpose) and the building technique (for example mainly concrete for waste from high buildings). The non-mineral fractions can be reduced by stripping the building by (partly) selective deconstruction. As each construction epoch has its typical building material, e.g. brickwork, steel skeleton or concrete, deconstruction waste will also change over time (tendency toward larger concrete and plastic fractions). More detailed information on deconstruction waste sorting and recycling is given in Section 7.3.3 (Schultmann, 2005; Scheibengraf and Reisinger, 2006)

Recyclability of recovered materials

Recycled construction materials from deconstructed buildings should be available in a quality that meets the required profile for virgin construction materials. Both plain and mixed grades of building waste could contain pollutants, giving rise to negative environmental impacts during storage or reuse. These pollutants are contained in construction materials due to their natural material composition, or following insertion during manufacture, for example in the form of additives. Nevertheless very few materials in demolition waste are invariably hazardous. The major pollutant sources in buildings have been identified through studies and are shown in Table 7.1. A large share of pollutants arise from surface area treatment such as painting. They are added partly for improvement and partly to protect the construction materials (Schumann, 2005; Rentz et al., 1997; Schultmann et al., 1997)

Table 7.1: Potential pollutant sources in buildings

Origin	Relevant Pollutants
Natural stone	Heavy metals
Gypsum	sulphate, heavy metals
Easily-bond asbestos fibre such as injection-asbestos, bonded asbestos-fibre (cement panels, fire-protection elements)	Asbestos
Treated wood	Heavy metals, lime, phenol, PCP
Plastics	Phenol, CH_x, organic components
Sealant	PCB
Roofing felt, bitumen construction parts, coal tar containing roofing	CH_x, PAH, phenol
Tech. installation (Transformers, paint coatings, capacitors; Fluorescent lamps, switches)	PCB, Hg, Cd
Soot	Heavy metals, PAH
Dust	Heavy metals
Fire	PAH, PCDD/PCDF
Accidents (use)	Includes oil, alkalis, acid
Pipe constructions	lead
Places where mineral oil CHs are used (tanks, heatings…)	Mineral oil CHs

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7.3 Best environmental management practices at the end of life of buildings

7.3.1 Selective deconstruction of buildings

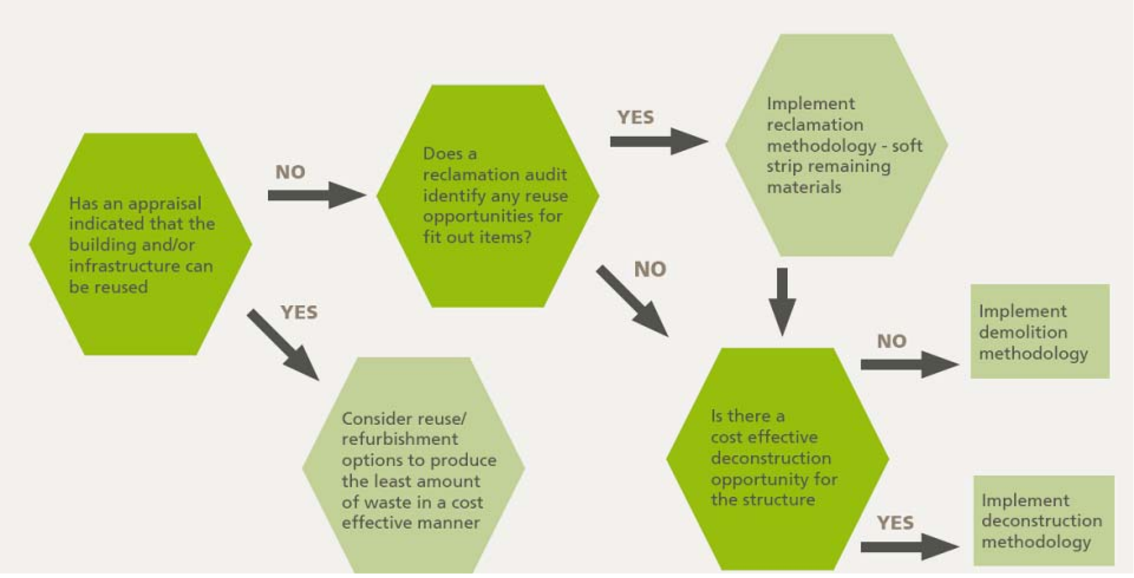
Description

The demolition of buildings, as it was traditionally performed, produces large amounts of debris that often results in a significant portion of the total waste stream. Selective deconstruction as an alternative to demolition means the systematic disassembly (‘construction in reverse’) of buildings in order to maximise the reuse and recycling of recovered materials. One of the main obstacles to the use of recycled construction materials in high-grade applications is the heterogeneity of the composition and the contamination of construction and demolition waste (C&D waste) resulting from demolition of buildings.

Whereas the demolition of a building often leads to the mixing of various materials and contamination of non-hazardous components, deconstruction aims at separating materials at source. Complete selective dismantling is currently often not the preferred technique, mainly due to the higher cost, at least when a high purity of waste streams is not required. A strategy in-between conventional demolishing and selective deconstruction is also possible, aiming at separating material flows and removing contaminants to a large extent with limited effort.

When a deconstruction process is planned for existing buildings, several outstanding practices can be defined:

- **Client specifications** on selective deconstruction, determining budgetary restrictions, timing, establishing goals and targets for waste sorting and recycling and identifying reuse opportunities. In terms of decision-making, the role of the waste hierarchy approach should be studied in order to indentify best options and opportunities. The Institute of Civil Engineers in the UK identified a flowchart of decision-making steps for assessing the most sustainable approach to the development of a building reuse/deconstruction/demolition project. Figure 7.1 shows this flowchart, available in the Demolition Protocol (ICE, 2008; ICE, 2003)



Source: ICE, 2008

Figure 7.1: Flowchart of decision making steps for assessing the most sustainable approach to redevelopment

- **Elaboration of deconstruction or demolition plans**. Detailed planning of the deconstruction process, including an evaluation of the appropriate scope for dismantling and an assessment of available recycling options, is recommended. In general, such plans can reduce the overall management cost and improve economic performance, working conditions, worker safety, and share and quality of recycled materials
- **Site management plan**. The elaboration of an environmental management plan of deconstruction sites is quite similar to the management of construction sites. Generally speaking, for deconstruction sites, the same best practices as given in Section 5.5 are applicable to demolition sites.

Prioritisation of building reuse, reclamation and reuse of products and deconstruction and demolition is made according to the waste hierarchy. In the demolition protocol of the UK ICE, the final decision-making process is summarised as shown in Table 7.2.

Table 7.2: Summary table for the waste hierarchy decision-making process

Consideration (What)	Stage (when)	Mechanism (how)	Demonstration of viability (why?)
Building reuse	Feasibility	Design and cost appraisal	Space, integrity, aesthetics and refurbishment costs satisfactory
Reclamation of internal fit out products	Design (of deconstruction phase)	Reclamation and design audit to assess potential for recovering internal products	Opportunities for reuse in situ (when the project comprises a new building) and ex situ identified and market potential is good
Deconstruction	Outline design	Audit to assess the potential of the structure for reuse	Opportunities for reuse in situ (when the project comprises a new building) and ex situ identified and market potential is good
Demolition	Outline design	Pre-demolition audit to assess recycling options	Recovery targets for recycling (in situ and ex situ)

Source: ICE, 2008

The number of dismantling steps necessarily depends on the type of building. Older buildings often consist of fewer materials than newer ones and require fewer dismantling steps. In general, selective deconstruction is performed according to the following steps (LFU, 2001; Scheibengraf and Reisinger, H., 2006; Dorsthorst, 2005):

- Check for hazardous substances: As a first step, the building has to be checked for any hazardous substances such as asbestos, which must be removed by a specialist (asbestos stripping requires extensive safety measures).
- Manual dismantling of reusable parts: The building is checked for any high value components which can be reused as salvage. These include for example leaded glass, marble fireplaces, precious woods such as walnut and oak, traditional sanitary ware, central heating boilers, water heaters and radiators.
- Then floor coverings and ceilings are removed and combustible and non-combustible waste is separated. Glass is removed from the window frames. Building service installations and all other metal parts are removed (if accessible). Roof tiles or roofing gravel (reusable) is removed and landfilled or recycled; if it is contaminated with PAH (polycyclic aromatic hydrocarbons, contained in tar) it has to be treated as hazardous

waste. In this step, all remaining materials are removed that could pollute the materials of the building fabric.

- For the next steps, buildings can be divided into the following types:
    - Buildings constructed of brickwork with wooden floors and wooden roof structures: When only the brickwork and floors are left, the building is taken down floor by floor. Joists and wooden floors are removed from the building using a crane and equaliser beam. The nails in joists and planks are removed by punching. The punching unit pushes the wood around the nail down and then extracts the nail by its head. Second-hand wood is often used for floors and has the advantage that it is fully seasoned - it will not shrink. Wood which cannot be reused as planks or beams is sometimes used for the production of chipboard. Brickwork is cut into sections and taken to a crusher plant.
    - Buildings with concrete skeleton frames, which may also include pre-stressed concrete elements: the roof, which is generally covered with bituminous material and gravel, is removed first. If present, the wooden roof structure is removed with a crane and equaliser beam. The concrete structure is cut up using breaker shears and taken to a crusher. In the past, the rubble was reduced in size on site and the iron was removed from it. However, current crusher plants can handle large sections (2 m x 2 m) and it is more economical for demolition contractors not to break up larger sections. Pre-stressed concrete structures pose special problems, especially if their presence is unknown. If it is suspected that a structure may be pre-stressed, a section is cut away to investigate this. If it is found to be pre-stressed, the terminations are first cut away at the ends of the structure, which will often lead to its collapse. Structures with unexpected pre-stressed sections can be dangerous, because the structure may suddenly give way and the concrete may fly around.
    - Buildings with steel frames: if the beams can be reused then the structure is disassembled. Otherwise, the steel structure is cut up and sent to a steelworks. Occasionally, structures such as steel bridges are sold whole and shipped overseas.
- Further demolition activities for all three types of buildings: The foundations (masonry or concrete) are broken up, like the rest of the building, and removed by diggers or pulled out of the ground. If the foundations include a deep basement then it may be necessary to create an excavation in which the work is carried out. It is difficult to remove wooden piles and piles formed in situ as they tend to break; precast concrete piles can be successfully removed through simultaneous vibration and pulling.

Achieved environmental benefits

Selective deconstruction has the following environmental benefits:

- Reduction of waste streams. Demolition debris is diverted from landfills, as mono-fraction waste from selective deconstruction can be recycled more easily and reuse opportunities are easily identifiable. Some case studies representing deconstruction and construction, with some reuse opportunities, are shown in Section 5.6.2.1.
- Reuse of parts and materials. Deconstruction is a good way to salvage quality building products that have not yet reached the end of their usable life, even if the building or part of it has. Salvaged materials are often less expensive to purchase than new materials, and may be of higher quality, especially salvaged wood.
- Reduction of waste contamination: The diffusion of contaminants in the waste stream is reduced. One study showed, for example, that the content of polycyclic aromatic hydrocarbons (PAHs) in waste samples from conventional demolition was six times higher as in those from selective deconstruction (where tarboard and chimney rubble was separated) (Sindt et al., 1997). sulphate content can be reduced by sorting out gypsum products.

Some case study performances are shown in Table 7.3.

Table 7.3: Case studies on the performance of several construction sites

No.	Country Year	Type of building	Construction	Volume	Dismantling Time, [weeks]	Costs	Recycling rate
1	DE, 1991	Foundry	Masonry	263 000 m^3	n.a.	11.8 € / m^3	94 %
2	DE, 1993	Brewery	Concrete and Masonry	210 000 m^3	n.a.	n.a.	> 96 %
3	DE, 1994	Residential Building	Timber Frame	4 950 m^3	6	13.5 € / m^3	94 %
4	DE, 1993	Industrial	Concrete	58 000 m^3	11	27.1 € / m^3	74 %
5	DE, 1993	Residential	Concrete	684 m^3	n.a.	n.a.	>90 %
6	DE, 1994	Industrial Building	Masonry	183 100 m^3	13	n.a.	n.a.
7	FR, 1995	Residential Building	Masonry	4 200 m^3	11	13.3 € / m^3	95 %
8	DE, 1995	Industrial Building	Masonry, Steel frame	22 086 m^3	6	9.7 € / m^3	98.5 %
9	DE, 1995	Office Building	Masonry	11 000 m^3	n.a.	n.a.	n.a.
10	DE, 1996	Industrial Building	Masonry	n.a.	22	n.a.	97 - 98 %
11	FR, 1997	Industrial Building	Masonry	13 250 m^3	4	1.5 € / m^3	98 %
12	DE, 1998	School Building	Masonry	50 000 m^3	18	15.1 € / m^3	98 %

WRAP, 2012, shows several examples of demolition and deconstruction projects. Demolition of residential buildings at Girbraid Avenue in Glasgow were not stripped and no segregation was possible on site, so all sorting and segregation processes were performed off site. A recycling rate of 96 % was achieved. The composition of all wastes was about 95.1 % concrete and brick, which were fully sent to recycling facilities. The unavailability of space for waste handling and the short time available for project execution were the limiting factors, reducing opportunities for reuse. The Bryan Donkin site recovered more than 95 % of materials over a period of 18 weeks. More than 100 m^2 of beech flooring and 100 m^2 of tiles were reused off site. Some wood elements were used for board manufacturing. Demolition costs were around EUR 9.5 per m^2.

Appropriate environmental indicators

Recycling rate (as a percentage): as defined by the Waste Framework Directive, recycling is considered as any operation in which materials are reprocessed into products, materials or substances, whether for the original or other purposes. For this definition, backfilling operations should be excluded. Calculation of the recycling rate can be quite complex if an exact value is required. Nevertheless, after correct management on site (including monitoring and segregation) the potential recycling rate can be easily estimated.

The quality of recycled waste and thus the increased number of potential uses is another important factor (see section 5.6.2.4).

Demolition Recovery Index DRI. This index (percentage) represents the potential for recovering material from demolition for recycling or reuse, following the methodologies of the

ICE Demolition Protocol. It is ‘a percentage which describes, in terms of area (m^2), how much of the structure, cladding, flooring/ceiling elements etc is able to be dismantled without significant risk of damage’. This DRI can then be used to develop a deconstruction target. It should be mentioned that risk is not defined as environmental risk but health risk (e.g. when safety or health risks are not acceptable). A collection of typical DRI values for standard practice, good practice and best practice is given in Table 7.4 (ICE, 2008). More information on the calculation of the DRI is shown in Operational data section.

Table 7.4: Potential demolition recovery indices/targets

Material	Standard DRI %	Good practice DRI %	Best practice DRI %
Concrete	75	95	100
Ceramics (e.g. masonry bricks)	75	85	100
Metals	95	100	100
Timber	57	90	95
Inert (e.g. subsoils)	75	95	100

Source: ICE, 2008

Cross-media effects

When increasing the segregation and sorting rate of demolition/deconstruction wastes, higher transport needs and longer working times are required. This means that the impact produced by transport services may be higher for the same material volume and the local impacts (dust, noise, vibrations, etc.) can be extended on time.

Operational data

Deconstruction of buildings has several advantages over conventional demolition but is also faced with several challenges. The advantages are an increased diversion rate of demolition debris from landfills, more sustainable economic development through direct reuse of building components and recycling of materials, all leading to an enhanced environmental protection, both locally and globally.

Many of the issues related to deconstruction refer to systematic planning for deconstruction and reuse already at the time of building design (see section 3.4.7.2). Existing buildings and building components have often not been designed for dismantling and special tools are being developed for the deconstruction of existing buildings. Disposal costs for demolition waste are usually still low, but government policy is beginning to encourage deconstruction by increasing disposal costs or, in some cases, forbidding the disposal of otherwise useful materials. However, the selective dismantling of buildings often requires additional time, which leads to difficult-to-quantify cost increases (costs of removing contaminants from lead-based paint and asbestos containing materials are also highly variable) (Chini, 2005; Scheibengraf and Reisinger, H., 2006).

One critical factor for selective deconstruction is the attainment of high quality recycling for sorted single material fractions. The presence of impurities can affect material quality. This is especially the case for gypsum, porous concrete, plastics and insulating material fibres. In selective and partly-selective de-construction, these impurities are removed as far as possible.

An important operating aspect of deconstruction is the timeframe. Time and resource allocation are usually the main drawback of the deconstruction process and the detailed management plan always critically depends on these factors. However, adaptative planning of the deconstruction works can also lead to reductions of deconstruction duration. Space availability is also an important issue; in this case, selective deconstruction requires less volume for machines than conventional demolition.

Regional recycling and disposal facilities should be available for high-grade use of demolition wastes from selective deconstruction to make selective deconstruction economically attractive. When long transportation distances are required, the economics of the process deteriorate significantly. A summary of economic, environmental and other aspects of different deconstruction/demolition strategies is given in Table 7.5.

Table 7.5: Aspects for choosing demolition/deconstruction method

Aspect	Conventional demolition	Partly-selective deconstruction	Selective deconstruction
Economic aspects			
Demolition and dismantling costs	⬀	⬄	⬂
Disposal costs	⬂	⬀	⬀
Transport costs	⬄	⬄	⬄
Planning costs for dismantling works	⬄	⬄	⬂
Environmental aspects			
Recycling quota	⬂	⬀	⬀
Support of high-quality recycling	⬂	⬄	⬀
Facilitated removal of impurities	⬂	⬀	⬀
Other aspects			
Monument conservation	⬄	⬄	⬄
Time frame for demolition measures	⬀	⬄	⬂
Availability of regional recycling and disposal facilities	⬀	⬀	⬀
Influence of building location and available space	⬄	⬄	⬄

Symbols:
'⬀' – positive influence of the demolishing method for the considered aspect
'⬄' – neutral or rather no conclusion possible
'⬂' – negative influence of the demolishing method for the considered aspect

Source: LFU, 2001

Calculation of the Demolition Recovery Index (ICE, 2003)

An example for the calculation of the Demolition Recovery Index is shown. For more information on this and on the integration of the calculated DRI in the demolition protocol, look to ICE (2003). The potential recovery of materials is one step of the demolition audit to be performed in advance of any deconstruction or dismantling project.

First, the bill of quantities (BOQ) should be completed. For that purpose, a full table describing the identified market for materials to be recovered from a demolition project is required. The recovery potential of materials is shown in Table 7.6.

Table 7.6: Recovery potential of materials from a deconstruction project

Material	Value	Potential applications
Concrete	High	1. Reuse: blockwork, structures 2. Recycling as recycled concrete aggregate (RCA) in new applications or as a sub base or as a recycled aggregate (RA) with brick stone, slate, etc. for fill operations
Non-concrete masonry	Medium	1. Reuse: brickwork, stone, slate 2.As RA as sub base or engineering fill
Metals	High	1. Reuse: steel beams 2. Recycle aluminium and copper materials with highest value, and steel (most significant tonnage)
Wood	Medium	1. Reuse (non structural applications) 2. Chipped and use in several applications
Glass	High	1. Recycle as sand aggregate, shot blasting, filtration material for water treatment, etc.

Source: ICE, 2003

The BOQ would allow the different components of the demolition to be aggregated into more general categories. Table 7.7 shows an example for the concrete category and Table 7.8 shows the final calculation for the DRI.

Table 7.7: Example of bill of quantities for concrete components

Component (Concrete)	Recovery Potential	Unit	Total tonnage	Recovery index
Blocks	RCA	100	10	100 %
Ceiling soffits	RCA	20	10	100 %
Floor slabs	RCA	40	40	100 %
Foundations	RCA	n.a.	200	100 %
Kerbing, haunching	RCA	100	10	100 %
Paving slabs	RCA	50	1	100 %
Star units	RCA	10	10	100 %
Lintels	RCA	100	25	100 %
Piles	RCA	20	50	100 %
Beams	RCA	40	80	100 %
Blinding	RCA	n.a.	50	100 %
Render	RCA	n.a.	10	0
Terrazzo	RCA	n.a.	10	100 %
Mass concrete	RCA	n.a.	20	100 %
Total			526	98.1 %

Source: ICE, 2003

Table 7.8: DRI calculation example of a demolition project

Material category	Total Tonnage	Recovered tonnage
Concrete	526	516
Non-concrete masonry	283	233
Metals	53	53
Wood	30.5	30.5
Glass	1.85	1.85
Composites	2.5	1.5
Plant	21	21
Architectural features	6	6
Miscellaneous	100	100
Hazardous waste (cont. soil)	37.5	5.39
Total	2122.7	968.24
DRI	**92 %**	

Source: ICE, 2003

The use of the BOQ and the DRI can help designers and planners to identify cost feasibility and optimisation options of a project, to allocate sufficient resources, and can also influence the planning for deconstruction or demolition. In addition, it can be used to negotiate with waste managers, to impose budgetary restrictions and for many other features. A full description of demolition planning can be found at ICE, 2003 and ICE, 2008.

Applicability

The deconstruction of whole buildings is primarily a strategy to meet environmental goals and requires a team of workers experienced in dismantling buildings. In some cases, deconstruction may cost more than traditional demolition. However, increasing pressure to avoid the landfilling of waste can make conventional demolition even more expensive. In summary, the main factors that determine whether a building will be deconstructed are (Shell et al., 2006):

- the local cost of landfill tipping fees
- the local cost of labour and equipment
- the ease of disassembly which affects labour cost

- the value of the materials recovered
- having adequate time available for deconstruction
- legal requirements.

Common salvageable materials include timber, doors, sinks, fencing, bricks, tile, pipes, hardware and light fixtures, these parts are worth being recycled in most cases. Reclaimed timber, in the form of studs, beams, flooring and trim, is among the most valuable and available of salvaged building products. Some building elements, such as water pipes and cables located under plaster, can be better sorted after the walls are taken down rather than being dismantled, at least from an economic point of view (Schultmann, 2005)

Economics

The most important economic aspects of selective deconstruction are (LFU, 2001):

- Demolition and dismantling costs: A distinction must be made between the demolition of the mineral basic structure of the building and the costs for the dismantling of the interior finishing and building services. Conventional demolition requires little dismantling, but leads to higher waste disposal costs, because the mixed demolition wastes must be separated in a more costly manner and a higher share must be disposed of (disposal costs are usually higher than recycling costs). As selective deconstruction is currently just emerging in some markets, costs for (manual) deconstruction activities can be quite high; however in many cases comprehensive planning can bring many cost savings for selective or partly-selective de-construction.
- Disposal costs: There are large regional differences in the cost structure. Partly-selective and selective de-construction leads to nearly homogenous (waste) material flows, which are easier to recycle at lower cost.
- Transport costs: There are large differences in transportation costs due to different regional markets. For rather short distances, transportation costs are often included in the general disposal/recycling costs. Material costs are usually not high, so transport of waste to be reused or recycled is usually a limiting factor for the economics of selective deconstruction.
- Costs for planning deconstruction/demolition activities: For selective or partly-selective deconstruction detailed planning is advisable in most cases, because coordination is needed between the different steps. Often these higher planning costs do not significantly increase expenses for the whole project.
- Other costs not determined by the deconstruction/demolition strategy include for example costs for a safe removal of hazardous pollutants.

Due to the high demand for manual labour or very specialised light machinery, a high degree of selective deconstruction is traditionally seen as a rather expensive solution.

A study from the French-German Institute for Environmental Research (IFARE/DFIU, 1996) compared costs for selective deconstruction and conventional demolition for similar buildings in Mulhouse, France (Table 7.9) (data is the average of four similar buildings for each case).

Table 7.9: Costs of selective deconstruction and conventional demolition

Method	Dismantling	Recovery/disposal	Transport	Total
Selective demolition, EUR	45700	3500	8600	57800
Conventional demolition, EUR	13200	7300	7900	28400

Source: IFARE/DFIU, 1996

Selective demolition lasted 50 days, while conventional demolition took 12 days. As shown in Table 7.9, costs for selective deconstruction were double those for conventional deconstruction.

However, materials recovery and processes were not really optimal and important savings could be achieved by reducing labour costs. About 4 % of total materials recovered from selective deconstruction compensated more than 9 % of the total costs. Nevertheless, the economic balance is now outdated since waste disposal policy and pricing has changed significantly since the development of this case study.

Driving force for implementation

Increasing the rate of construction materials recycling, and thus reducing demolition waste, is the main driving force for selective deconstruction. Increasing legislative pressure for high recycling quotas and bans for landfilling waste support the widespread use of (partly) selective deconstruction.

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7.3.2 Selection of environmentally friendly deconstruction / demolition techniques

Description

Demolition contractors can choose from a range of methods to demolish buildings and civil engineering structures. These range from manual demolition to the use of explosives, each with their own applications. The selection of a specific technique is normally based on economic and safety issues. Often a combination of several techniques (for example cutting techniques and techniques for breakup) are applied. In the following, different contemporary deconstruction techniques are described with their field of application and specific (environmental) benefits and problems.

For selective deconstruction, a stripping and reusing or recycling of salvaged parts and materials is often performed manually or using light machinery that can operate on the building floors. In itself, this stripping step is not a new development as all buildings are stripped to some extent before demolition. When a building is stripped whilst maintaining an intact structure, smaller equipment is used, which can move inside the buildings.

For the final step of deconstruction, which is taking down the building fabric, similar but often rather selective methods (i.e. excluding explosives and balling) are applied, as in conventional demolition, to the complete building.

Recently, there has been a trend to replace labour with specialised machines in deconstruction and demolition activities. This is because of the increased complexity in building design, the financial pressures from clients, health and safety issues, regulatory and legal requirements and advances in plant design. The industry now employs fewer, but more highly skilled operators and specialised equipment. Knocking down a building with a heavy steel ball (balling) is no longer widely used, as it has a major impact on the surrounding area through noise and vibration. The most difficult aspect of balling is aiming the ball accurately. Demolition by blasting is only to be used when a building has to be brought down very quickly, for example if it is close to a major road and there is not enough space to screen the demolition site. Generally, buildings will only be demolished by blasting if the local authority or the client requires this. Removing the rubble requires significant effort.

Older buildings of non-complex construction are generally simpler to demolish, at least when toxic materials like asbestos are not present. Components often have an aesthetic or antique value which results in them being salvaged. As the complexity and size of buildings has risen so have the technical demands placed on contractors taking them down safely.

The following tables give an overview of main demolition (of building fabric) techniques (derived from Lippok and Korth, 2004 and Hurley and Hobbs, 2005). According to Lippok and Korth, 2004, the following techniques are mainly used (in Germany): demolition excavators with hydraulic equipment (82 %), explosives (4 %), cable excavators (3 %), other construction machines (3 %), saws, high pressure water, milling (3 %), manual demolition and small equipment (3 %), remote controlled machines/robots (0.3 %), other techniques (1.7 %).

Table 7.10: Traditional methods of demolition

Method	Tools/Equipment required	Application suitability	Preparation /procedure	Environmental and health criteria	Other criteria / comments
By Hand	Portable tools: crowbars or mattocks, pneumatics drills, power saws	Now mainly for high and inaccessible areas or architectural salvage	Top-down fashion, floors in buildings are removed prior to demolition to prevent premature collapse due to weight of debris collection	Debris is easily segregated for salvage purposes; Low damage to adjacent buildings; High risk of accidents (working at height)	Oldest method; Labour intensive and slow; Expensive if labour costs are high;
Pulling	Wire Rope Vehicle to provide pulling power	Often brick or masonry structures (constriction), all structures (knock over)	Remove all stabilising components e.g. pipework, beams and lintels; Detach from adjacent buildings; Set rope around section of brickwork and drag to collapse	Causes dust nuisance	Time consuming if uncontrolled collapse occurs; Destabilised for a period before demolition – safety implications.
Impact	Demolition ball between 0.5 and 2.0 tonne suspended from a crawler crane	Fairly large, brick, masonry, (reinforced) concrete .	Remove floors as per by hand; Buildings > 30 m high should be reduced by hand before using ball; Detach from adjacent buildings	Produces noise, vibration and dust	Widely used in the past, now less as rather uncontrollable (safety), but cheap; Can be set to drop weight vertically onto floors and foundations
	Pusher arm (extended arm and steel pad fitted to tracked vehicle)	Normally brickwork	Arm is positioned at top of wall and forward motion applied		More controllable and versatile then demolition ball; Restricted in terms of height of wall to be demolished
Hammers and breakers	Hammer/breaker hydraulic or pneumatic: (handheld or) vehicle mounted	Versatile (concrete, brickwork, masonry and steel) capable of partial demolition	Involves repeated impact, also applicable to removal of rocks, compacting or underwater applications	Produces small size materials, no need for secondary crushing before use as recycled aggregate	Pneumatic hammer is smaller and lighter, but noisier than hydraulic; Both produce persistent noise; High wear of hammers
	Hydraulic or mechanic (concrete) crusher / pulveriser	Concrete, brickwork, (often in combination with other methods)	Jaw-like attachments break or cut concrete and steel (hydraulic shears) by holding and crushing into sections	Produces small size materials, no need for secondary crushing before use as recycled aggregate; Specially suited for recycling	Reasonable cost; Low noise

Table 7.11: Demolition using explosives

Method	Application suitability	Preparation/procedure	Environmental and health criteria	Comments
Borehole Charges	Concrete, brickwork and masonry, not suitable for narrow members	Place in pre-drilled holes	Produces medium sized materials that may require further crushing before use as recycled aggregates	Shock waves from powerful explosives can be transmitted over great distances by some ground conditions e.g. clay and by airwaves; Risk of flying debris; Often as last resort
Lay-on charges		Placed in contact with structure and contained with sandbags or clay		
Con-cussion charges	Enclosed structures e.g. tanks	Bulk charge placed within structure		

Table 7.12: More recent methods of demolition

Method	Tools/Equipment required	Application suitability	Preparation /procedure	Environmental and health criteria	Comments
Expansion/ bursting	Buster with wedges	Concrete or masonry	Mechanical wedges forced into pre-drilled holes and expanded by hydraulic pressure	Create noise and dust at drilling stages, otherwise nuisance free.	Slow; Good for working in close proximity to other buildings.
Static	Chemical expansive agent	Cannot be used for narrow structural members, reinforced or pre- stressed concrete	E.g. injection of unslaked lime composite mixed with water into predrilled hole, hydration of mixture causes expansion which splits surrounding material		
Dynamic	Explosives, high-pressure water, gas pressure		Apply to pre-drilled holes		
	CARDOX		Liquid carbon dioxide in metal tube inserted in pre-drilled hole, heated by electric filament, causes expansion		
Abrasive	Hammer drill, hand operated, or vehicle mounted	General	Reduces concrete to dust using rapidly rotating and hammering bit		Vehicle mounted hammer drill used for the destruction of mass concrete

Table 7.12: More recent methods of demolition

Method	Tools/Equipment required	Application suitability	Preparation /procedure	Environmental and health criteria	Comments
	Concrete cutter/miller (vehicle mounted)	General, including removal of surfaces in layers	Reduces concrete to dust using rapidly rotating heads or discs	Produces homogeneous small size materials	
	Diamond boring machine	Drilling concrete	Diamonds form abrasive interface, creates very smooth holes	Cooling water required	Quite slow and expensive
	Diamond disc cutter	Capable of cutting r.c.			Often combined with pulling or other deconstruction techniques; Noisy
	Diamond wire saw	Cuts around circumference of concrete sections		Little dust or vibration	
	High-pressure water jet	Can be used to cut cement grout to release components	250-300 MPa water jet forced through small nozzle can cut plain concrete. Addition of particles of steel allows it to cut through reinforced concrete	Uses large quantities of water	Expensive in comparison to other methods.
Heating	Thermo lance (metal tube, approx. 3 m long containing aluminium alloy or iron alloy rods		Tip of lance heated to 1000 °C oxygen fed to tip produces flame 2500 °C, can melt reinforcing rods and concrete	Cutting of some materials can cause toxic fumes	
	Fuel oil flame		Combustion of mixture of kerosene and oxygen gas produces flame to melt concrete		
	Argon-hydrogen/Argon-nitrogen plasma, and carbon dioxide laser beam		Development stage (Kasai 1998)		Specialist use only
	Heating and peeling using electrical conductors		Drill holes to reveal rebars, attach electrical conductors to induce current through the rebars, causes heating which dries out surrounding concrete so it peels		Little noise or dust after drilling stage; Could use microwaves to dry out concrete, avoids use of drilling but expensive
Cryogenic		Reinforced concrete, steel framing	Quick-freezing steel in a restricted area makes it brittle		Time consuming, limited use and expensive
Bending	Jack-up	Reinforced concrete horizontal members	Application of point force upwards against floor slab induces bending and shearing forces into slab designed for down loading only		Rarely used

Table 7.12: More recent methods of demolition

Method	Tools/Equipment required	Application suitability	Preparation /procedure	Environmental and health criteria	Comments
Separating	Sieve buckets for excavators	Separation of waste fractions during deconstruction	Excavator bucket with rotating sieve for separating fine fractions from bricks etc. at the construction site	Allows direct reuse (filling) of fine fractions at deconstruction site	
Crushing	Bucket crusher	Crushing of tiles or concrete chunks	An excavator bucket with a jaw-like crusher, crushed material falls through a grate in the bucket	Crushing of materials to defined sizes at deconstruction site	

Achieved environmental benefits

See achieved environmental benefits of Section 7.3.1.

Appropriate environmental indicator

The assessment of the environmental performance of environmentally-friendly deconstruction techniques should be based not only on the performance of the demolition (in terms of recycling rate or recovery index, shown below) but also on the level of nuisance and local impacts generated: noise, vibrations, dirtiness, etc. Nevertheless, as the main objective of this technique is to increase the waste fraction diverted from landfill, the main indicators for this technique relate to the overall waste management performance: recycling rate and demolition recovery index, DRI, as described in section 7.3.1.

Cross-media effects

Dust, noise and vibration plus other nuisance elements are generated during deconstruction, and the best techniques to maximise recycling rates may produce undesirable impacts, although the global balance may be positive compared to conventional demolition. Also, some techniques use water (dust abatement, cooling, high pressure water cutting).

Operational data

Some general judgements of preferred demolition techniques are listed in Table 7.13, based on demolition type, site, and object, as given in Table 7.14. Generally preferred techniques for demolishing or separating building parts are presented in Table 7.15 and an evaluation of demolition techniques for mineral materials, concerning economic and time characteristics, are presented in Table 7.16 (Lippok and Korth, 2004).

Table 7.13: List of techniques for demolition

No. used in following tables	Technique
1	Road impact crusher
2	Hydraulic hammer
3	Demolition jib
4	Deconstruction/sorting grab
5	Breaker
6	Concrete cutter/miller
7	Borehole
8	Chisel drilling
9	Crane/lifter
10	Fluid heavy lift (FLUIDTS)
11	Manual deconstruction
12	Deconstruction excavator
13	High pressure water
14	Lifting strand jack
15	Wire core lance
16	Plasma burner
17	Powder lance
18	Powder cutting torch
19	Pulveriser
20	Expanding agent
21	Caterpillar, wheel loader
22	Diamond disc cutter /wire saw
23	Flame cutter
24	Hydraulic splitter
25	Impact / Balling
26	Explosives
27	Hydraulic shears
28	Pulling (rope)

Table 7.14: Preferred demolition techniques for constructions of mineral materials according to building and site conditions

Construction type	Demolition site	Clear		Bordered	
	Demolition object	Detached (1)	Bordered (2)	Detached (3)	Bordered (4)
High buildings	• Frame construction	26, 28, 9, 5, 27	26, 28, 9, 5, 27	26, 28, 9, 5, 27	9, 11
	• Solid construction	26, 28, 25, 9, 4, 19	26, 28, 25, 9, 19	26, 28, 25, 9, 3, 4	9, 11
	• Mixed construction	26, 28, 25, 9, 3	26, 28, 25, 9	26, 28, 9, 3	9, 11
Low-rise buildings and halls		25, 9, 5, 4	25, 9, 5, 4	25, 5, 4, 9	9, 11 5
Bridges		26, 9, 5, 25	26, 9, 5, 14, 10	9, 26, 5	9, 26, 11, 14, 10
Towers and masts		26, 28, 25, 5	26, 9, 11, 28 22	9, 26, 25, 5	11, 5, 22
Industrial smoke stacks		26, 28, 25, 5	26, 28, 5, 22	26, 11, 25, 5	11, 5, 22
Silos and containers		26, 25, 2, 5, 19	26, 25, 2, 22, 9	25, 2, 5, 19, 11	25, 2, 5, 22, 11
Compact buildings		26, 25, 2	26, 25, 2, 20, 24	26, 25, 2, 20, 24	2, 20, 11, 24
Foundations		26, 2, 25	26, 2, 20, 24	26, 2, 20, 24	2, 20, 11, 24
Traffic areas		1, 26, 25, 2	1, 25, 2, 6	1, 2, 6, 20, 24	1, 2, 11, 20, 6, 24
Remark: For bordered demolition objects, a separation from neighbouring buildings by cutting (or loosening bolts) has to be made before applying crushing techniques.					

Table 7.15: Preferred demolition generally preferred techniques for demolishing or separating building parts

Building part	**Thickness [mm]**	**Demolition technique**	**Separation technique (selection based on material)**
Horizontal building parts			
• Ceilings, roofs, platforms	< 400	5, 11, 3, 9	11, 22, 16, 23, 18, 13
• Roof binder, ceiling beam, joist	< 400	9, 11, 3, 5, 27	11, 22, 18 23, 16
• Beams, joists	> 400	9, 5, 3	11, 22, 18, 23, 16
• Traffic areas, foundations	< 400	1, 25, 2, 6, 4	22, 24, 2, 13
• Foundations	> 400	26, 11, 2, 25, 20, 24	24, 17, 15, 23 (steel), 6 20
Vertical building parts			
• Walls	< 100	11, 2, 19, 21	11, 22, 16, 18, 23
• Walls	< 300	9, 26, 28, 25, 4, 2, 3, 5	16, 22, 11, 2, 18
• Walls	> 300	26, 25, 20, 2, 5, 6	17, 16, 22, 11, 6
• Pillars	< 250	9, 25, 28, 11, 5, 27	17, 11, 22, 23, 16
• Pillars	< 500	9, 26, 28, 27, 5	11, 23, 27, 22, 16

Table 7.16: Evaluation of demolition techniques for constructions of mineral materials concerning economy and time effort

Construction type	Cases (see below)	Demolition technique (see Table 7.13)												
		11	28	25	2	1	4	26	9	3	5	20	12	24
High buildings Frame construction	1	-	-	0	-	-	-	+	0	+	+	-	-	-
	2	-	-	-	0	-	-	+	0	+	+	-	-	-
	3	-	0	0	-	-	-	0	+	+	+	-	-	-
	4	0	-	0	-	-	-	-	+	-	-	-	-	-
High buildings Solid construction	1	-	0	0	-	-	-	+	0	+	+	-	+	-
	2	-	0	0	-	-	-	+	0	+	+	-	+	-
	3	-	+	0	-	-	-	0	0	+	+	-	+	-
	4	0	-	-	-	-	-	-	+	0	0	-	0	-
High buildings Mixed construction	1	-	0	0	-	-	-	+	0	+	+	-	+	-
	2	-	0	0	-	-	-	+	0	+	+	-	+	-
	3	-	0	-	-	-	-	+	0	+	+	-	0	-
	4	0	-	-	-	-	-	-	+	+	+	-	0	-
Low-rise buildings and halls	1	-	0	0	-	-	+	+	0	0	+	-	+	-
	2	-	0	0	-	-	+	+	0	0	+	-	+	-
	3	-	0	0	-	-	+	+	0	0	+	-	+	-
	4	0	+	-	-	-	0	-	0	0	+	-	+	-
Towers	1	-	-	-	-	-	-	+	-	+	-	-	-	-
	2	-	-	-	-	-	-	+	0	0	-	-	-	-
	3	-	-	0	-	-	-	0	+	+	-	-	-	-
	4	-	-	0	-	-	-	-	+	-	-	-	-	-
Industrial smoke Stacks	1	-	-	-	-	-	-	+	-	+	-	-	-	-
	2	-	-	-	-	-	-	+	-	0	-	-	-	-
	3	-	-	-	-	-	-	+	0	-	-	-	-	-
	4	0	-	-	-	-	-	+	0	-	-	-	-	-
Silos and containers	1	-	-	0	0	-	-	+	0	-	0	0	+	0
	2	-	-	0	0	-	-	+	0	-	-	0	0	-
	3	0	-	+	0	-	-	0	-	-	0	0	0	0
	4	0	-	+	0	-	-	-	0	-	-	0	0	-
Compact buildings	1	-	-	-	0	-	-	+	-	-	-	+	-	+
	2	-	-	0	0	-	-	+	0	-	-	+	-	+
	3	-	-	0	0	-	-	+	0	-	-	+	-	+
	4	-	-	0	+	-	-	0	0	-	-	+	-	+
Bridges	1	-	-	-	-	-	-	+	0	-	0	-	-	-
	2	-	-	-	-	-	-	+	0	-	0	-	-	-
	3	-	-	-	-	-	-	0	+	-	0	-	-	-
	4	-	-	-	-	-	-	0	+	-	0	-	-	-
Foundations	1	-	-	-	-	-	-	+	+	-	-	+	0	+
	2	-	-	0	0	-	+	+	-	-	0	+	0	+
	3	-	-	0	0	-	+	+	0	-	0	+	0	+
	4	0	-	+	0	-	0	0	-	-	0	+	-	+
Traffic areas	1	-	-	0	-	+	+	0	-	-	+	0	0	-
	2	-	-	0	-	+	+	0	-	-	+	0	0	-
	3	-	-	-	0	+	+	0	-	-	+	0	0	-
	4	0	-	0	0	+	0	-	-	-	+	0	0	-

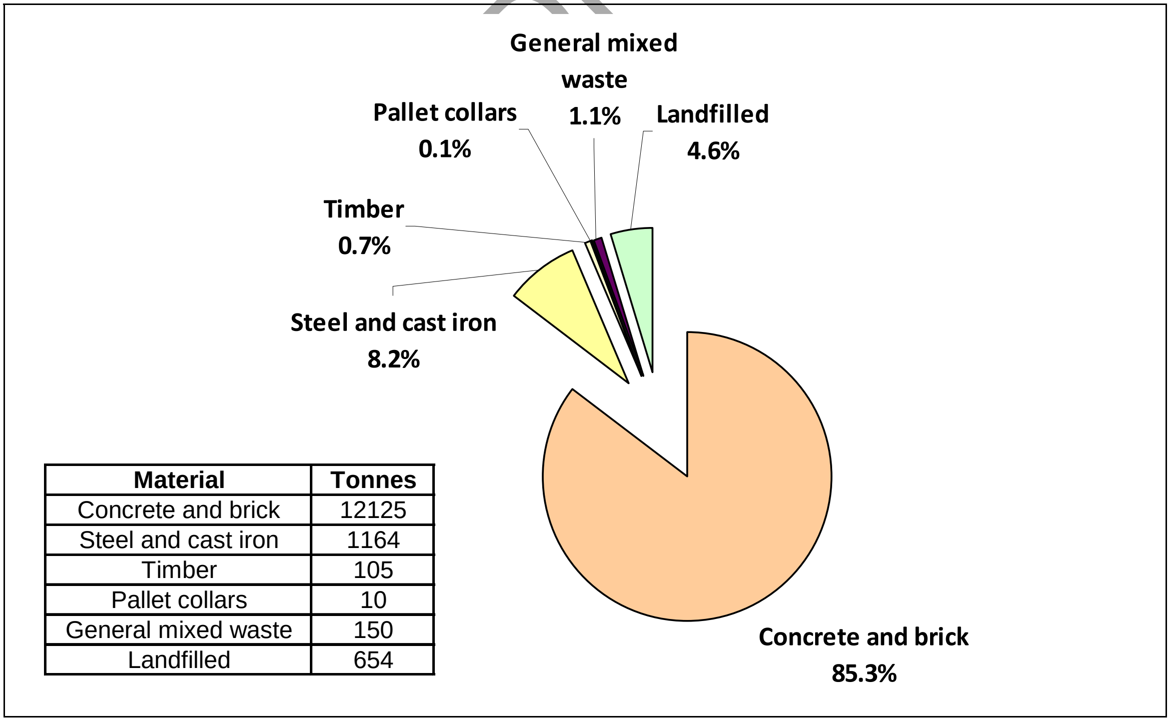
Case 1: Demolition site clear, demolition object detached; Case 2: Demolition site clear, demolition object bordered; Case 3: Demolition site bordered, demolition object detached; Case 4 Demolition site bordered, demolition object bordered; + = preferred; 0 = passable; - = not passable/not applicable.

Note: For demolition of steel constructions, preferred techniques are deconstruction, steel shears, or pulling.

In the UK, a demolition case study from WRAP (WRAP, 2007) showed a recovery rate higher than 95 % in the Bryan Donkin Valves manufacturing site in Chesterfield. In total, 43 buildings were demolished (48 500 m^2 of floor area). The project took 18 weeks in total. Except for several asbestos contamination cases, all the materials produced on site were recycled or reused. The process for materials recovery was divided into three stages:

- Salvage of items for reuse. Mansfield imperial bricks were reclaimed, cleaned and sold. Cast-iron columns and beams, 100 m^2 of beech flooring, 100 m^2 of rosemary roof tiles and slates were also salvaged. Timber was salvaged and chipped for board manufacture. One thousand pallet collars were found on site.
- Soft stripping. This is the operation of removing non-structural items from building interiors. Stripped materials are plasterboard, carpets, false ceilings, furnishings, fixtures and fittings, furniture, doors and doorframes. The application of soft stripping and its segregation was undertaken at the contractor's discretion. Market forces or financial incentives are quite important for this process. Nevertheless, it was observed that a good soft stripping reduces the contamination of materials segregated in the final demolition.
- Demolition of structural elements. Concrete, steel reinforcement and brick were segregated and they were crushed on site (see section 7.3.3). All the materials were used as a sub base for pavements and roundabout extensions, and as a working platform. Concrete and bricks separated during soft stripping as mixed wastes were segregated and processed off-site.

As a result of these activities, recycling and reuse rates in the Bryan Donkin site reached those shown in Figure 7.2. In total, more than 14 000 tonnes of waste were generated and 13 500 were reclaimed.



Material	Tonnes
Concrete and brick	12125
Steel and cast iron	1164
Timber	105
Pallet collars	10
General mixed waste	150
Landfilled	654

Figure 7.2: Materials reused, recycled and landfilled in the Bryan Donkin site

Applicability

WRAP published in 2005 a guide on the implementation of best practice for demolition, under the framework of Aggregain, a framework programme for the application of aggregates by the construction industry and focusing on all the elements of the value chain for aggregates. Best practice should be focused on the application of deconstruction/demolition protocols for reuse and recycling of materials on the same site where, maybe, there will be a new building (this can be the case for projects involving both deconstruction and construction) (WRAP, 2005).

The application of best demolition management practice requires the allocation of resources to the planning stage. Deconstruction protocols may identify a demolition project not as the end-of-life of a project, but as a potential source of materials for a new one. Desk studies and audits of the pre-demolition phase are essential to ensure maximum recovery of materials. In addition, factors affecting the deconstruction process which may limit material recovery are:

- Safety, which may increase project costs.
- Time. Deconstruction projects need more time than conventional demolition, so higher costs are expected. Optimal solutions regarding potential recyclability and reuse should be considered.
- Quality and market acceptance. The cost of removing an element (e.g. a roof tile) should be compensated for by its price, while, at the same time, the reused element should be competitive and accepted by future users.
- Space. When there is a space limitation on a site, good planning is required. At the same time, some potential recycling processes may not be possible due to excessive time or higher costs (e.g. through intermediate storage)
- Location. The number of facilities may limit the potential recovery of materials from a deconstruction project.
- Weather. Some applications may require certain weather conditions that may not be coincident with project timing.
- Price fluctuations. For instance, scrap and other construction material recyclability depends in part on fluctuating market prices.

Economics

See Table 7.10, Table 7.11, Table 7.12 and section 7.3.1 for some indications on the economics of deconstruction/demolition economics.

Driving force for implementation

The selection of demolition techniques is traditionally based on economic and practical criteria. A growing demand for low environmental impact techniques that realise the highest achievable recycling rate is expected. In fact, the Waste Framework directive established an objective of 70 % recycling and reuse of construction and demolition waste, so more enforcement may be required, especially for those regions with lower recycling rates.

Reference organisations

- International Council for Research and Innovation in Building and Construction, Task Group 39 on Deconstruction, http://www.cibworld.nl
- Deutscher Abbruchverband e.V. (German demolition association), http://www.deutscher-abbruchverband.de/

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7.3.3 Construction and Demolition (deconstruction) waste sorting and processing

Description

Deconstruction/demolition waste should ideally be separated during deconstruction activity, as mono-fractional waste streams are preferable for recycling. Subsequent separation and improvement of the quality of recycled materials by processing and sorting is technically limited. However, it is still important to use technologies for sorting and upgrading this remaining stream of mixed waste (or the entire waste stream in cases where separate collection is not an option at the deconstruction site). In general, large pieces (wood, metal, plastics) are removed manually in a first step. Afterwards, the waste is crushed using impact or jaw crushers and separated in order to create useful secondary material. The material is usually sieved, in order to get rid of the sieve-sands. After this first sieving, the materials can be fed into a pre-crusher to create smaller particles so that the largest parts will not damage the main crusher. Between the first and the second crusher, the materials are de-ironed by a magnetic band. Other materials, like glass, plastic, wood etc. are removed by washing, air separation or manual separation. Finally, the material is sieved in order to create the right fractions for the road building and concrete industries (Dorsthorst and Kowalczyk, 2005).

<u>Manual sorting of mixed waste</u>

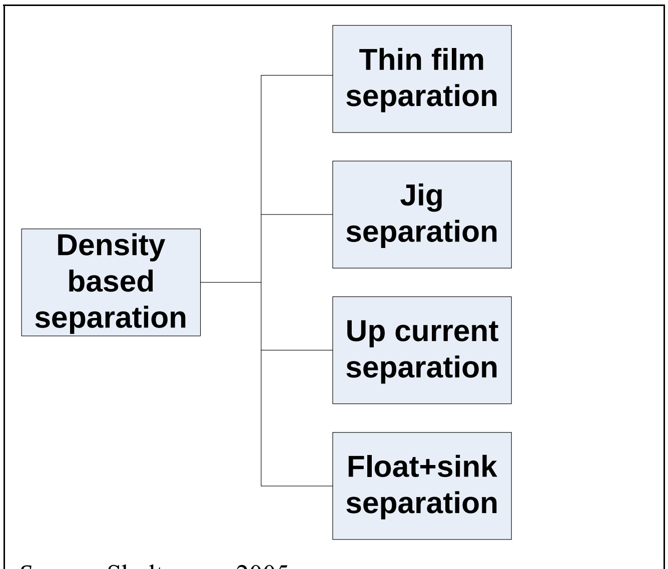
As a first step, different building materials are separated by manual sorting after deconstruction. The material separation achieved by manual sorting is not as exact as if the building were dismantled. In many cases, sorting takes less time, which makes it cheaper, compared to dismantling. That means that if the requirements regarding the purity of the recycling material are not very strict, sorting is often preferred. Some building elements such as water pipes and cables, located under the plaster or iron radiators, may even be sorted more efficiently after demolition rather than being dismantled beforehand (Schultmann, 2005).

<u>Separation devices in recycling plants</u>

A further possibility to separate the foreign matter from the mineral building waste is the use of separating devices in recycling plants (which can be on site and portable if the volume of wastes and/or distance to recycling facilities are sufficiently high to justify that). Waste is crushed before automatic sorting. Most stationary recycling plants involve a two stage process using first a jaw crusher and then an impact crusher.

Experience from Germany shows that most stationary recycling plants use either an airflow-based or a water-based separation device. Whereas the majority of recycling plants use airflow-based separation devices, water-based techniques provide better quality. Wet separation techniques use water to separate lighter (wood, plastics, paper) and heavier materials. In some cases, other substances are added to the water to increase its specific weight and change its separating characteristics. Some water-based separating devices use supplementary water jets or air to support the separation by density differences (Schultmann, 2005)

Figure 7.3 gives a general overview of the different kinds of water based separating techniques: thin-film separation, jig separation, up-current separation, float and sink separation. Within these four categories several different devices are available based on the same technique, which may vary in detail.



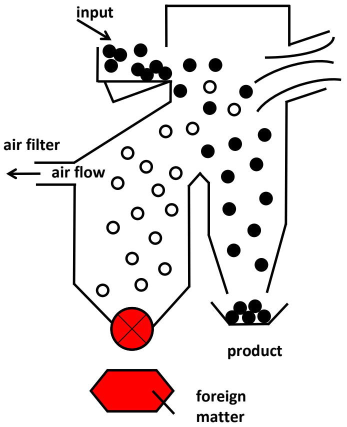
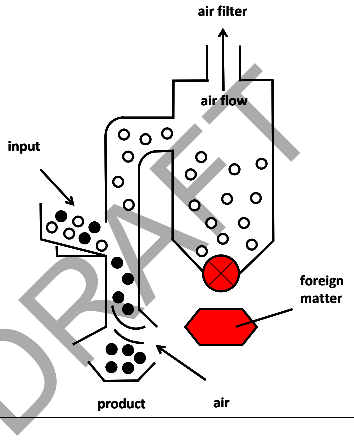
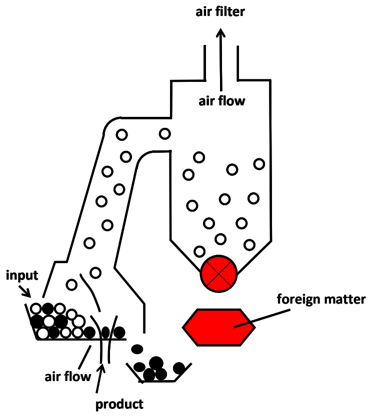
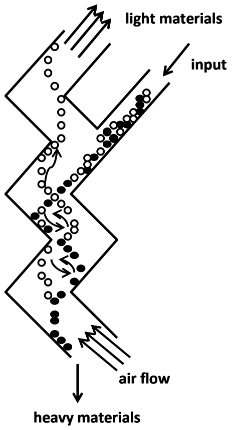
Source: Shultmann, 2005

Figure 7.3: Water-based separation techniques

Airflow-based separating devices use the air flow to 'blow away' light materials and to isolate the lighter non-mineral materials from the heavier materials. In general, the airflow-based techniques are characterised by lower operating costs. But, on the other hand, the resulting material separation is not as effective as for wet techniques. However, mineral waste streams cleaned by both sets of techniques are basically free of non-mineral fractions and thus allow relatively high recycling rates (for example, as part of construction materials). Table 7.17 shows the functionality of frequently applied airflow-based separating devices. The 'reverse airflow sorting technique' and the 'cross airflow sorting technique' are the fundamental systems in the field of airflow-based separating devices. Cross airflow sorting has the advantage that the materials remain in the device for a much shorter time, which increases performance. The 'exhaust of foreign matter' is a modification of the cross airflow sorting technique. Instead of using a free fall system, the materials to be sorted lie on a vibrating conveyor belt that pre-separates the light materials from the mineral fraction. Zig-zag separation devices use the reverse airflow sorting technique, which is modified by the zig-zag form of the mechanism. Thus, the effectiveness of sorting can be increased, since the zig-zag form has the same effect as a succession of several single cross airflow sorting devices.

In practice, dry separation techniques have established themselves as the preferred option due to the simple construction of the devices and high throughput (both leading to lower cost), although wet separation techniques achieve better separating performance. However, a major factor for the quality of sorted material for any technique is the quality of input material. Thus, at least partly selective deconstruction and a sorting of foreign materials during deconstruction is crucial.

Table 7.17: Main airflow based separation techniques

Airflow separation techniques	Diagram
Reverse airflow sorting technique	
Cross airflow sorting technique	
Exhaust of foreign matter	
Zig-zag airflow sorting	

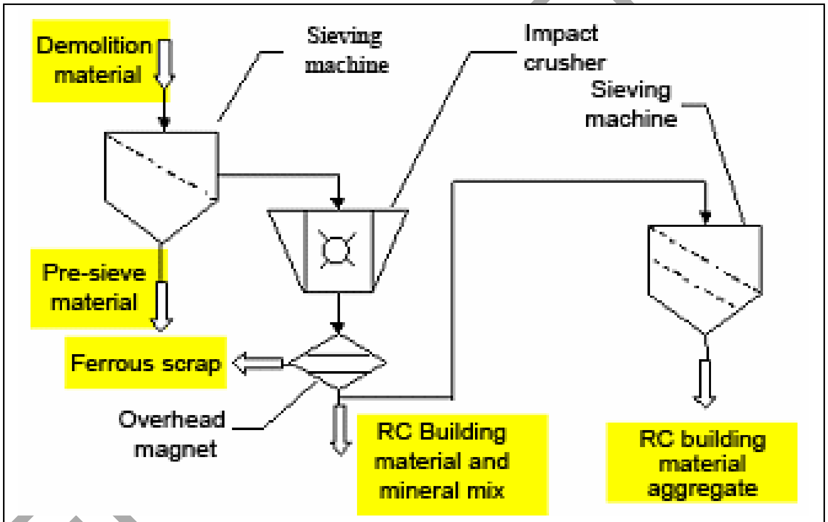
Source: Schultmann, 2005

Concerning further uses of cleaned mineral fractions, it has to be considered that recycled construction materials have to fulfil the same requirements as new construction materials, especially concerning stability in high construction and the absence of pollutants. The preferred uses for this recycled material are road (or dam, canal, etc.) construction, use in new concrete and other uses like foundations or green roofs.

Recycling plants

Recycling plants can be mobile, semi-mobile or stationery. It depends on the nature of the material to be crushed, the total amount, and the purpose of the installation. For instance, stationary plants are commonly used for recycling plants, integrating several technologies to produce products of a high quality. Mobile plants can be used directly in quarries or large construction sites that produce a large quantity of construction waste (e.g. excavated soil or stone).

Common recycling processes consist of a first manual sorting and/or visual inspection. An excavator or similar device feeds a pre-classifying sieve to separate sand and the fine fraction, which makes up one product from the facility. Then, materials are crushed to several fractions and metals are separated with a magnetic separator. Material screening and classification is then carried out and the products are stored in several piles. Figure 7.4 shows an example of construction and demolition waste processing taken from Weisleder and Nasseri, 2006.

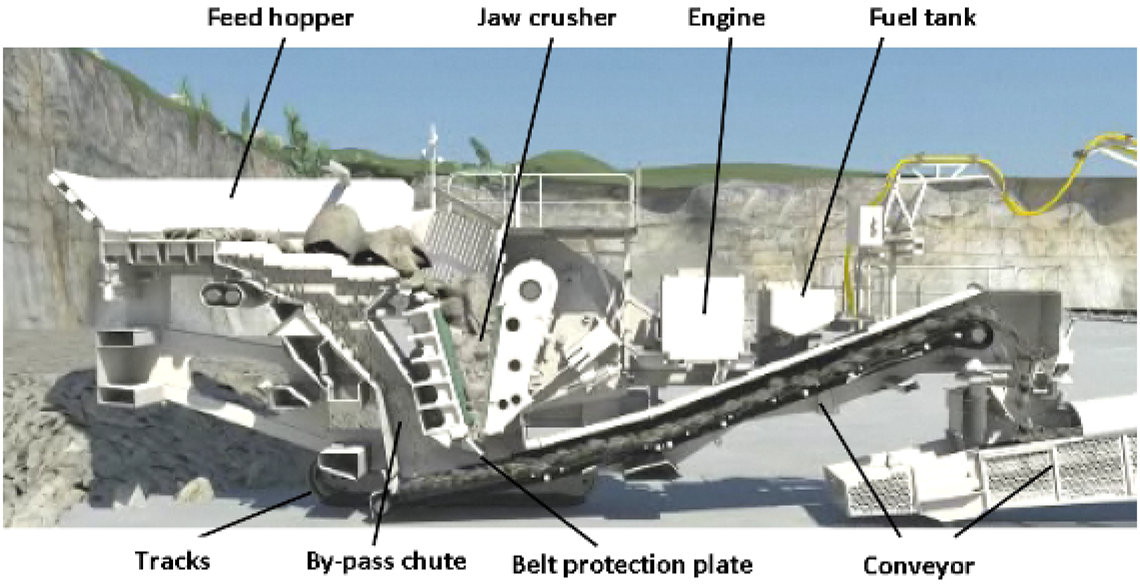


Source: Weisleder and Nasseri, 2006

Figure 7.4: Example of a concrete recycling process

The same technology is used for crushing materials in a quarry or for reprocessing construction waste to produce gravel. Figure 7.5 shows a portable jaw crusher, incorporating tracks for mobility. Materials are fed to the hopper. After screening to separate fine materials through a by-pass (in order to avoid problems with the jaws), stones are crushed and fall onto the conveyor. A protection plate helps to avoid strong impacts to the belt. The fine material by-pass can be connected to another belt, and sand type materials can be stored in a different pile. Figure 7.6 shows the picture of one portable plant with fines separation.

The key stage of the process is screening (described above) and the crushing technique. While a good screening process can separate a significant proportion of products to be used, the crusher determines the quality and can considerably vary the proportion of materials produced at different sizes. Crushers can be jaws, impactors, cones, etc. The most common is the jaw crusher, which is usually combined with impactors in recycling plants. A short description of each application is given in Table 7.18.



Source: Metso, 2012

Figure 7.5: Jaw crusher process

Source: Metso, 2012

Figure 7.6: Portable crusher with fines separation

Table 7.18: Comparison of different crusher types in mobile, semi-mobile and stationary plants

Type	Advantages	Disadvantages	Applications
Semi-mobile and mobile with jaw crusher	Simple, rugged construction Low wear Crushes hardest rocks	Lowe crushing efficiency Problems with crushing bituminous broken road paving Recycling of oversize practically impossible	Crushing of unproblematic building rubble where no demands are placed on product quality or capacity
Semi-mobile and mobile with impact crusher	Favourable crushing efficiency with all types of building rubble and broken road paving	Relatively high wear rate Can generate excessive fines	Suitable for all-round rubble crushing with a high capacity
Stationary plant with jaw and impact crushers or two impact crushers	Combines advantages of both crusher types High capacity Can crush large size reinforced concrete waste	Plugging problems with bituminous material High capital costs	Good for high capacities combined with high demands on product quality
Stationary plant with jaw and cone crusher	Very good product quality, sharp, cubical form Low wear rate	Susceptible to rebars and tramp metal in cone crusher High capital costs	Recommended for generation of high quality secondary materials
Stationary plant with beater drum and impactor	Particularly good for handling large concrete lumps	Very high wear High capital costs	Ideal combination for recycling concrete waste, railway sleepers, concrete masts, etc.

Source: FAS, 2002

Achieved environmental benefits

See achieved environmental benefits of Section 7.3.1.

Environmental indicators

As the main objective of this technique is to increase the waste fraction diverted from landfill by producing high quality products from the recycling of demolition waste, the main indicators should consider overall recycling performance. So, preferred indicators are the same as for techniques described previously (see 7.3.1)

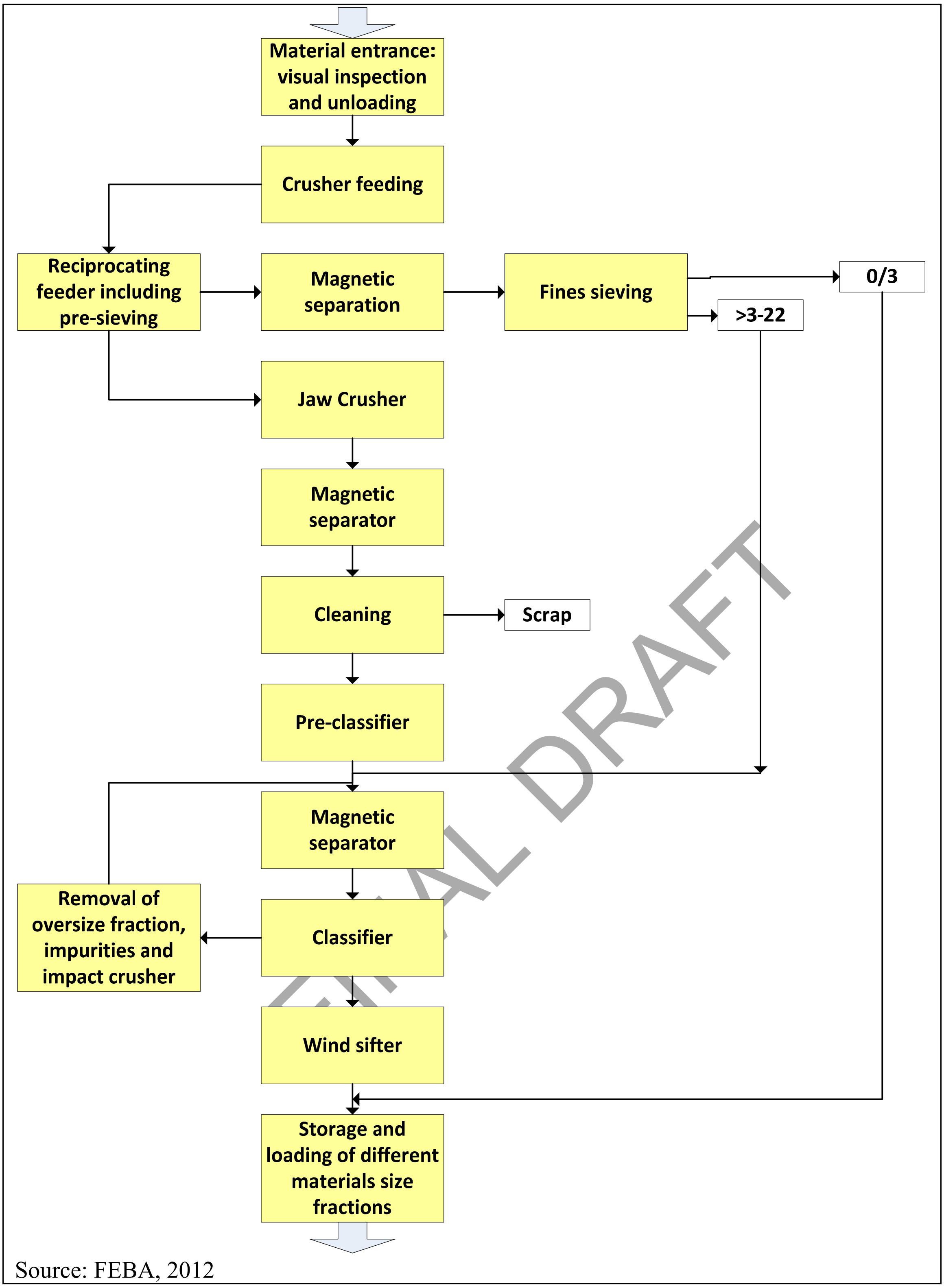
Cross-media effects

Crushing and sorting of materials consumes an significant amount of energy. The impacts of transport have to be minimised, as they also influence process economics. Transport must be adapted to site planning and logistics, and according to the selection of equipment (mobile or stationary). Mobile sorting devices usually create materials of lower quality than stationary installations. The use of wet separation is often more efficient in sorting and cleaning waste (also removal of pollutants), but creates waste water that must be treated.

Operational data

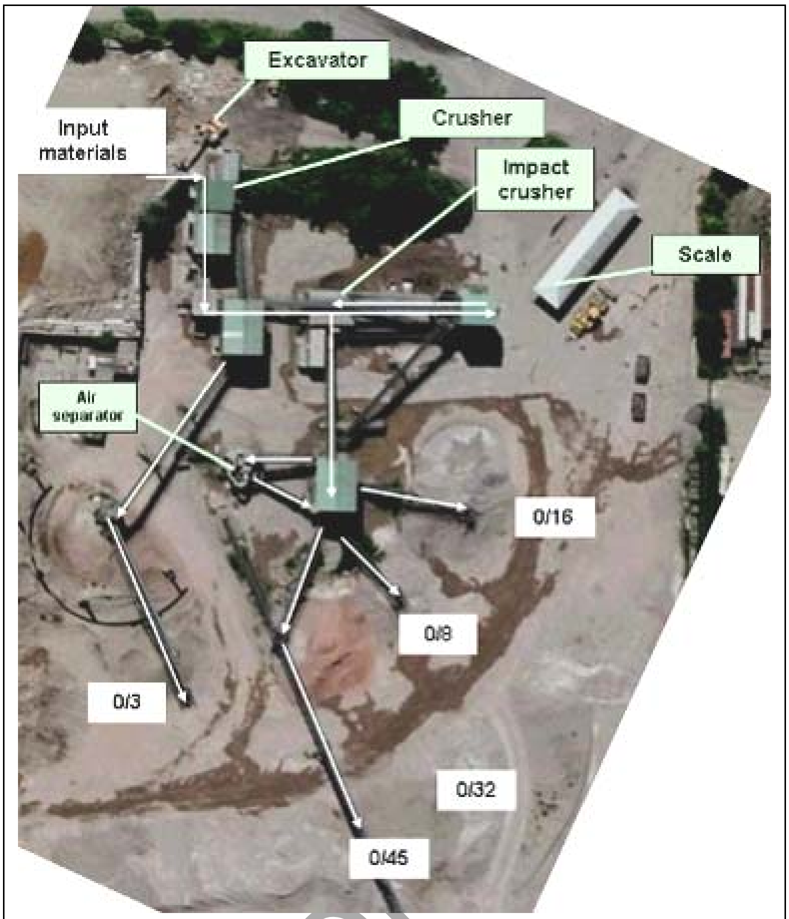
Construction and demolition waste recycling process: FEBA case study

An example of a construction and demolition waste recycling plant was provided by Feba, in Freiburg, Germany. (FEBA, 2012). Figure 7.7 shows a flowchart of the plant and Figure 7.8 shows an aerial view for the implementation of the recycling process.



Source: FEBA, 2012

Figure 7.7: Example of a recycling plant process



Source: FEBA, 2012

Figure 7.8: Aerial view of a recycling plant

With respect to reducing the landfilling of construction waste, in the mid 1980s the city of Freiburg initiated the construction and operation of the plant shown in Figure 7.8. As a private public partnership, the City provided the ground and contributed to the investment costs. As the start-up and operation proved successful, the city left the joint venture and sold the ground to FEBA who have been operating the plant.

The origin of the construction wastes is demolition projects, retrofits and repairs of buildings, and other structural design objects, road demolition debris such as asphalt, excavated material containing stones, concrete, masonry, tiles, roofing tiles, ceramics and natural stones. The materials are delivered by demolition companies, all types of construction companies, such as firms doing gardening and landscaping, civil engineering, building construction, pipeline construction, cable installation, forestry, as well as municipalities and authorities, engineering firms and architects. The main application areas for the recycled materials are road construction, gardening and landscaping, filling trenches, soil exchange, construction of agricultural roads, noise protection walls, industrial processing, etc. The plant has a capacity of about 120 000 tonnes per year. Nevertheless, as recycling plants typically do not have a stable level of input due to the variability of construction projects in a region, high storage capacities are required. As an example, Table 7.19 shows the input-output balance of the recycling plant. The annual quantity of products sold is usually different from the quantity of waste intake.

On a 2- to 3-year basis, all the processed materials received in the plant are recycled and, except for small quantities of contaminant fractions (wood fraction, material from the wind sifter and the foreign materials manually separated from the conveyor belt – see process description below), nothing is disposed of.

The plant is operated with one day-shift with six employees.

All input and output is weighed on two calibrated scales and automatically documented. Every delivery is visually checked. Analytical field equipment to detect tar is available. If accepted, the material is unloaded at different piles. From there, the materials are transported to the jaw crusher via a wheel loader. There, the input material is fed by an excavator to the jaw crusher via a reciprocating feeder. The experienced operator of the excavator again performs visual control of the feed material. The reciprocating feeder consists of a steel plate with holes (22 mm), so, a high percentage of fine particles are separated. After removal of metals by means of a magnet, this fraction is divided by a sieve into two fractions: 0-3 mm fraction (sand type), which is considered a product, and the 3-22 mm fraction which is mixed with the material coming from the jaw crusher.

After the separation of metals (by means of a magnet) and impurities (manually), the material flow from the jaw crusher is classified in several categories (0-8 mm, 0-16 mm, 0-32 mm, 0-45 mm using different sieves). The oversize fraction (>45 mm) is temporarily stored in a silo and undergoes secondary crushing in an impact crusher. The oversize fraction moves via a belt conveyor where plastic, metals, wood, etc is manually removed. The material from secondary crushing is fed to the classifiers.

The 22/32 and 22/45 fractions resulting from the classifier stage are fed to a wind sifter in order to remove impurities which could not be separated before (mainly small pieces of plastic). Dust is avoided through water spraying, with nozzles installed on the transport line just before the crushers.

The recycled materials must comply with a number of requirements. Certain conditions must be maintained, such as the sieving curve that is determined weekly by an independent third party (University of Karlsruhe), and the technical delivery conditions and the requirements on construction materials. This includes composition requirements (following max-values): 30 % asphalt, 30 % roof tiles, 1 % light construction material (such as pumice stone and Ytong), 5 % limestone or mineral plaster, 0.2 % wood, rubber, plastics, textiles as a sum and 0 % gypsum.

Four times a year, a representative sample is analysed for the following parameters: hydrocarbons (C_{10}-C_{22}-fraction and C_{10}-C_{40}-fraction), PAH according to US-EPA, EOX, PCB (6 congeners), phenol index, As, Pb, Cd, total Cr, Cu, Hg, Zn, chloride, sulphate, pH, conductivity. For more information on material quality and harmonisation of recycled products to be reused for construction, see Use of recycled materials in section 5.6.2.4.

Table 7.19: Input-output balance of the FEBA recycling plant

Waste Input	**LoW Number**	**2009 Tonnes**	**2010 Tonnes**	**2011 Tonnes**	**2009+2010+2011**
Concrete	170101	27 400	18 000	36 500	81 800
Bricks	170102	1 800	1 800	3 500	7 100
Tiles and ceramics	170103	1 000	1 400	200	2 600
Mixed	170107	8 400	6 500	15 000	29 900
Soil and excavated materials	170504	28 500	17 000	29 100	74 600
Asphalt and bituminous (mixed)	170302	12 900	16 900	20 200	49 900
Total Input		**79 900**	**61 500**	**104 600**	**246 000**
Waste Output		**2009 Tonnes**	**2010 Tonnes**	**2011 Tonnes**	**2009+2010+2011**
Waste for disposal		50	30	40	130
Sold scrap		260	170	420	850
Total		**310**	**210**	**460**	**980**
Product Output		**2009 Tonnes**	**2010 Tonnes**	**2011 Tonnes**	**2009+2010+2011**
Crushed brick 0/8		60	110	30	200
Crushed brick 0/16		180	360	40	590
Screening at 0/3 (sand)		6 100	3 400	9 500	19 000
Screening at 0/8		590	340	360	1 290
Screening at 0/16		4 700	3 100	2 500	10 300
FSS 0/32		9 700	10 400	8 800	28 900
FSS 0/45		48 300	61 000	44 300	153 600
STS 0/32		630	10	510	1 150
STS 0/45		2 800	12 400	13 500	28 800
Blown material 16/100		250	5 900	1 100	7 200
Special mixtures		730	2 100	1 500	4 300
Total-Output		**74 100**	**99 000**	**82 100**	**255 300**

Construction and demolition waste recycling process: SalmedinaTri case study

SalmedinaTri is a Spanish construction and demolition waste recycling plant with a very large back landfill (17 million tonnes and with an extended capacity up to 35 million tonnes). Due to the initiation of recycling activity, the lifetime of the landfill was extended from 10 years to more than 50 years.

The plant processing capacity is about 2 600 000 cubic metres per year, but currently processes 960 000 m^3. They have two treatment lines, one for clean concrete and the other for mixed waste (mainly ceramics plus concrete). The mixed waste line crushing is currently not in operation owing to the current unmarketability of aggregates. These wastes are screened, and sand from the first screening (in trommel) is used for municipal waste landfill sealing. The sand appears to be of the appropriate quality for this purpose. Concrete aggregate material is sold at EUR 2.75 per tonne, which is quite low considering its quality. More info on the input output balance can be seen in Table 7.20.

Table 7.20: Input-output balance for SalmedinaTri CDW recycling plant

Parameter	Value	Comments / Symbols
Waste input (approx)., m^3	960 000	A
Sand from mixed waste used for landfill sealing, m^3	360 000	B
Concrete aggregates (amount sold), tonnes	200 000	C
Non recyclable waste, m^3	211 000	D
Recovery rate,	78 %	R = 1- D / A
Accumulated input as recycled product, m^3	246 000	E = A - B - C/density - D
Total accumulated input,m^3	457 000	F = D+E
Accumulated input as recycled product, %	26 %	E/A
Total accumulated input %	48 %	F/A
Sold recycled product, %	15 %	(C/density) / A

One of the main problems for the operation of the plant is the low segregation rate, even though they employ two people and a skip for the first manual screening (removing plastics, cardboard, removable gypsum and others). Nevertheless, they have increased the recovery rate from 20 % in 2005 to 78 % in 2012. The high accumulation rate is noticeable (up to 48 % of materials stay in the plant)

There is no differentiated regulation for recycled aggregates, but European standards for CE marking are applicable. In Spain, there is a regulatory gap for quality criteria for construction and demolition wastes, and the potential hazards of polluted aggregates fall under the responsibility of the aggregate producer.

It is possible that the results from this plant are not exemplary in relation to other construction waste recycling plants. The technology used, the process used and the produced aggregates are not different from those shown in the previous section for the German plant. But, this example demonstrates how several local factors strongly influence the performance of construction and demolition waste recycling, namely:

- low segregation
- the huge stock of natural aggregates in the surrounding area is competing directly with recycled aggregates
- lack of public awareness
- lack of incentives for the use of recycled aggregates
- lack of control of illegal landfills.

In summary, this and preceding chapters have demonstrated that the integration of several best environmental management practices is required:

- Customers, developers and designers should prevent waste with an appropriate selection of materials with high recycled content (see Section 4), designing out waste (Section 3.4.7.1) and think about deconstruction (Section 3.4.7.2)

- Construction and demolition companies should prevent waste generation (Sections 5.6.1.1 and 5.6.2.1), increase material efficiency (Section 5.6.2.2), reuse as much as possible (5.6.2.4), separate and segregate waste materials (Sections 5.6.2.1 and 7.3.1) and use recycled products whenever possible to realise the highest achievable substitution of natural materials (Section 5.6.2.4)
- Demolition companies should be encouraged to harvest the highest amount of material possible, in a segregated manner, in order to achieve high recovery rates (e.g. 95 %) (see Section 7)
- Public administration should play an active role as a construction customer, and as a regulator (setting ambitious benchmarks for recovery rates, introducing landfilling taxes, controlling illegal dumping, etc.).

The aerial view of the SalmedinaTri plant, storage area and landfill is shown in Figure 7.9. The process aerial overview is shown in Figure 7.10.

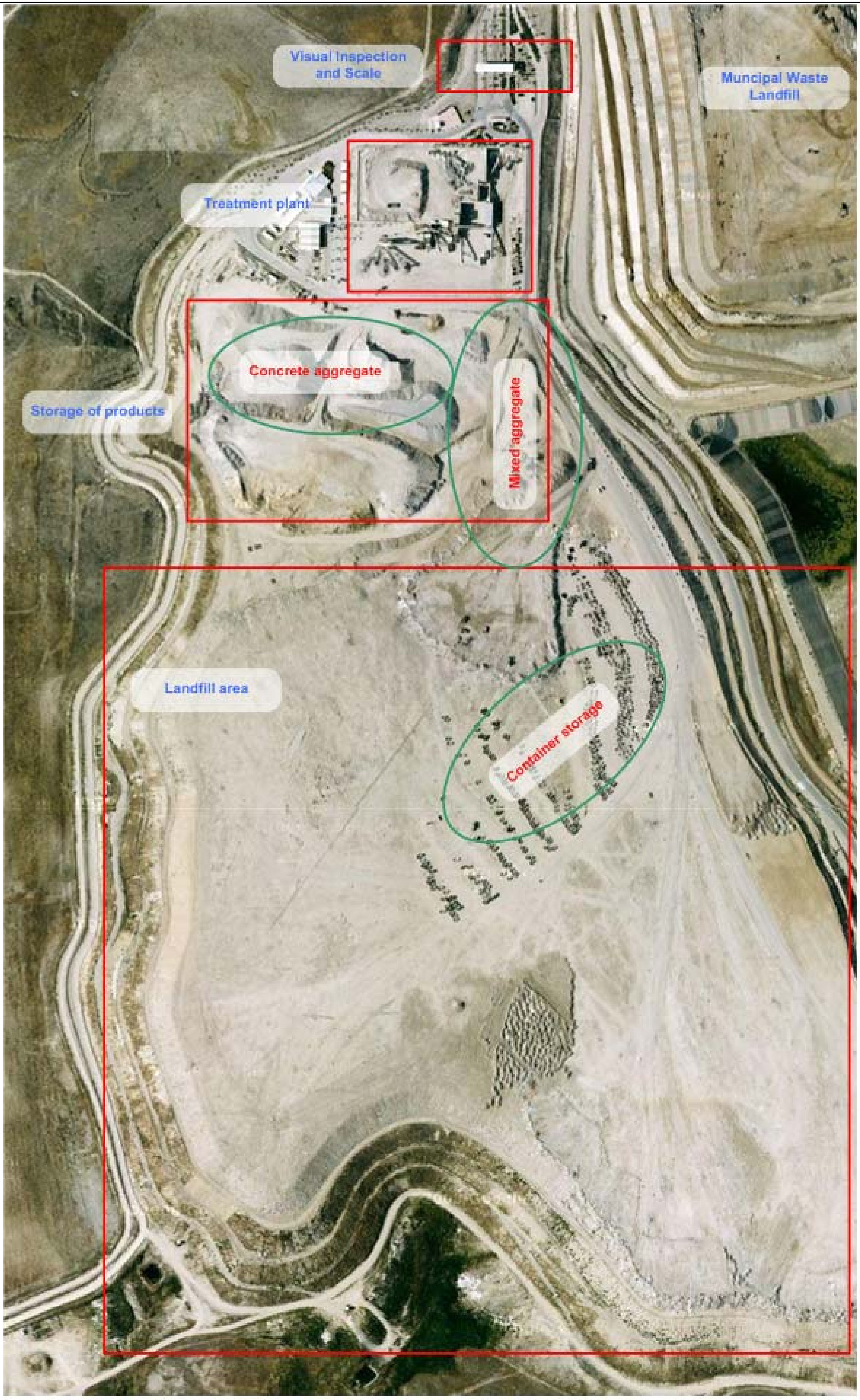


Figure 7.9: General overview of the Salmedina plant, storage and landfill area

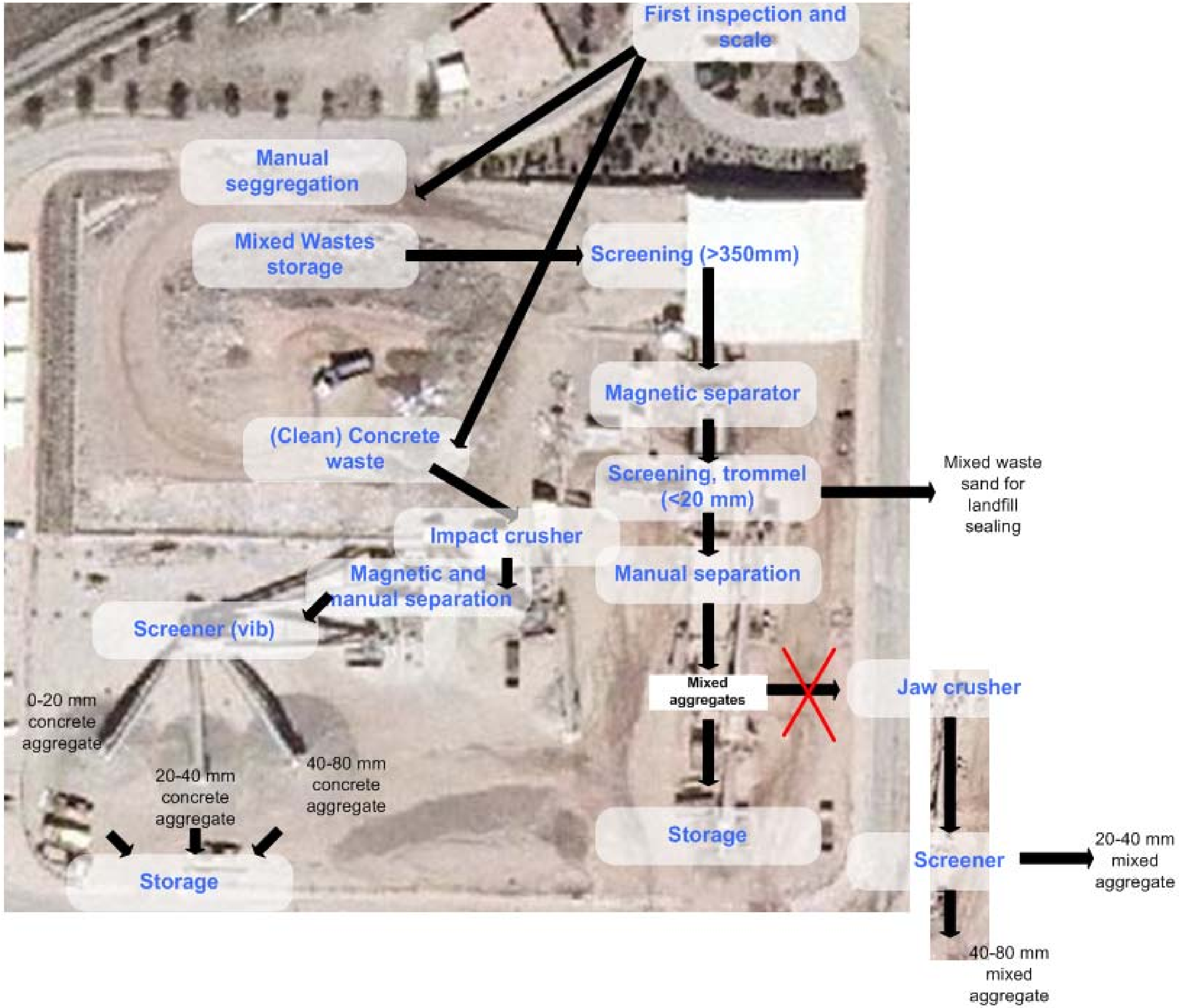


Figure 7.10: Overview of the recycling process at SalmedinaTri

Recycled products quality

Regarding the final applications, recycled product quality standards are the same as those for natural materials. Figure 7.11 shows some examples of recycled material fractions. More information on the applicability of recycled products in construction is shown in section 5.6.2.4.

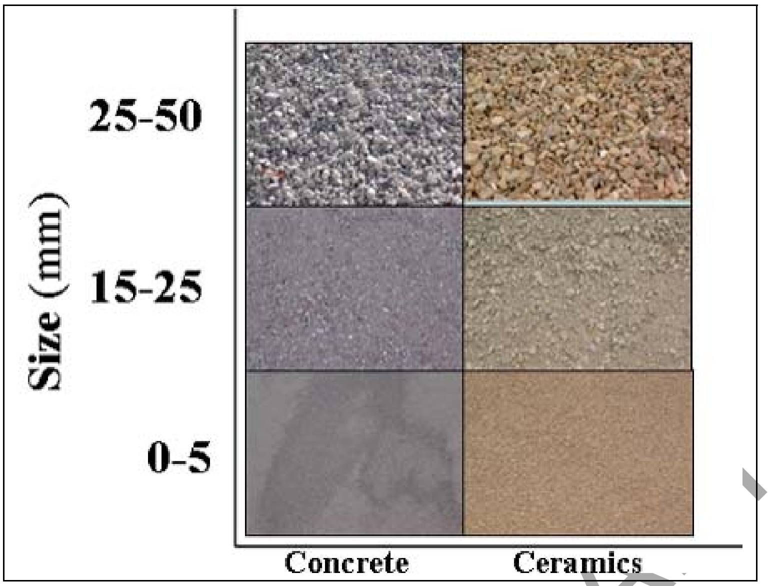


Figure 7.11: Different material sizes coming from concrete wastes and ceramics wastes

Applicability

Generally, applicable to all construction wastes though the quality requirements of planned recycling uses determine the degree of separation required. Market aspects can influence the final economic performance. Aggregates and other recycled products may have low acceptance levels in several European regions.

Economics

Little data are available concerning economics. In general, wet separation techniques produce purer fractions, but from an economic point of view, crushing, magnetic separation and airflow based separation is the preferred option (Scheibengraf and Reisinger, H., 2006).

Table 7.21 shows a comparison made for Germany in 2001 of recycling costs (or revenues) versus deposit fees. This table may be also compared with Table 5.35 from Section 5.6.2.1.

Table 7.21: Average deposit fees and recycling costs for various types of material in Germany

Category of Materials	Deposit Fees [EUR]	Recycling Costs [EUR]
Mineral materials		
Concrete Scrap	-	7 to 10 EUR/tonne
Bricks	-	7 to 10 EUR/tonne
Mixed mineral Materials	80 to 200 EUR/tonne	9 to 13 EUR/tonne
Metals		
Iron	-	-40 to 0 EUR/tonne
Aluminium	-	-250 to -100 EUR/tonne
Copper	-	-1000 to -250 EUR/tonne
Wood		
Untreated Wood	-	35 to 65 EUR/tonne
Lightly treated Wood	-	50 to 100 EUR/tonne
Treated Wood (pressure impregnation)		50 to 250 EUR/tonne
Other Building Materials		
Glass	-	30 to 65 EUR/tonne
Plastics	-	50 to 200 EUR/tonne
Mixed Building Materials *		
Mixed Materials (only recycling)		125 to 200 EUR/tonne
Mixed Materials (recycling and disposal)	125 to 300 EUR/tonne	
Mixed Materials (only disposal)	125 to 300 EUR/tonne	

Source: Schultmann, 2005.

* Mixed material has to be sorted according to its material composition

Driving force for implementation

The increase of the construction material recycling rate and, thus, the reduction of demolition waste to be landfilled, is the main driving force for selective deconstruction. Increasing legislative pressure for high recycling rates and bans on landfilling waste support the widespread use of (partly) selective deconstruction.

Reference organisations

- International Council for Research and Innovation in Building and Construction, Task Group 39 on Deconstruction, http://www.cibworld.nl
- Deutscher Abbruchverband e.V. (German demolition association), http://www.deutscher-abbruchverband.de/
- Recycling plant, FEBA (Germany). More info at www.febarecycling.de
- Recycling plant, Salmedina (Spain). More info at www.salmedinatri.com.

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8 CIVIL WORKS

8.1 Scope

Best environmental management practices specifically addressing civil engineering works (CEW) (e.g. roads, airports, railways, harbours, forestry work, etc.) are out of the scope of this reference document. Nevertheless, several indications will be provided here on the overlap between civil engineering construction works and building construction works. During the development of this document, it was agreed to develop a chapter highlighting the applicability of some of the techniques already described for buildings. In relation to this chapter, it should be taken into account that:

- Medium and large construction companies develop projects both for CEW and buildings.
- Environmentally friendly design options are regulated under the Environmental Impact Assessment Directive. Nevertheless, there is no regulated indication on best environmental management practice for the design of infrastructure. A completely new reference document would be needed to cover all the types of infrastructure construction.
- Generalisation is not always possible, as local circumstances often play a critical role in the applicability of best environmental management practices, especially for planning and design. Construction activity can be better assessed following a horizontal approach regarding, for instance, waste, natural waterways, dust, noise, machinery energy efficiency, etc.
- Some indications on environmental criteria for the lowest impact on biodiversity and land use planning, with respect to public administration responsibility, will be summarised here, although more detail will be provided in the reference document for public administration.
- Although some evident indicators or benchmarks of excellence can be described here, these should be regarded as informative only. A more detailed analysis is required to develop specific best environmental management practices for the implementation of environmental management systems at civil engineering construction works.

8.2 Introduction

The construction of civil infrastructure produces very similar environmental impacts to building construction, and the environmental aspects to be managed are also similar in nature. Nevertheless, the magnitude of the environmental impact, the biodiversity aspect, organisational management and allocation of resources differ between common building practices and among different civil works. For instance, the generation of waste in road construction is dominated by excavated soil, and design practices tend to aim to balance excavation and filling in order to avoid external management of excess soil.

Planning and design is partiuclarly important, as the lifetime of infrastructures and its presence can lead to significant and usually permanent habitat loss and fragmentation, can alter habitat conditions, disrupt patterns of wildlife movement and cause wildlife mortality, as is usually the case for roads, railways and many other civil works. For instance, the length of motorways has increased by 19 % over the last ten years, from 16 metres to 19 metres per km^2, and countries like Spain and Portugal have gone from an average of 17-18 m per km^2 to almost 30 m per km^2 in only ten years (see Figure 8.1).

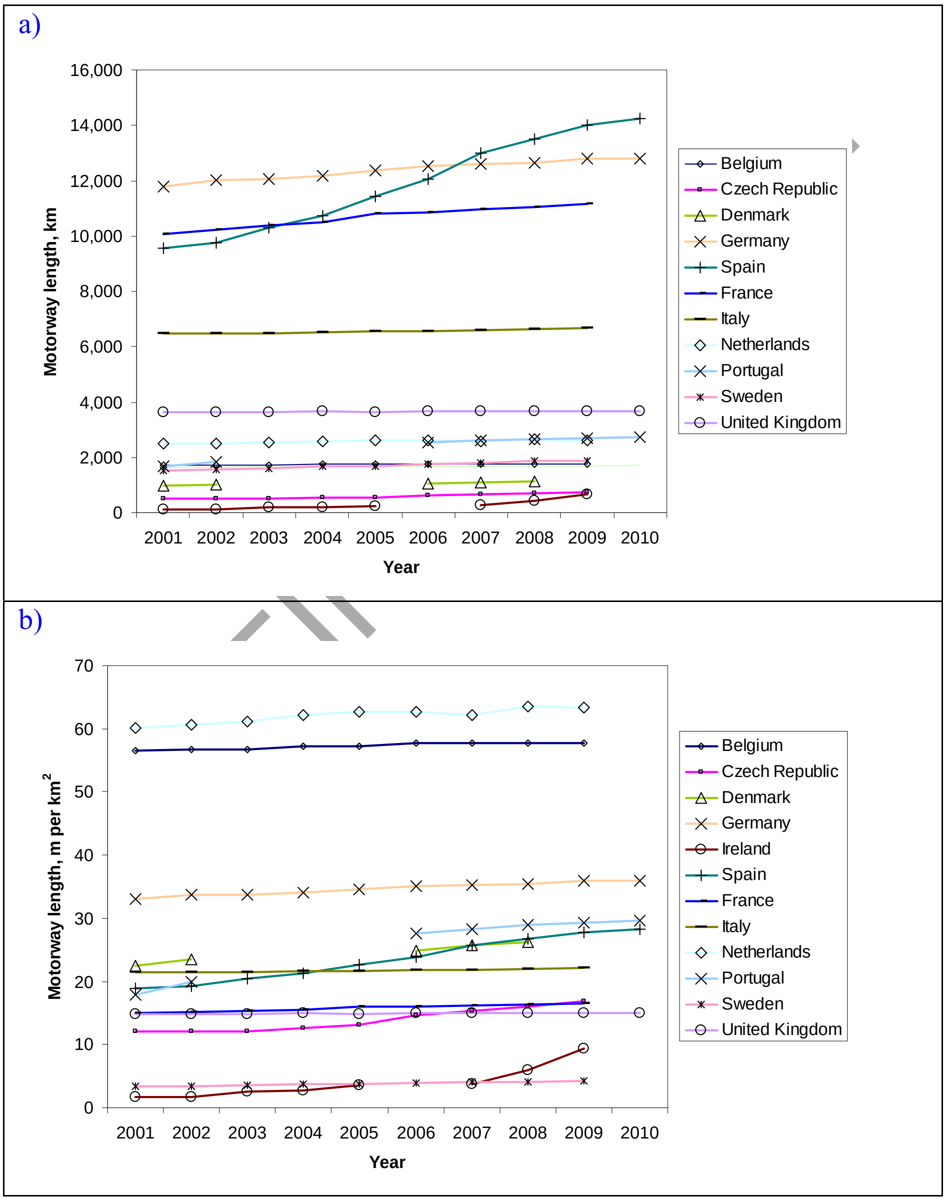

Figure 8.1: Ten years evolution of motorway length and length per km^2 for European countries

As for the building sector, the main environmental impacts are considered during the planning and design stages (see section 5.3). The significance of the environmental impact of civil works is large enough to be considered under the Environmental Impact Assessment Directive.

The EIA Directive on the assessment of the effects of certain public and private projects on the environment was adopted in 1985 and amended by Directives 97/11/EC61, 2003/35/EC62 and 2009/31/EC63. The Directive was codified along with the amendments in the directive 2011/92/EU. The assessment of the effects of certain public and private projects on the environment is a procedure, integrated in the existing procedures for consent, ensuring that environmental consequences of projects are identified and assessed before authorisation is given, where the public is correctly informed of the request for development consent early in the environmental decision-making procedures and, at the latest, as soon as information can reasonably be provided. Regarding civil works, the Directive makes the assessment of several projects, especially industrial installations and civil engineering projects (gathered in Annex I of the Directive), mandatory. Specifically, construction related projects falling under the scope of the impact assessment are:

- Construction of lines for long-distance railway traffic and of airports with a basic runway length of 2 100 m or more;
- Construction of motorways and express roads.
- Construction of a new road of four or more lanes, or realignment and/or widening of an existing road of two lanes or less so as to provide four or more lanes, where such new road or realigned and/or widened section of road would be 10 km or more in a continuous length.
- Inland waterways and ports for inland-waterway traffic which permit the passage of vessels of over 1 350 tonnes.
- Trading ports, piers for loading and unloading connected to land and outside ports (excluding ferry piers) which can take vessels of over 1 350 tonnes.
- Works for the transfer of water resources between river basins where that transfer aims to prevent possible shortages of water and where the amount of water transferred exceeds 100 million cubic metres/year.
- In all other cases, works for the transfer of water resources between river basins where the multi-annual average flow of the basin of abstraction exceeds 2 000 million cubic metres/year and where the amount of water transferred exceeds 5 % of that flow.
- Waste water treatment plants with a capacity exceeding 150 000 population equivalent as defined in point 6 of Article 2 of Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment.
- Dams and other installations designed for the holding back or permanent storage of water, where a new or additional amount of water held back or stored exceeds 10 million cubic metres.

According to the Directive, Member States may establish a case-by-case methodology or thresholds for the assessment of other projects (in Annex II of the directive). Relevant infrastructure projects are:

- Industrial estate development projects.
- Urban development projects, including the construction of shopping centres and car parks.
- Construction of railways and intermodal transhipment facilities, and of intermodal terminals (projects not included in Annex I).
- Construction of airfields (projects not included in Annex I).
- Construction of roads, harbours and port installations, including fishing harbours (projects not included in Annex I).
- Inland-waterway construction not included in Annex I, canalisation and flood-relief works.
- Dams and other installations designed to hold water or store it on a long-term basis (projects not included in Annex I).
- Tramways, elevated and underground railways, suspended lines or similar lines of a particular type, used exclusively or mainly for passenger transport.

- Oil and gas pipeline installations and pipelines for the transport of CO_2 streams for the purposes of geological storage (projects not included in Annex I).
- Installations of long-distance aqueducts.
- Coastal work to combat erosion and maritime works capable of altering the coast through the construction, for example, of dykes, moles, jetties and other sea defence works, excluding the maintenance and reconstruction of such works.
- Groundwater abstraction and artificial groundwater recharge schemes not included in Annex I.
- Works for the transfer of water resources between river basins not included in Annex I.

The effects of a project should be estimated according to the following factors:

- Human beings, fauna and flora.
- Soil, water, air, climate and the landscape.
- Material assets and the cultural heritage.
- The interaction between the factors mentioned in the first, second and third indents.

The role of Public Administration is relevant; they are committed to give public information during the development of projects and are also responsible for giving permits and establishing consents for the development of projects. In addition, according to Directive 2001/42 on the assessment of the effects of certain plans and programmes, public administrations are required to develop the environmental impact assessment of lands and programmes for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use (which may require the development of projects in Annex I and II of Directive 2011/92) or other plans and programmes requirering assessment according to criteria developed by Member States.

Regarding the environmental aspects, every CEW project may have different environmental impacts, although there may be some similarities in the number of environmental aspects to be managed. Usually, civil works produce a significant environmental impact and, among other measures, the management of environmental aspects by stakeholders is essential (e.g. developer, customer, contractor and subcontractors, municipalities, etc.). Table 8.1 shows an example from the assessment of relevant environmental aspects in the construction of a tunnel (Geldermalsen, 2004). As shown, planning, feasibility and design have the strongest influence on the environmental impact, which mainly arises during the use and realisation phases. Specifically, the main influence is attributed to initial feasibility and conceptual design decisions. Appropriate planning can avoid a large amount of the environmental impact. An integrated view is absolutely necessary, as lack of action during one of the project stages would reduce the significance of outstanding practices applied in other stages.

Table 8.1: Environmental aspects per relevance, for a tunnel construction example

Environmental issue	Environmental effects/aspect	Feasibility study	Conceptual design	Outline design	Detailed design	Realisation	Exploitation
Emissions	Air pollution (traffic during exploitation)	■	■	■	■	□	▨
Living conditions	Noise & vibrations during exploitation	■	■	■	■	□	▨
Energy	Traffic during exploitation	■	■	▨	▨	□	□
Cultural quality	Visual design and landscape values	■	■	▨	▨	□	□
Environmental quality	Groundwater level during realisation	▨	■	■	■	■	□
Environmental quality	Soil stability during realisation	□	■	■	■	■	□
Habitat	Fragmentation of habitats	■	▨	□	▨	▨	□
Habitat	Degradation of habitat	■	▨	□	▨	▨	□
Habitat	Disturbance of fauna	■	▨	□	▨	▨	□
Cultural quality	Historical and cultural heritage	■	▨	□	▨	▨	▨
Energy	Installations	□	▨	■	■	□	□
Living conditions	Noise, vibrations & dust during realisation	□	▨	▨	▨	■	□
Emissions	Waste water	□	▨	▨	■	■	▨
Emissions	Pollution of ground and groundwater	□	▨	▨	■	■	▨
Materials	Primary building materials	□	▨	▨	■	□	□
Materials	Secondary building materials	□	▨	▨	■	□	□
Materials	Reusable excavated material	□	▨	▨	■	□	□
Materials	Chemical products	□	▨	▨	■	□	□
Materials	(Dangerous) waste material	□	▨	▨	■	□	▨
Environmental quality	Quality of soil and groundwater	▨	▨	▨	▨	■	□
Emissions	Pollution of excavated material	□	▨	▨	▨	■	□
Cultural quality .	Archaeological values etc	□	□	□	□	■	□
Materials	Renewable materials	□	▨	▨	■	□	□
Emissions	Pollution of surface water	□	▨	▨	▨	▨	▨
Cultural quality	Demolition of real estate etc.	□	▨	▨	▨	▨	□
Energy	Production of building materials	□	▨	▨	▨	□	□
Energy	Transport of building materials	□	□	□	□	▨	□
Energy	Construction equipment	□	□	□	□	▨	□
Environmental quality	Air quality	▨	□	□	□	□	□
Environmental quality	Surface water quality	▨	□	□	□	□	□
Emissions	Air pollution (explosives/rock tunnel)	□	□	□	□	▨	□

N.B. Source: (van Geldermalse, 2004)

■ Relevant
▨ Partially relevant
□ Not relevant

The impact of civil engineering on biodiversity is often significant (BB, 2012). These impacts can be on site (those produced because of the use or construction of the civil works) or off site (derived from the existence of civil works, such as water table depletion, loss of flood plain capacities, etc.), direct (directly influenced by planners, designers, contractors etc.) or indirect (which can be influenced during the use phase or due to sourcing of materials). A summary of environmental impacts associated with civil engineering works are shown below:

- **On-site disturbance**: there is a particularly significant impact on designated sites. In some cases, protected species may only be discovered late in the planning and realisation process. Proper management should protect species and these should never been seen as an inconvenience or impediments.

- **Off-site impacts**. Indirect effects on adjacent areas because of air pollution, water pollution, hydrological impacts, disturbance, increased risks of fires, unregulated access to protected areas, isolation, fragmentation and displacement are mechanisms that generate environmental stress for species that are not clearly identified in standard environmental impact assessments. These should be correctly managed by stakeholders, taking them into account from an early stage in the decision making process.
- **Disturbance and fragmentation**. Noise and light during construction affect feeding and breeding behaviours. Use of land can separate habitats, modifying mobile species dynamics.
- **Sourcing of materials**. Timber, gravel, sand, etc. are products whose extraction produce a significant effect on biodiversity.

A special focus on biodiversity is made in Section 2.2.1.

References

BB, Buisness and Biodiversity, 2012. Construction sector, biodiversity and wildlife conservation. Available at www.businessandbiodiversity.org/construction.html, last access on 27/2/2012

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Van Geldermalsen, L.A. 2004. Environmental Aspects in Tunnel Design. First Intenational Syposium on Safe and Reliable Tunnels. Innovative European Achievements.

8.3 Common best environmental management practices of civil engineering works and building construction

This section refers to the overlap between management practices related to building construction and civil engineering works. Herein, it is important to highlight that similarities of environmental aspect management occur mainly in the construction phase. Planning and design for CEW is unique and covered by separate regulations. Reference documents for best environmental management practice always focus on the full value chain. However, the huge number of techniques and products for CEW would require separate documents for every single activity. This document only deals with buildings and it is likely that other documents or guidelines would be needed for roads, railways, etc., especially regarding planning and environmentally friendly design.

Building and CEW demand a huge amount of natural materials and construction products, and both are affected by construction product regulation. Concrete is the main product used, although, generally speaking, more environmentally friendly construction products are preferred for all uses. The availability of ecolabeled, third party verified products with substantially improved environmental performances may vary considerably for construction companies across Europe. In addition, CEW end-of-life shares some similarities with buildings end-of-life, and may require highly specific deconstruction techniques in order to increase the recyclability of harvested materials, although the nature of these materials is often fundamentally different to those harvested from buildings. The large scope of activities under the CEW term requires a diversity of techniques that can, nontheless, all be considered under the same environmental management concept.

Regardless of the magnitude of the scope of CEW, it is notable that a large number of common aspects and, therefore, best environmental management practice techniques, apply to all construction sites. In addition, many contractors are companies working both with building and civil works. For instance, the nature of wastes is often similar, and the same standards and laws are applicable. A summary of these is shown in Table 8.2.

Of course, the magnitude and intensity of environmental risks is different between building practices and CEW practices, and may thus require different approaches, even within the same management system of the same company, because of the different impacts. For instance, dust is generated in dry climates for both building and CEW construction, but its management may be quite different. While a building construction site can easily cover the full exposed area with aggregates to facilitate vehicle movements and avoid dust generation, it is not possible to do so in the construction of a road. For this example, neither the magnitude of the impact nor the practices to avoid or mitigate them are the same.

Another example is waste. Waste management requires a large area for waste handling, especially if the expected segregation rate is high. This is only possible in the construction of buildings without neighbouring buildings. For some CEW, space availability is not a critical concern, but the dispersion of waste generation hotspots (e.g. for roads) necessitates the allocation of a large quantity of resources for proper waste segregation.

Table 8.2: Best Environmental Management Practices for CEW during construction

Environmental aspect	Related Best Environmental Management Practices	Related sections
All	Organisational EMS	5.6.1.1
All	Environmental Management Plan	5.6.1.1, 5.6.1.2
All	Monitoring	5.6.1.2
All	Awareness and communication practices	-
All	Public administration role	See Public Administration Reference Document
Materials and construction products	Use of environmental criteria	4.3.1.1
Materials and construction products	Materials use efficiency	5.6.2.2, 5.6.2.3
Materials and construction products	Use of recycled materials	5.6.2.4
Waste	Waste prevention	5.6.2.1, 5.6.2.2
Waste	Reuse of materials	5.6.2.3
Water	Protection of natural waterways and drainage systems	-
Energy	Energy efficient equipment	5.6.2.7
Dust	Dust prevention and management	5.6.2.5
Soil	Erosion and restoration	2.2.1, 4.3.1.1

It is not within the scope of this document to cover the specificities of CEW construction. An assessment of overlapping and shared schemes is not likely to be useful in the absence of an overview of the environmental performance of civil works. Chapter 2 covers some relevant issues for biodiversity, which is also linked to land planning and the public administration sectoral reference document. Furhermore, an important linkage between building construction and civil engineering is that road construction and other CEW projects can be significant repositories for recycled materials (e.g. as road bases). This reuse/recycling of materials has become quite important.

Herein, some examples of outstanding environmental practices, collected during the development of this document, are given.

Recycled asphalt.
Recycled asphalt has been used for several years for road pavements all over the world. Old asphalt from previous construction projects can be 100 % recycled. Therefore old asphalt can be removed and incorporated into new pavements. Hence this material is not transported to local landfills. The quality and resistance of asphalt can be enhanced close to that of concrete by incorporating modifying additives. Bitumen is easily recycleable up to 100 %, due to its thermoplastic characteristics. The softening and hardening of bitumen is a reversible process. The recycling of bitumen is either performed in mixing plants or on site. For production in mixing plants, old asphalt is crushed and the recycled material is reused as additives in the production of new asphalt, for loose binder, base and bounded courses. The old road surface is heated in situ, removed and replaced again directly after adding extra aggregates and bitumen.

The application of asphalt in general and recycled asphalt in particular in the road construction process has a positive effect on the environment. The production of 1 m^3 asphalt pavement requires only 50 % of the energy consumed for 1 m^3 concrete, because producing bitumen consumes only 20 % of the energy required for cement production. Recycled asphalt reduces the use of natural resources through aggregate mining and extraction and refining of crude oil. Used asphalt is 100 % recycled, hence transportation of old asphalt and land use for landfill are reduced.

Pavement minimising noise – open-pored asphalt layer

By using open-pored asphalt or whispering asphalt with a high void content instead of normal asphalt for road construction, noise emission can be reduced directly at source without any deformation problems or other negative outcomes. Air-pumping noise, which occurs when the air within the tyre profile is compressed through the weight of the vehicle and is set free explosively, increases with increasing density of the road surface. Hence air-pumping noise is minimised through open-pored asphalt, as compressed air can escape sideways. This open-pored asphalt with void content above 22 % reduces noise by more than 8 dB. To produce good quality open-pored asphalt, the percentage of coarse grains has to be at least 90 wt. %. Good grain sizes have a length:thickness-ratio of higher than 3:1.

Open-pored asphalt is applied as single-layer or double-layer asphalt. The double-layer technique, with an open-pored bottom layer and a denser, but still open-pored upper layer, is longer lasting with regard to noise-protection abilities than the single-layer technique, as the small voids are less susceptible to contamination.

In general the technique is applicable on all motorways and streets. It is most effective on motorways, where high speeds (> 60km/h) are allowed and where the major noise is the interaction between tyres and the road surface. The technique is applied on various motorways all over Europe. For instance, since 2003 all new motorways in Italy have been constructed with this asphalt type, and also the Netherlands use it to a great extent. The pilot project in Germany, the western ring street in Ingolstadt, Bavaria, showed that traffic noise could be reduced by more than eight decibels. Older versions of open-pored asphalt led to problems in winter, as frozen water in the pores destoyed the surface, but recent products have solved this issue.

Environmental criteria for the assessment of Civil Engineering and Infrastructure

The spread of environmental labels for civil engineering and infrastructure construction is less extensive than for buildings. So, assessment methods for the overall performance of infrastructure, and benchmarks, are still to be developed. Nevertheless, some schemes have already been developed in Europe, such as the CEEQUAL example. CEEQUAL is an award scheme for civil enginnering infrastructure. It is aimed at improving the specifications and, among other aspects, the environmental performance of Civil Works beyond legal requirements. It uses a rating system to achieve a total score. This system can be used to encourage and raise awareness among planners and designers to take into account some environmental and, generally, sustainability criteria in the early stages of project development. These criteria and weighing methods are proposed by CEEQUAL (CEEQUAL, 2012) within its 4th version:

- Project Management (10.9 %) covers the need for environmental risk assessments and active environmental management, training, the influence of contractual and procurement processes, delivering environmental and social performance, construction issues, minimising emissions.
- Land Use (7.9 %) covers design for minimum land-take, legal requirements, flood risk, previous use of the site, land contamination and remediation measures.
- Landscape (7.4 %) covers consideration of landscape issues in design, amenity features, local character, loss and compensation or mitigation of landscape features, implementation and management, and completion and aftercare.

- Ecology & Biodiversity (8.8 %) covers impacts on sites of high ecological value, protected species, conservation & enhancement, habitat creation measures, monitoring and maintenance.
- The Historic Environment (6.7 %) covers baseline studies and surveys, conservation and enhancement measures to be taken if features are found, and information and public access.
- Water resources and the Water Environment (8.5 %) covers control of a project's impacts on, and protection of, the water environment, legal requirements, minimising water usage, and enhancement of the water environment.
- Energy and Carbon (9.5 %) covers life cycle energy and carbon analysis, energy and carbon emissions in use, and energy and carbon performance on site, but not embodied energy, which is in Section 8.
- Material Use (9.4 %) covers reducing the environmental impact of materials used, minimising material use and waste, responsible sourcing of materials including selection of timber, using reused and/or recycled material, minimising use and impacts of hazardous materials, durability and maintenance, and future de-construction or disassembly.
- Waste Management (8.4 %) covers design for waste minimisation, legal requirements, waste from site preparation, and on-site waste management.
- Transport (8.1 %) covers location of a project in relation to transport infrastructure, minimising traffic impacts of a project, construction transport, and minimising workforce travel.
- Effects on Neighbours (7.0 %) covers minimising operation and construction-related nuisances, legal requirements, nuisance from construction noise and vibration, and from air and light pollution, and visual impact, including site tidiness.
- Relations with the Local Community and other Stakeholders (7.4 %) covers community consultation, community relations programmes and their effectiveness, engagement with relevant local groups, and human environment, aesthetics and employment.

Reference

CEEQUAL, Sustainability and Assessment Awards for Civil Engineering, Infrastucture, Landscaping and the Public Realm. Version 4. Available at www.ceequal.com, last access on 27/3/2012.

Waste prevention: A46 Improvement, Balfor Beatty case study.

Balfor Beatty provided the example of the A46 motorway, Newark to Widmerpool (UK), for this document. The framework for this project was the achievement of 50 % waste reduction to landfill by 2012 in order to achieve zero waste to landfill objectives, according to the Balfor Beatty Group 2020 Vision Roadmap.

First, an integrative approach was established. Priorities were given according to the waste hierarchy:

- Minimise: Designing out waste, Just-In-Time deliveries, appropriate material storage and handling, accurate material orders.
- Reuse of pallets, polypipe offcuts, top soil and fill balance.
- Recycle concrete, bituminous based plannings, wood packaging, canteen oil, plastics, cateen food, metals, clinical waste, hazardous wase, electronic waste/
- Waste to energy at the cement factory.

At completion, 0 kg of waste from the construction of this road went to landfill and 100 % seggregation was achieved for waste reuse and recycling. Unrecyclable waste was only 0.9 %, which was incinerated in a cement kiln to recover energy.

Reference

Balfor Beatty, 2011, Personal communication..

CACEC case studies.

CACEC(36) is the Spanish advisory board for the certification of construction companies. It is composed of big construction companies, umbrella organisations, public administrations and AENOR – the Spanish standardisation body. Construction companies are dedicated to both building and civil works, although their main activity is related to civil engineering. During the development of this work, several examples of the application of best environmental management practice were given (CACEC, 2012). Some of the most relevant implemented practices are given in Table 8.3.

Table 8.3: Best Environmental Management Practice for CEW during construction

Aspect	**Related Best Environmental Management Practices**	**Practical Implementation**
All	Organisational EMS	CACEC companies have implemented environmental management systems, which are certified under ISO 14001
All	Monitoring	Construction companies have applied a monitoring system, managing a number of indicators according to ISO 14031
All	Awareness and communication practices	Development of guidelines for office work. Environmental awareness training courses for labourers and workers. Development of guidelines for workers and managers on environmental management and practices. Developemnt of guidelines and requirements for the environmental performance of subcontractors.
All	Redesign and public administration role	A case study on the implementation of redesign practices were shown for the construction of a drinking water treatment plant. Final design result in lower consumption of resources and less required earthworks.
Materials	Materials use efficiency	Implementation of Just-In-Time, planning practices, appropriate storage
Materials	Use of recycled materials	Some examples on the use of recycled materials from waste produced from demolition activities are given. Usually, they own one or two portable recycling plants, avoiding the use of natural materials.Pavement recycling.
Waste	Waste prevention	Implementation of Just In Time, planning practices.
Water	Affectation of natural waterways and drainage systems	Recovery and reuse of water from concrete pipes cleaning by sedimentation and fat separation. Water treatment by sedimentation for large emmissions to natural water ways Water reuse, where feasible.
Energy	Energy efficient equipment	Use of Biodiesel to reduce CO_2 by up to 90 %.
Dust	Dust prevention and management	Dedusting activitis in concrete plants and liner coverage for shot blasting activities. Periodical water irrigation.
Soil	Erosion and restoration	Use of barriers to avoid water turbidity due to works in lakes and coasts.
Noise, vibration, light and other disturbance.	Avoiding disturbance to neighborhood	Screens and noise barriers. Reduction of light pollution during night works. Wheel washers to avoid street dirtiness.
Biodiversity	Biodiversity protection	Trees, vegetation and roots protection at construction sites with big impact. Monitoring and corrective measures for local biodiversity (e.g. birds, trees). Transplanting and/or compensation measure. Use of greenwalls.

N.B. Source: CACEC, 2012

Reference

CACEC (Spanish Advisory Board for the Certification of Construction Companies), 2012. Personal communication. Madrid, 7th and 8th February 2012.

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(36) The working group on environment of CACEC contributed to the elaboration of this document. Companies from CACEC do not allow to be referenced separately, so references are given to CACEC communications.

8.4 Impact on biodiversity

Civil works, such as road construction, may divide up land and separate previously adjacent areas. **Fragmentation results** in habitat loss and degradation and can influence population dynamics, in particular for mobile species that rely on large habitats for foraging, breeding, migration and dispersal (EEA, 2011a). The impact of habitat fragmentation on different species can be complex and may lead to gradual declines in populations. Furthermore, fragmentation may prevent populations and communities from moving across the landscape in response to changing environmental conditions, especially climate change.

To some extent, landscape fragmentation due to transport infrastructure can be avoided or mitigated by environmentally sensitive planning and by implementing specific measures that reduce the barrier effects of roads and railways. Transport regulations or guidelines can be used to guide the development of transport networks away from areas of conservation importance (for example, by preventing the development of roads and railways within large areas of contiguous ecologically valuable habitat). Strategic Environmental Assessments (SEAs) provide a suitable tool for addressing these issues.

Artificial pathways such as wildlife bridges and tunnels and other measures to reduce collision risks can be used to improve the permeability of transport networks. Such measures can reduce mortality rates and enable certain species to cross roads and railways. However, in order to effectively support the movement of species within fragmented landscapes, artificial passages need to be designed and located according to scientific studies of connectivity needs. Moreover, encouraging movement of species along transport corridors can have a negative impact if it facilitates the spread of alien species.

Green infrastructure is a concept used to address the connectivity of ecosystems and their protection. At the same time, it addresses mitigation and adaptation to climate change. It promotes integrated spatial planning to identify multifunctional zones. Connectivity in land planning should be considered (e.g. linking peri-urban and urban areas and marine spatial planning). Two main scales are used to define and design green infrastructure: urban scale and landscape scale. The first is important for municipalities managing significant built environments, while the second involves many types of land, such as built area, farmed land or other types (EEA, 2011b).

The scale of green infrastructure is one characteristic that may be used to categorise these:

- Local, neighbourhood and village scale: trees, verges, hedges, green roofs, green walls, urban plazas, town and village green commons, etc.
- Town, city and district: business settings, urban canals, forst parks, country parks, lakes, rivers, etc.
- City-region, regional and national scale: regional parks, rivers, shorelines, forests, reservoirs, etc.

The use of green infrastructure can have many benefits when the approach for this infrastructure is to provide the widest range of functions. Among others, one of the main benefits is the provision of main ecosystem service types (EEA, 2011b) which produce several environmental, economic and social benefits:

- Habitat Services
    - Biodiversity protection
        - Habitatas for species
        - Permeability for migrating species
        - Connecting habitats
- Regulating services
    - Climate change adaptation

    - Mitigating urban heat island (see 2.2.4)
    - Strengthening ecosystems resilience
    - Storing floodwater and amelioriating surface water run-off
  - Climate change mitigation:
    - Carbon sequestration
    - Encouraging sustainable travel
    - Reducing energy use for heating and cooling buildings
    - Providing space for renewable energy
- Provisioning services:
  - Water Management:
    - Sustainable drainage systems
    - Fostering groundwater infiltration
    - Removal of pollutants from water
  - Food production and security
    - Direct food and fibre production on agricultural land, gardens
    - Keeping potential for agricultural land
    - Sil development and soil cycling
    - Preventing soil erosion
- Cultural services
  - Recreation, well being and health:
    - Recreation
    - Sense of space and nature
    - Cleaner air
    - Tourism and ecotourism
  - Land values:
    - Positive impact on land and property
  - Culture and communities:
    - Local distictiveness
    - Opportunities for education, training and social interactions
    - Tourism opportunities

Best practice implementation of green infrastructure should define targets and goals through spatial land use planning. So, the role of the public administration is essential in preserving and encouraging green infrastructure. Policy-driven measures are very relevant for the application of green infrastructure. The European Environment Agency provides some examples (EEA, 2011b). It is also recommended to consult the sectoral reference document on best environmental management practice for the public administration sector, which addresses best practices for biodiversity.

References

European Environment Agency, 2011a. Landscape fragmentation in Europe. EEA Technical report 2/2011.

European Environment Agency, 2011b. Green Infrastructure and Territorial Cohesion. EEA Technical report 18/2011.

8.5 Waste Recycling

Civil works represent great opportunities for waste recycling, as they consume a huge volume of aggregates that are easily replaceable by recycled aggregates that may be lower quality than required for technical applications in the case of buildings (e.g. for non structural concrete). Several flows of material may be established when dealing with construction of CEW (Figure 8.2., Figure 5.30 for reuse and recycling best practices, Section 5.6.2.3 and 5.6.2.4).

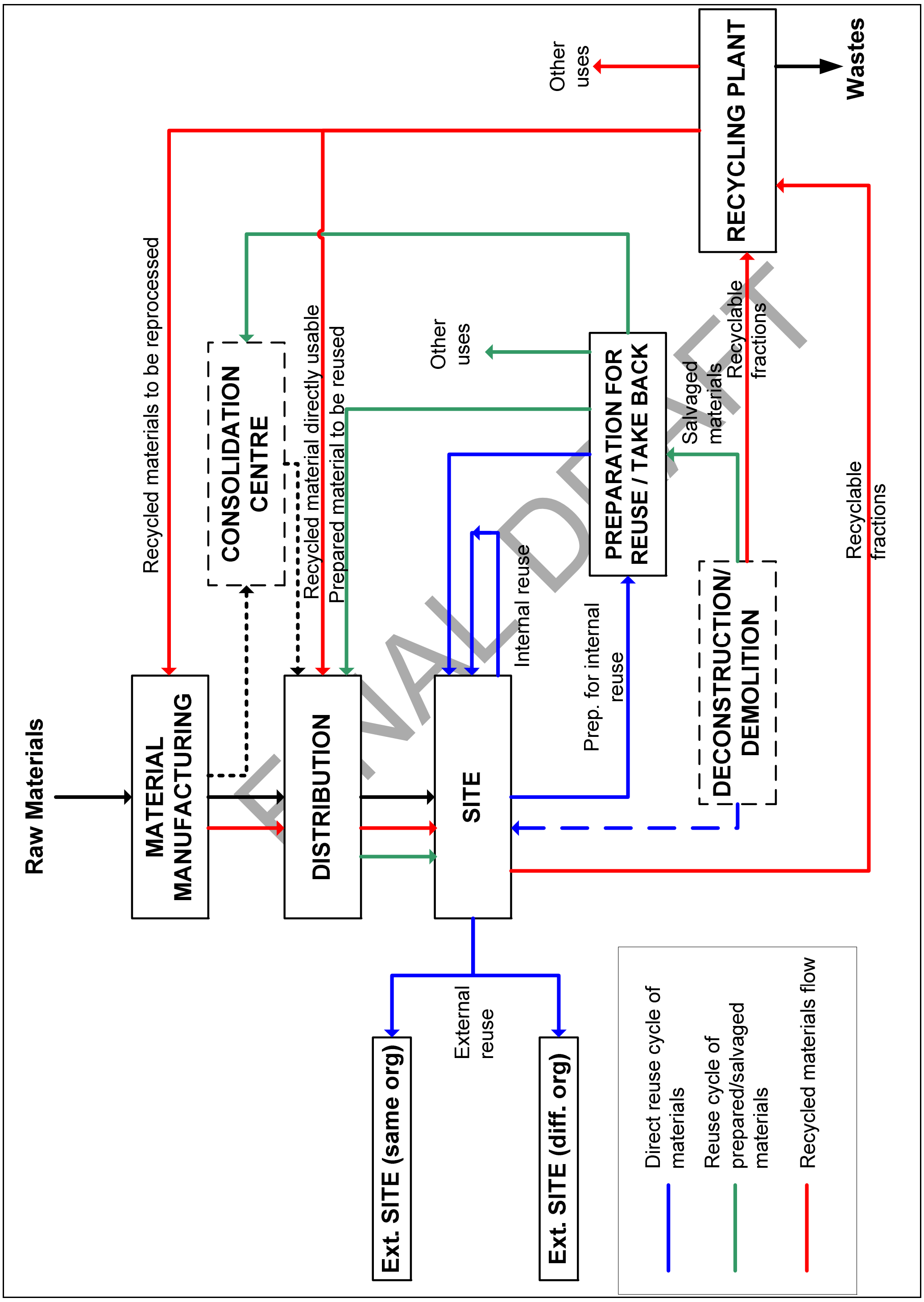
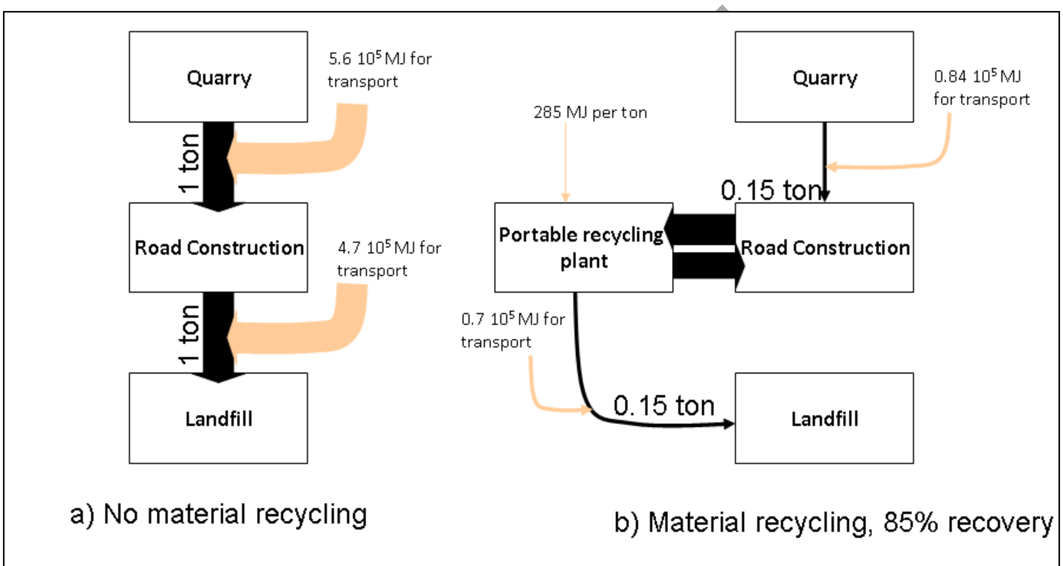


Figure 8.2: General overview of main reuse and recycle flows in construction sites

The specific requirements for road base materials make recycled construction waste products suitable for use as a base material, although some specifications must be fulfilled (see Table 5.44). According to BioIS, 2011, up to 75 % of all concrete waste can be recycled as aggregates in road bases and sub bases. This huge waste absorption capacity of roads produces a double benefit: a significant reduction of landfilled waste is achieved and an equivalent amount of natural material extraction is avoided.

The use of construction waste as sub-base material (after its appropriate processing) is technically feasible. However, its use for roads represents a downgrade in material quality. Recycled concrete can substitute up to 20 % of coarse aggregates for high quality concrete and up to 100 % for non-structural concrete. These uses should also be encouraged in order to maintain all material possibilities during recycling processes (see Section 5.6.2.4).

An example from WBCSD, 2009, demonstrates that the direct recycling of materials on site has both an environmental and economic rationale. Figure 8.3 shows the energy and material consumption of road construction materials with and without recycling of harvested materials from the demolition of an old road and the construction of a new one. Energy savings are greater than 80 %.



Source: WBCSD, 2009

Figure 8.3: Energy and material flows without and with recycling for road construction

References

BioIS, 2011. Service contract on management of construction and demolition waste – SR1. Final report. Available at ec.europa.org, last access on 3/3/2012.

WBCSD, 2009.The cement sustainability initiative: recycling concrete. Report, available at www.wbcsdcement.com, last access on 25/4/2012

9 EMERGING TECHNIQUES

9.1 Emerging techniques for building design

- ESP for fossil fuel combustion: Electrostatic precipitators (ESP) are a best available technique for large coal fired power plants. They reduce particulate emissions in coal plants by more than 99 % by up to 5-30 mg/Nm³. In small combustion installations, ESPs do not achieve these efficiencies, because cost factors limit the ESPs to be as simple as possible. New products for installations < 50 kW achieve reduction rates of 60-90 % at optimum, with costs of EUR 750 – 2 000. Specific investment costs decreases with growing installation size (Sattler, 2007).
- Gas-fired heat pumps: Since heat pumps need large amounts of electricity, development trends have gone in the direction of providing the energy required by burning gas. It is an environmentally-friendly approach of thermal energy production, as overall emissions can be reduced. Two different types of gas-fired heat pumps have been developed, heat absorbing and adsorbing pumps.
- Reversible heat pumps with cool water production capacity: This evolving type of process has its basis in the classical heat pump principle. Since heat pumps, equivalent to refrigerating machines, produce heat and cooling energy, with usually one type not being used, the advantage of reversible heat pumps is the use of both types of energy. The heating cycle can be specially operated for one main use, with the other energy being a useful by-product. Hereby, overall efficiency, in heat-pump-terms the HSPF, and overall energy demand can be improved.
- High temperature reversible heat pumps with process heat reuse: Basic heat pumps use water and glycol as the heat delivery medium. High specific heat capacity values and low compressibility constrains then actual and efficient application to low temperature areas. High temperature heat pumps use other non-poisonous media, such as CO_2. Improved compressibility facilitates high temperature application with good performance results. Additionally, the compressibility of CO_2 facilitates good performance for cooling applications and hence, enables the heat pump to be variable with regard to temperature levels and reversibility. Actual reversible high-temperature heat pumps are only installed in small and medium sized industrial applications, since investment costs are high.
- Solar thermal systems with integrated cooling: Solar cooling means that the refrigerating machines will be provided with solar thermal energy instead of electricity. Therefore, electricity needs are reduced and the cooling process emits less CO_2. As cooling needs and sunlight intensity generally exist in parallel, cooling possibility increases with cooling needs. Up to now, two different forms of solar cooling have reached the market: direct and indirect cooling. Direct cooling means cooling of the ventilation system, indirect cooling means providing radiators (especially floor radiators) with cool water.
- Geothermal heat storage: Pilot projects with geothermal heat storage have been completed successfully. Herein, large solar collectors provide heat for actual use and excess heat to be stored in the ground. This seasonal storage provides heat during times in which solar heat is not available (especially in winter times). According to a year 2000 pilot project in Crailsheim (Germany), the installation could cover around 50 % of total heat demand with solar thermal heat (Müller-Steinhagen, 2005). High investment costs for the storage installation necessitates a local heating system and an additional heat generation such as thermal combustion or additional heat supply by district heating. A summary of two feasibility studies for geothermal heat storage of solar heat energy are given by Reuß in (Reuß and Müller, 2001).

References

Müller-Steinhagen, H., 2005. Solar unterstütze Nahwärme und Langzeitwärmespeicher, Institut für Solar- und Wärmetechnik, Universität Stuttgart, available at www.solarthermie2000.de.

Reuß, M.; Müller J., 2001. Erdwärmesonden zur thermischen Energiespeicherung im Untergrund, in: Tiefbau 08/2001

Sattler,M., 2007. Staubabscheider für den Hausbrand (<50 kW). Available at http://www.so.ch/fileadmin/internet/bjd/bumaa/pdf/luft/staubabscheider.pdf , last accessed 26/8/2011

9.1.1 Phase change material (PCM)

Description

Currently, only Micronal® PCM (BASF) is available. Inner loads and sun radiation lead to large fluctuations in temperature, losses of comfort and on increased need for air conditioning, as some buildings lack the required thermal storage mass because of their construction method. PCM is a phase change material, which completes a phase change from solid to liquid within the indoor temperature and human comfort range, i.e. at 21 °C, 23 °C or 26 °C and in doing so can store a large quantity of heat. Therefore, the indoor temperature can be stabilised without mechanical cooling. The core of the PCM is a microcapsule, which contains a special wax mixture for latent heat storage. At a defined temperature threshold, i. e. 21 °C, 23 °C or 26 °C, the wax mixture absorbs the excessive heat energy (e.g. provided by high outdoor temperatures or sun radiation) and stores it via a phase change. Thus, further increase in indoor temperature can be avoided. When the temperature falls below the temperature threshold, the stored heat is released again. The discharge of the storage material can occur via natural ventilation or can be supported by mechanical ventilation or also via sustainable or conventional cooling concepts(37).

Achieved environmental benefits(38)

- Reduction of cooling energy demand
- Quiet air conditioning without the occurrence of draughts and transference of noise
- Stabilisation of the indoor temperature in the healthy temperature zone, i.e. between 21 °C and 26 °C
- Summertime excessive heat protection.

Appropriate enviromental indicators

Environmental indicators are the annual savings in cooling energy demand per square metre component area and useful building floor area [kWh/(m²yr)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature, the solar radiation, etc.

Cross-media effects

No information available.

Operational data

The surface mass ratio is about 30 m²/g. The higher the surface mass ratio [m^2/g] is, the better the heat exchange is and the lower the cooling energy demand is. Further operational data of Micronal® PCM (BASF) is provided in Table 9.1. The higher the latent heat capacity [kJ/kg] and the overall heat capacity [kJ/kg] are, the lower the cooling energy demand is.

Table 9.1: Operational data of Micronal® PCM

Product desgination	Product type	Melting point approx. [°C]	Operational Range [°C]	Overall storage capacity [kJ/kg]	Latent heat capacity approx. [kJ/kg]
DS 5000	Dispersion	26	10-30	59	45
DS 5007		23		55	41
DS 5030		21		51	37
DS 5001	Powder	26		145	110
DS 5008		23		135	100
DS 5029		21		125	90

Applicability

The application area depends on the melting point, i.e. in Germany for surface cooling system (21 °C), summertime excessive heat protection (26 °C) and stabilising of the indoor temperature in the comfort zone (23 °C). Therefore, diurnal temperature variations are needed to allow daily phase change of the wax. The higher the melting point is, the higher the latent heat capacity is.

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(37) BASF AG: http://www.highglosspaint.com/portal/basf/ien/dt.jsp?setCursor=1_290868, accessed 18.08.2010.
(38) BASF AG: http://www.micronal.de/portal/streamer?fid=443847, accessed 18.08.2010.

An application of PCM is possible with or without simultaneous use of mechanical cooling. PCM can be directly integrated into the building material, i.e. it can be used without the need for additional work processes or higher complexity on the construction site. It can be incorporated into building materials in different forms. A dispersion can be used for all applications in which a liquid form is needed, whereas the microcapsules are dispersed in water. Redispersible powders can be used for all applications which require a powder form (such as dry blends like plaster or cement mortar).

In general, the following are application areas for PCM in buildings: (BINE, 2009)

- Integration into the building structure (ceiling, wall)
- Integration in other building elements (e.g. façade elements)
- Utilisation in separate heat and cold storage devices.

Further information can be found under http://www.ise.fraunhofer.de([39]) and http://www.deutscher-zukunftspreis.de/content/nominierte-2009([40]).

As an example, in the gypsum wallboard from Knauf PCM (http://www.knauf.com) 'Smart-Board' PCM has been integrated. This building material contains 3 kg PCM per m². The heat capacity of a wall construction, twice equiped with 15 mm PCM SmartBoard®, is thus comparable to a 14 cm thick concrete wall or a 36.5 cm thick brick wall. This might contribute to increase market acceptability for certain low weight building materials.

Economics

- No specific cost data is available, but aggregated data is available in (Schmidt, 2005). A payback period of 5 years is calculated for a German single family house, if 360 kg PCM corresponding to an investment of 3 500 € are used in order to reduce air conditioner use.
- no operating and maintenance costs

Driving force for implementation

- Reduction of cooling energy demand, by raising the thermal mass of the building envelope
- Summertime excessive heat protection.

Reference organisations

- BASF AG
- Knauf Gips KG
- Saint-Gobain Weber GmbH
- H+H Deutschland GmbH
- Ilkazell Isoliertechnik GmbH.

References

BINE, 2009. Latent heat storage in buildings, BINE Themeninfo I/2009, FIZ Karlsruhe, Germany, available under http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/Themeninfo_I09_engl_internetx.pdf, accessed 18.08.2010.

Schmidt, M. 2005. Latentwärmespeicher PCM: Grundlagen und Wirtschaftlichkeit, BASF AG, Germany, available under http://www.eor.de/fileadmin/eor/docs/aktivitaeten/asue_eor_14_02_2006/Unterlagen/01_ASUE_PCM-Grundlagen+Wirtschaftlichkeit-A4.pdf, accessed 18.08.2010.

([39]) Fraunhofer Institute for Solar Energy Systems ISE: http://www.ise.fraunhofer.de, accessed 18.08.2010.

([40]) Büro Deutscher Zukunftspreis: http://www.deutscher-zukunftspreis.de/content/nominierte-2009, accessed 18.08.2010.

9.1.2 Integration of titanium dioxide in roof tiles

Description

Nano-crystalline titanium dioxide (TiO_2) can be integrated into a concrete surface of roof tiles. TiO_2 is a semiconductor which photocatalyses under illumination by daylight or solar radiation. Hence, the photocatalytic reaction can be repeated any time. It absorbs and degrades mineral or organic molecules. Therefore, the surface of the roof can remove hazardous substances, such as nitrogen oxides (NO_x) and convert them into nitrates. (Dachzentrum, 2004)

Achieved environmental and health benefits

Roof tiles with surfaces including TiO_2 can reduce diverse air pollutants, such as nitrogen oxides, aldehydes, benzenes and chlorinated aromatic compounds, and convert them into less harmful substances to the environment. NO_x is converted into nitrate (NO_3^-). NO_3^- reacts with calcium hydroxide of the roof tile surface and is washed off by rain. Approximately 4.81 g NO_x can be depleted per m² of roof area during one year (Dachzentrum, 2004).

Appropriate environmental indicators

The quantity of NO_x that is being depleted per m² of roof area during one year [g/(a*m²)] (Dachzentrum, 2004) can act as an environmental indicator.

Cross-media effects

The environmental assessment of nanoparticles is still ongoing.

Operational data

Product data sheets are available under http://www.nelskamp.de(41):

- product *Finkenberger Pfanne*:
    - length: ~ 42.0 cm, Width: ~ 34.0 cm
    - covering length: ~ 31.4 - 34.5 cm
    - covering width: ~ 30.0 cm
    - demand per m²: ~ 10.0 Stück
    - weight per roof tile: ~ 4.6 kg
    - roof pitch: ~ 22°.
- product *S-Pfanne*:
    - length: ~ 42.0 cm, Width: ~ 33.2 cm
    - covering length: ~ 31.4 - 34.5 cm
    - covering width: ~ 30.0 cm
    - demand per m²: ~ 10.0 Stück
    - weight per roof tile: ~ 4.7 kg
    - roof pitch: ~ 22°

In the German Saxony, on approximately 500 multi-family houses with a roof area of about 500 000 m² roof tiles with TiO_2 have been installed (Dachzentrum, 2004). Further example installations are referenced in the following section.

Applicability

Generally, all products made out of concrete, such as concrete paving stones, road paving, roofing tiles, building surfaces and noise protection walls can be produced and applied with TiO_2 to reduce NO_x in the surroundings (Juschkus, 2008). The photocatalytic feature is not visible and does not influence other durability properties. No special measures are necessary.

Example installations:

- Roof tiles with titanium dioxide have been installed in eight residential buildings in Duisburg, Germany. Further example installations exist in Bremen, Barsinghausen, Duisburg, Essen, Braunschweig, Münster, Darmstadt, Leinfeld-Echterdingen, Greifswald, Fulda and other German cities.[41]

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(41) Dachziegelwerke Nelskamp GmbH: http://www.nelskamp.de , accessed 18.08.2010.

- The de-soiling and de-polluting abilities of titanium dioxide by introduction into the building matrix or surface coatings have been investigated in the PICADA EU project.([42])

Economics

Nano-crystalline titanium dioxide is a very expensive raw material, but only small amounts of TiO_2 are required for roof tile production, as only the surface contains TiO_2 (Juschkus, 2008). Therefore the economics of TiO_2-containing roof tiles is comparable to conventional roof tiles. The prices of these roof tiles range from 4.2 EUR/m² to 6 EUR/m²([43]).

Driving force for implementation

Driving force is the enhanced living quality through better air conditions.

Reference organisations

- Dachziegelwerke Nelskamp GmbH: http://www.nelskamp.de/

References

Deutsches Dachzentrum, 2004. Reduktion von NOx durch 'ClimaLife', 2004, available under http://www.dach-zentrum.de/portals/ddz/story_docs/Reduktion_NOX_durch_ClimaLife.pdf, accessed 18.08.2010.

Juschkus, U., 2008. Superzwerg TiO2 – Umweltschutz mit Nanotechnologie, RKW Kompetenzzentrum, 2008, available under http://www.rkw-kompetenzzentrum.de/fileadmin/media/Dokumente/Mitarbeiter/2008_MA_Superzwerg-TiO.pdf, accessed 18.08.2010.

([42]) Photocatalytic Innovative Coverings Applications for Depollution Assessment (PICADA), official web site: http://www.picada-project.com/, accessed 18.08.2010.

([43]) Modach Baushop GmbH: http://www.baustoffe-modach.de/, accessed 18.08.2010.

9.1.3 Vacuum insulation glass

Description

Glazings are highly important for the energy efficiency of a building. Highly-insulating, passive house standard glazings have insulation values of U_g = 0.5-0.7 W/(K*m^2), which can only be realised with costly triple-pane systems that diminish the passing light. One attractive possibility to improve the insulation properties of a glazing is evacuating the space between the glass panes. Conventional double-pane vacuum glazings only have insulation values of, at best, U_g = 1.1-1.3 W/(K*m^2). This is due to the high temperatures which occur in manufacturing processes, which preclude the implementation of high-quality low-e coatings (softcoatings). A production process which avoids high temperatures in the low-coated areas allows the use of highly efficient low-emissivity-coatings to reduce thermal radiation, which otherwise is the major heat transfer mechanism in such an evacuated glazing. A manufacturing process to produce such vacuum insulation glass in series is being developed within the framework of the project ProVIG([44]) and is to be realised by the end of 2012. Figure 9.1 illustrates the structure of vacuum insulation glass in a double-pane design.([45]) (Schneider, 2008).

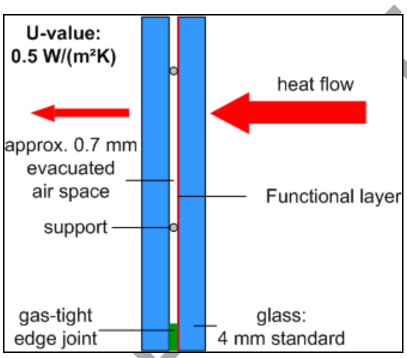


Figure 9.1: Structure of vacuum insulation glass[45]

Achieved environmental and health benefits

By the enhancement of the thermal insulation of the building envelope, a high solar gain and airtightness the heating or cooling demand of buildings can be reduced. The benefit of the reduced heating or cooling of buildings depends on the climate zones. The window should incorporate an insulated window-frame, three gaskets and has to be installed in an airtight way. Thus, also noise protection can be enhanced remarkably. Furthermore, living comfort and indoor climate can be improved by elevated surface temperatures, airtightness and prevention of 'cold radiation' (Hensler, 2009).

Vacuum insulation glass in a double-pane design achieves heat transfer coefficients of U_g = 0.5 W/(m^{2}K)([45]).

Appropriate environmental indicators

The heat transfer coefficient of the glazing U_g and the window U_W [W/(m²*K)], the G-value [-] and the emissivity can serve as environmental indicators, as they influence the heating or cooling demand of a building.

Cross-media effects

See Chapter 3.

([44]) Grenzebach Maschinenbau GmbH, page of the network project ProVIG (Production Methods for Vacuum-Insulating-Glass): www.vig-info.de/, accessed 18.08.2010.

([45]) The Bavarian Center for Applied Energy Research (ZAE Bayern), VIG - Vacuum Insulation Glass/ProVIG - Production Technology for Vacuum Insulation Glass: http://www.zae-bayern.de/english/division-2/projects/vig.html, accessed 18.08.2010.

Operational data

The advantages of vacuum insulation glass in the double-pane design are:[45]

- excellent insulating properties
- easy to retrofit
- slim design <10mm (with 4mm thick glass)
- low weight
- gas-tight edge joint
- same mechanical stability as conventional glazing systems (e.g. double glazing).

Thus, their use in new buildings and building renovation is a promising application.

Applicability

Vacuum insulation glass can be applied in new buildings and building renovation.

Economics

Specific data is not available.

Driving force for implementation

- Reduction of heating or cooling energy demand
- Enhancement of indoor climate and living comfort

Reference organisations

No information is available.

References

Hensler, G.; Scheider, M; Miehle, P., 2009. Energiesparen mit 3 Scheiben – Heizkosten senken und Lärm vermindern, Bayerisches Landesamt für Umwelt, available under http://www.lfu.bayern.de/umweltwissen/doc/uw_102_energiesparfenster.pdf, accessed 18.08.2010.

Schneider, B., 2008. Vacuum glazing: When inert gas is replaced by a vacuum, BINE Projektinfo 01/08, FIZ Karlsruhe, Germany, available under http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0108_engl_internetx.pdf , accessed 18.08.2010.

10 MICRO, SMALL, AND MEDIUM SIZED ENTERPRISES

10.1 Micro- and small- and medium- sized enterprises in the construction sector

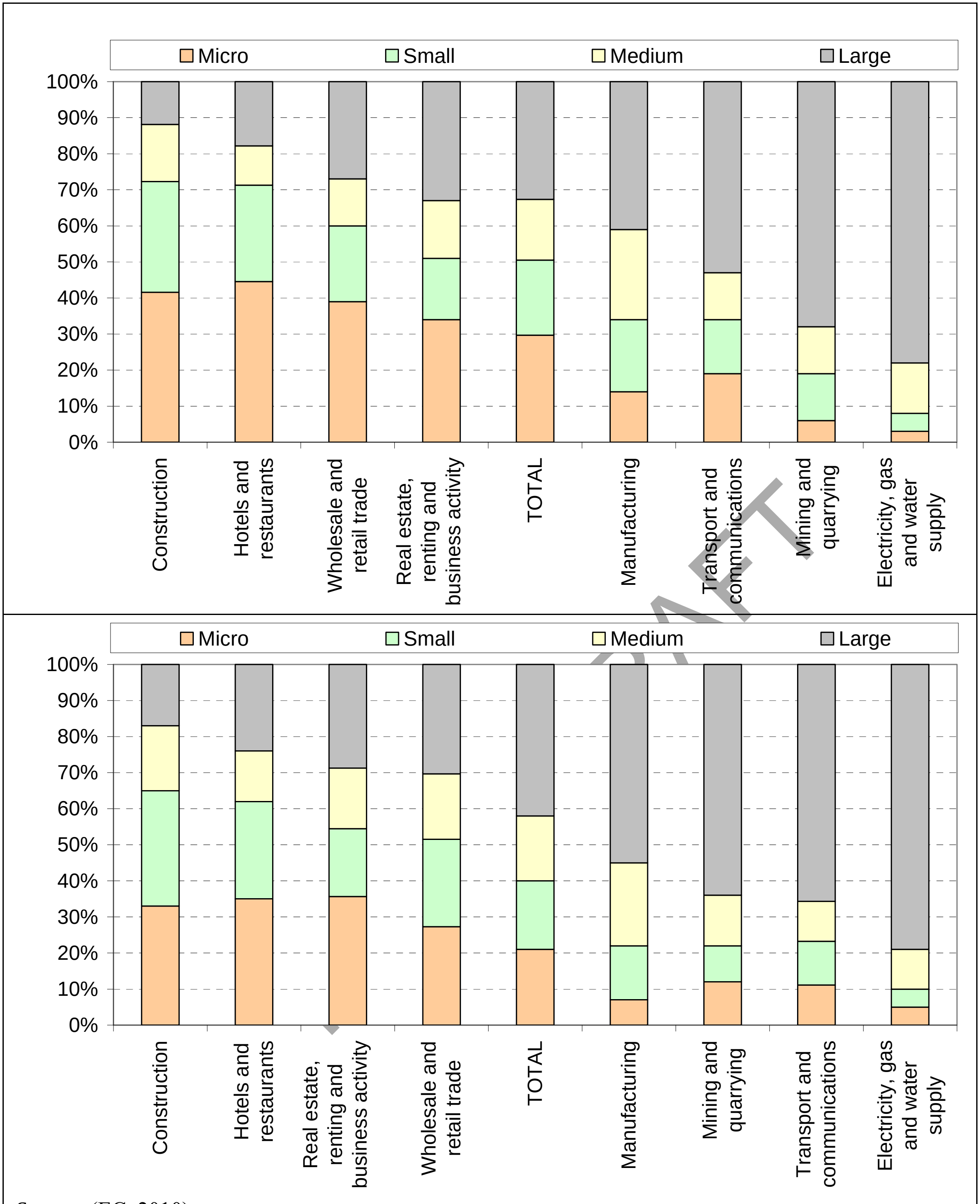
Definitions of micro-, small- and medium-sized enterprises are given in Table 10.1. The term 'SME' includes micro-enterprises when used in this chapter. One of the most widely used proxies to rapidly identify an SME is the number of employees. As stated in section 1.1, construction companies for buildings (e.g., those belonging to F41 and most of F43 NACE codes), serve a local market and the construction sector is characterised by a large number of small enterprises and a few larger ones. Micro and small companies employ more than 71.8 % of the EU-27 construction workforce. Large companies provide employment for a small portion (12.5 %) of the workforce, which is low compared to the non-financial business economy average of one third (33 %).

Table 10.1: European Commission definitions of 'micro', 'small', 'medium' and 'large' enterprises

Enterprise size class	Definition
Micro	An enterprise that employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million.
Small	An enterprise that employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 10 million.
Medium	An enterprise that employs fewer than 250 persons and whose annual turnover does not exceed EUR 50 million or whose annual balance-sheet total does not exceed EUR 43 million.
Large	An enterprise that employs 250 or more persons and/or has an annual turnover greater than EUR 50 million or an annual balance-sheet total greater than EUR 43million.

Source: EC (2003).

Over the EU-27 as a whole, SMEs represent 83 % of gross value added in the construction sector and employ almost 90 % of sector workers (Figure 10.1). This is one of the highest share in the EU-27.



Source: (EC, 2010).

Figure 10.1: The size-class distribution of enterprises across different sectors within the EU-27, according to the number of persons employed (top figure) and gross-value-added (bottom figure)

10.2 Sustainability of SMEs

The study 'SMEs and the environment in the European Union' (Danish Technological Institute, 2010) estimated that 64 % of environmental impact arising in the EU-27 originates from SMEs that, in some sectors, may be less eco-efficient than larger enterprises owing to scale effects and lower investment in new technologies. Comprehensive environmental management systems are more suitable to large companies with established management structures and with enough resources allocated to sustainability issues of the company. In fact, environmental legislation poses is more seen as a barrier for SMEs because they have fewer resources to interpret and comply with new legislation. Therefore, financial support from government may be necessary to alleviate the costs of complying with environmental legislation for SMEs. With regard to the application of BEMPs, the simplicity, cost and level of staff training required are key factors affecting uptake by SMEs.

In 2010, the European Commission published a report titled 'Opportunity and Responsibility: how to help more small businesses to integrate social and environmental issues on what they do' (EC, 2010). The aim of this report was to encourage the uptake of Corporate Social Responsibility by SMEs, and follows from a similar earlier report entitled 'Fostering CSR among SMEs' (EC, 2004). A brief summary of key points contained in these two reports is presented below.

The main drivers of environmental responsibility among SMEs are:
- management of internal aspects;
- some environmental measures pay off in the medium/longer term;
- environment, health and cost-efficiency can be improved;
- branding: SMEs identified as good or best performer at local level;
- external aspects: as better response to existing or new legislation..

The main barriers to improving environmental performance across SMEs are:
- the diversity of SMEs makes it difficult to identify generic solutions;
- the difficulty of disseminating information to SMEs;
- the limited management resources typical of SMEs;
- high perceived costs and relatively high actual investment costs (though the latter are usually significantly lower than the former);
- generally, there is lack of awareness, motivation, know-how and know-who;
- reluctance to seek external help.

The main conclusions on mechanisms required to facilitate SMEs with environmental performance improvement include:
- solutions for SMEs should be practical and result oriented;
- education of staff and managers is essential;
- building SMEs clusters to address common problems could reduce costs;
- intermediary organisations with a high level of awareness can facilitate uptake (trade unions, consultants, commerce chambers, etc.);
- advice and financial support from national, regional or local level government is often required.

10.3 Applicability of BEMPs to SMEs in the construction sector

The economic relevance of SMEs in the construction sector is quite high, and therefore, the environmental impact of SMEs activities can be also regarded as highly significant. The application of Best Environmental Management Practices, BEMPs should ensure relevant and significant environmental benefits in the sector. Actually, the document is focused in best practices at every step of the construction value chain, from land planning to building deconstruction or demolition. This wide scope involves many actors, not only small construction contractors, but also designers, developers, land planning policy and decision makers, technology suppliers, clients, public administration and building users.

The description within the technical chapters tries to give a full picture of techniques and practices and the results from their application. In Table blabla, it is explained the specific role of building construction SMEs, i.e. those micro, small or medium enterprises, which activity is defined under NACE F.41 or NACE F.43 building construction.

Table 10.2. Applicability of Best Environmental Management Practices to SMEs belonging to NACE codes F41 and F43 (building construction related activities)

Section	BEMP	SME Applic-ability	Remarks
2.2.1	Biodiversity protection	**Low**	Practice oriented to land planners. Small actions can be performed at site for biodiversity protection. Planning of urban biodiversity management is out of the scope for this practice.
2.2.2	Water drainage in sealed soils	**Low**	Practice oriented to land planners.Water drainage is an important element of water management at construction sites and on the design of new buildings.
2.2.3	Green public procurement for construction	**None**	This practice is oriented to public administration, especially for local governments. It may be relevant to look on criteria assessed by ad
2.2.4	Reducing the Urban Heat Island effect	**None**	This practice is oriented to planners and designers, the influence of small construction companies is negligible, except for Build and Design tendering.
2.3	Site selection, land consumption and urban sprawl avoidance	**None/low**	Site selection is a matter of customer. Nevertheless, involvement of small construction companies in projects oriented to avoid urban sprawl (e.g. refurbishment, rehabilitation) can be regarded as best practice
3.4.1.1	Increasing the performance of insulation	**None**	Practice description oriented to designers.
3.4.1.2	Techniques to improve the performance of walls	**None**	Practice description oriented to designers.
3.4.1.3	Improving the environmental performance of roofs	**None**	Practice description oriented to designers.
3.4.1.4	Best options for glazing	**None**	Practice description oriented to designers.
3.4.2	Integrated concepts for buildings and the example of the Passive House approach	**Medium**	Although the description is oriented to designers, users and developers, expertise in building air-tight buildings is required to contractors. As a matter of fact, small construction companies, specialised in air-tight buildings, are highly appreciated.
3.4.3	Design and Retrofitting of the Heating, Ventilation and Air Conditioning (HVAC) system	**Low/Medium**	Although this is a practice for designers, expertise for facilities installers (F43 codes) may be required, especially for novel technologies.
3.4.4.1	Demand reduction through lighting concepts, strategies and integrated daylight optimisation	**None**	Practice description oriented to designers.

Table 10.2. Applicability of Best Environmental Management Practices to SMEs belonging to NACE codes F41 and F43 (building construction related activities)

Section	BEMP	SME Applic-ability	Remarks
3.4.4.2	Increasing the efficiency of lighting devices	**None**	Practice description oriented to designers.
3.4.5	Use of renewable energy sources	**Low**	Expertise for small companies in the installation and maintenance of renewable energy systems is required.
3.4.6.1	Environmentally friendly water drainage systems	**Low**	May require especialised contractors.
3.4.6.2	Water saving plumbing fixtures	**Low**	May require especialised contractors.
3.4.6.3	Non-potable water recycling systems	**Low**	May require especialised contractors.
3.4.7.1	Preventing waste during the design phase	**Medium**	Although the description is oriented to designers, SMEs contractors should be especialised and aware on the techniques oriented to prevent waste.
3.4.7.2	Design for Deconstruction (DfD)	**Medium**	Contractors in charge of demolition should be aware of the potential deconstruction design practices applied to the building to be dismantled in order maximise the recovery rate of the building.
4.3.1.1	Selection of environmentally friendly products	**Low**	SMEs contractors usually have scarce opportunity to select environmentally friendly building materials due to restrictive contracts, budgetary limitations or scarce availability.
4.3.1.2	Choosing environmentally friendly paints	**Low**	Same as 4.3.1.1
4.3.1.3	Choosing certified wood and substituting tropical wood	**Low**	Same as 4.3.1.1
4.3.1.4	Choosing environmentally friendly materials for floor covering	**Low**	Same as 4.3.1.1
5.6.1.1	Improving environmental performance through better management: definition of environmental management plans and specific needs for environmental management systems	**High**	It may require extra resources to allocate to the environmental management system (except for EMAS registered or ISO 14001 certified systems)
5.6.1.2	Monitoring the environmental performance of sites	**High**	Fully applicable. Some examples given in the description come from SMEs.
5.6.2.1	Waste prevention and management	**High**	Fully applicable. Some examples given in the description come from SMEs.
5.6.2.2	Increasing materials use efficiency	**Medium**	Materials efficiency depends also on design practices, not fully under the influence of SMEs. Some SMEs use their own consolidation centre to remove inefficiencies. Some opportunities for auxiliary materials are shown in this section
5.6.2.3	Reuse of materials	**Medium**	Same as 5.6.2.2

Table 10.2. Applicability of Best Environmental Management Practices to SMEs belonging to NACE codes F41 and F43 (building construction related activities)

Section	BEMP	SME Applic-ability	Remarks
5.6.2.4	Use of recycled materials	**Medium**	Same as 5.6.2.2
5.6.2.5	Water Drainage Management and Erosion Control	**High**	Applicability of this practice does not depend on the size of the company but on the size and nature of the site.
5.6.2.6	Dust prevention and control	**High**	Dust prevention is also a matter of regulation and reduced disturbance, independently of the size of the contractor.
5.6.2.7	Disturbance management	**High**	Noise, vibration and night lighting management practices are fully applicable. The applicability of these practices depend on the nature of the site and on the surroundings.
5.6.2.8	Improving energy efficiency and reducing pollution from engines	**Medium/High**	Some contractors may not own their machinery and they should subcontract or rent it. Environmental selection criteria may be used based on this description.
6.5.1.1	Simulation based building design	**None**	This practice has no impact on the performance of the construction site and of SMEs contractors.
6.5.2.1	Building management systems	**None/Low**	Some specialized companies, belonging to the NACE code F43, may be especialized on this issue. Nevertheless, the approach given is reffered to the user's perspective.
6.5.2.2	Water monitoring, maintenance and management optimisation	**None/Low**	Same as 6.5.2.1
6.5.3.1	Self-cleaning coating	**None/Low**	Same as 6.5.2.1
6.5.3.2	Green cleaning services	**None/Low**	Same as 6.5.2.1
7.3.1	Selective deconstruction of buildings	**Medium**	Many small contractors are also responsible for deconstruction or demolition of buildings. Many SMEs may be involved in selective deconstruction projects, although there are important budgetary restrictions.
7.3.2	Selection of environmentally friendly deconstruction / demolition techniques	**High**	Same as 7.3.1. There are restrictions regarding to specialised SME.
7.3.3	Construction and Demolition (deconstruction) waste sorting and processing	**Low**	Best segregation of materials and wastes is required. Processing of segregated waste is out of the scope of NACE F41 and F43 SMEs.

References

EC, *Commission Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises (Text with EEA relevance) (notified under document number C(2003) 1422),* OJEU 124 (20.05.2003).

EC, *European multistakeholder forum on CSR: Report of the round table on 'Fostering CSR among SMEs'*, EC, 2004, Brussels. Available at: http://circa.europa.eu/irc/empl/csr_eu_multi_stakeholder_forum/info/data/en/csr %20forum %20rt %20report %20sme.pdf

EC, *Opportunity and Responsibility: How to help more small businesses to integrate social and environmental issues into what they do,* EC (DG ENTR), 2010, Brussels.

Danish Technological Institute, *SMEs and the environment in the European Union: main report*, Teknologisk Institut, 2010, Copenhagen.

11 CONCLUSIONS

11.1 General aspects about the development of the document

Timing of the work process
The kick-off meeting for the elaboration of the pilot reference document on best environmental management practice for the Construction sector was held in March 2011. The overall structure of the document and the one for presenting the techniques was agreed. After the period for collecting information and data, carrying out important site visits and developing the draft document, the second working group meeting was held in November 2011 in order to verify and to agree on information and data to be used for the document. The working group concluded by expert judgment on the most appropriate environmental performance indicators and benchmarks of excellence.

Sources of information and development of the document
A pre-study was done by Karlsruhe University of Technology. A lot of information needed for this document was obtained directly from construction companies, public administrations, designers, research institutions and other stakeholders. There were significant differences in the intensity of collaboration and on the information provided by the various members of the technical working group. Many technical descriptions were consulted in the scientific literature and from relevant technical reports, which are publicly available.

Level of consensus
The conclusions on the environmental performance indicators and benchmarks of excellence were drawn at the second meeting of the working group in November 2011. There was consensus and no split views were recorded.

11.2 Conclusions on best environmental management practices, specific indicators and benchmarks of excellence

This document is the reference report on best environmental management, indicators and benchamarks of excellence for the Construction sector and has been developed according to Article 46(1) of the EMAS Regulation 1221/2009/EC. The most important environmental aspects, direct or indirect, relevant to the organisations or companies belonging to the construction sector were identified.

This document summarises the best environmental management practices dealing with these identified aspects, including sector specific environmental indicators and derived benchmarks of excellence for the environmental performance of organisations and processes/techniques carried out by these organisations respectively. The conclusions, gathered on this chapter, have been derived by expert judgement, performed by the European Commission through the JRC-IPTS, and with the support of the Technical Working Group (TWG). This group was composed of companies' representatives, umbrella associations, verification bodies, accreditation bodies, researchers, and the European Commission, who organised and chaired the meetings of the TWG.

This document was developed based on information exchange with construction organisations, consultation with experts, literature review and site visits. Some of the companies providing information were big players at a European and also at global level. Small and medium size companies were also addressed.

EMAS is a voluntary scheme and the document should be regarded as a support for the efforts of all the actors in the sector who intend to improve the environmental performance therein, with or without a certified environmental management system. The document may be helpful both for all those organisations who have implemented EMAS, or who want to implement it, and also for all those who have implemented any other environmental management system or who intend to improve their environmental performance and to move towards greater sustainability.

In the EMAS registration process, with respect to preparing the environmental statement and to assessing their environmental performance, organisations shall take the reference documents into account. Consequently, the environmental performance may be reported using the specific indicators as described below, if they are appropriate. Best practice techniques and benchmarks of excellence provide reference points against which an organisation can compare its environmental performance in order to identify improvement potentials. The document may be used in the same manner by verifiers when checking the requirements according to Article 18 of the EMAS regulation. This document has been written with the basis of helping organisations or verifiers to identify their relevant environmental aspects, both direct or indirect. There is no mandatory requirement on the application of best environmental management practices shown here.

Indicators presented here are the most common used by exemplar organisations of the sector. This implies that not all the indicators are applicable to every company of the sector. Therefore, verifiers should check that selected specific indicators (or an appropriate alternative to them – see 11.2.2) from the list of indicators presented here are the most suitable for every single case.

None benchmark of excellence has to be accomplished to be registered in EMAS. A benchmark of excellence is a front-runner performance, which can be used to compare organisation current performance and their progression. They do not constitute environmental criteria to be verified according to current performance.

The specific conclusions of the reference document are structured according to the bullet points of Article 46(1). First, identified best environmental management practices (BEMP) are listed. Then, the common specific indicators of the construction sector are described. Finally, derived benchmarks of excellence for each aspect, where appropriate, are shown.

11.2.1 Best environmental management practices

A best environmental management practice, BEMP, is defined in the EMAS regulation as 'the most effective way to implement the environmental management system by organisations in a relevant sector and that can result in best environmental performance under given economic and technical conditions'. In this document, identified best practices are described from Chapter 2 to Chapter 7 for the building and construction sector. Some cross-links are made to Civil Works (Chapter 8), as some management practices may be quite similar and fully applicable to the construction of civil engineering projects. Chapter 9 shows the description of some emerging techniques, applicable to building design and Chapter 10 shows some specific issues for SMEs.

The environmental performance of described practices has been evaluated in technical detail along with economic considerations. The practices address the most important environmental aspects of the construction sector. Following the preamble of the EMAS regulation, the aim of the reference document is to help organisations to better focus on the most important environmental aspects of the sector. For this purpose, detailed technical information and data were collected and collated, based in many situations on case studies. The structure of the technical descriptions of the different practices is similar to the Best Available Techniques Reference Documents (BREFs) according to Article 13 of the Industrial Emissions Directive (formerly the IPPC Directive): description, achieved environmental benefits, appropriate environmental indicator, cross-media effects, operational data, applicability, economics, driving force for implementation, reference companies and reference literature. In the description, all management possibilities are described, i.e. as direct or indirect aspects, as the potential reader of the document are designers, local and regional public administrations, construction and deconstruction/demolishing organisations, building users, land planners, developers and verifiers with technical knowledge of the construction environmental management.

Table 11.1 summarises best environmental management practices.

Table 11.1. Summary table of best environmental management practice in the construction sector

BEMP is to…	Described in
Land Planning	
Protect biodiversity through the implementation of local biodiversity protection strategies and action plans. For construction projects, e.g. in a city, it is required that these plans include wildlife protection during all construction stages (site clearance, site setup, haul roads, groundwork and construction).	2.2.1
Apply low impact drainage measures in the construction of new developments and in the retrofitting of existing ones to prevent and control flooding, soil erosion and pollution, groundwater pollution, establishing mechanisms to replicate as closely as possible, natural drainage of sites before development.	2.2.2
Establish water drainage monitoring systems to control water run-off, infiltration and rainwater pollution and to employ these data on the improvement of existing systems	2.2.2
Establish criteria for the green procurement of construction services, both in public or private tenders, for: • the energy performance of buildings (going beyond legislation) • the renewable energy to be produced in new or renovated buildings (going beyond legislation) • recycled content and recyclability of construction materials • environmental friendliness of construction materials and building elements • restriction on construction materials • water saving measures • ecodesign of building structure • environmental performance of the construction site • environmental capabilities of contractors • management of construction and demolition waste • water drainage and groundwater management • heating and/or cooling systems • indoor lighting	2.2.3
Take into account the mitigation of the Urban Heat Island effect through the application of environmentally friendly measures, as green roofs, the use of reflective materials, increasing the efficiency of hot pipes insulation and the use of waste heat	2.2.4
Build in brownfields, minimise the space between buildings, refurbishment of unused buildings, adding floors, improving the quality of land use, etc. to avoid urban sprawl, reduce soil sealing and avoid undesired impacts over natural spaces.	2.3
Building Design	
Use integrative approaches achieving best environmental performance and best life cycle costs.	3.4.2
Insulate and keep air tightness avoiding thermal bridges, minimizing the heat transfer and without a significant loss of useful area	3.4.1.1
Use innovative insulation techniques for walls, as vacuum insulation, with improved environmental and economical performance	3.4.1.2
Design and use cool, brown and green roofs to improve the thermal behaviour of the building, also with a positive effect on biodiversity, water drainage performance and on the mitigation of heat island effect	3.4.1.3
Use building configuration allowing best performing glazing, maximizing gains in winter and using shading systems.	3.4.1.4

BEMP is to…	**Described in**
Design or retrofit HVAC system according to: • Its total integration, taking into account the envelope performance, an optimal solar gain, enhance air tightness, expected internal gains and optimised monitoring and control • The use of environmentally friendly heating and cooling systems, with proven performance in order to reduce the demand of primary energy and without cross-effects over other environmental aspects. • The optimal maintenance cycles of the system	3.4.3
Reduce the energy demand for lighting through the application of lighting strategies, daylighting and lighting devices	3.4.4.1 3.4.4.2
Use adequate renewable energy systems, if the application of best practices to reduce the demand and increase the efficiency is maximised in the design or in the planned renovation of the building.	3.4.5
Plan, design and optimise water drainage in order to improve run-off water quality, increasing infiltration and avoiding flooding risks	3.4.6.1
Plan, design and implement water saving fixtures according to best available techniques for water saving and fulfilling internationally recognised environmental criteria	3.4.6.2
Harvest rainwater, reuse it and recycle grey water, according to the applicability of these options	3.4.6.3
Prevent waste generation during construction through designing out waste techniques, as modern methods of construction, reducing extensively the environmental impact of the construction site	3.4.7.1
Prevent waste generation during deconstruction through better design and selection of materials	3.4.7.2
Construction Products	
Use environmental selection criteria for materials, products and construction elements attending to the performance of their supply chain, distribution and transportation distance, the performance during use (toxicity, release of pollutants, energy performance, noise protection and other indoor quality requirements) and the recyclability at the end of building lifetime. The performance of paints, wood and floor coverings are deeply described in the document.	4.3.1.1 4.3.1.2 4.3.1.3 4.3.1.4
Construction and Refurbishment	
Establish specific environmental management plan where all the measures to prevent, control and monitor the environmental performance is outline. It should content consents between clients and contractors, environmental risk assessment and allocation of resources. For 'Build and Design' projects, it may content preventive design measures.	5.6.1.1
Train and educate labourers on the environmental management practices	5.6.1.1
Monitor the environmental performance of the construction site, to estimate the environmental impact during design and preconstruction site and to establish mechanisms to check improvement of the environmental management performance of construction sites	5.6.1.2
Prevent and manage waste: • Site waste management plan, which includes specific actions for every type of waste, the expected amount of every type of waste, management options, allocation of resources, responsibilities definition, etc. This waste management plan should be included in the communication to stakeholders. • Separate and sort waste, diverting waste from landfill as much as possible. • Maintain or establish a waste logistics system with optimised routing to reduce the carbon footprint of its transport	5.6.2.1

BEMP is to…	Described in
Establish materials use efficiency procedures to reduce the amount of waste: just-in-time deliveries, consolidation centres, reverse logistics (where appropriate).	5.6.2.2
Use materials salvaged from deconstruction of other buildings, as metal frames, concrete structure, bricks or other ceramics. Reuse as much as possible auxiliary materials for construction sites.	5.6.2.3
Select recycled materials, with especial regard to those aggregates produced from construction waste.	5.6.2.4
Protect soil from erosion and design a temporary drainage system with pollution control for exposed land. Minimise exposed soil to wind and rainfall water and use sedimentation and filtering devices to avoid run-off water pollution: use planning strategies to reduce the costs of water management at site; use vegetative barriers, energy dissipators, dams, etc. to avoid heavy erosion.	5.6.2.5
Reduce dust by establishing a dust management plan if dust is expected to be a sensitive issue for the construction site, limit clearance of areas, spray water and apply physical and chemical barriers and control for dust generation. Monitor the effects of dust prevention plans.	5.6.2.6
Reduce disturbance to the neighbourhood, especially in sensitive areas, as residential areas or sites close to natural spaces. Reduce noise and vibration by establishing appropriate prevention and mitigation measures. Reduce night lighting by re-scheduling works when it is adequate, screens and directional lighting. Prevent odours and air emissions avoiding fires, stopping machinery not in use and keeping good practices for chemicals and fuels. Establish procedures for complaint management.	5.6.2.7
Select machinery with high energy efficiency and with low associated emissions, especially regarding to NO_x and particulate materials. Purchase or retrofit cabins to achieve best energy efficiency.	5.6.2.8
Building Use	
Install building management systems to ensure the appropriate monitoring and use of building facilities.	6.5.2.1
Monitor water consumption, detect leakages and maintain properly the water system in the building	6.5.2.2
Use environmentally friendly cleaning agents and services	6.5.3.1, 6.5.3.2
Building deconstruction	
Deconstruct and demolish building selectively, maximizing the amount of salvaged materias and the recyclability of obtained wastes	7.3.1
Use environmentally friendly deconstruction techniques	7.3.2
Maximise materials amount and applicability from waste sorting and processing	7.3.3

11.2.2 Common specific key performance indicators of the construction sector

The conclusions on the environmental indicators associated with the application of best environmental management practice are compiled in the following summarizing table and the list of benchmarks of excellence is shown after the table. Organisations shall take the reference document into account when preparing the environmental statement according to Annex IV of the EMAS regulation 1221/2009. Consequently, the environmental performance can be reported using the specific indicators as described below, if they are appropriate. Some explanations should be given for the application of indicators:

- this document has been written with the basis of helping organisations or verifiers to identify relevant environmental aspects, both direct or indirect. There is no mandatory requirement on the application of best environmental management practices described in the document. Also, indicators presented here are the most common used by exemplar organisations of the sector. The list has been kept short and concise and based on the indicators that companies are actually using.
- more practice-related indicators are shown in the technical description of the core text, where even more alternatives are provided

Indicator	Common Units	Short description	Recommended minimum level of monitoring	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	Example of Alternative indicators
BUILDING DESIGN AND USE					
Specific energy consumption	kWh/m^2 yr	Energy consumption (electricity, heat from gas or others) per unit of useful area and year. Indications: Renewable energy consumption should not be subtracted or offset through CO_2 emissions. Correction factors can be used to determine the useful area depending on the final building use and typology.	Per site or equivalent and at the organisational level (aggregated value) Per main energy-consuming processes: heat, electricity for lighting, total electricityand specific processes (where applicable) and total primary energy consumption disclosed per source	Energy efficiency	Specific primary energy consumption Installed heating or cooling, W/m^2 Use of integrative approaches
Use of localised renewable energy sources	% (of total primary energy demand)	Renewable energy consumed from own generation at site or equivalent. Indications: Green purchasing should not be included.	Per site Per source of energy	Energy efficiency	Specific energy generation, kWh/m^{2}yr Percentage of alternative energy generation in excess to consumption Greenhouse gases emissions avoidance

Indicator	**Common Units**	**Short description**	**Recommended minimum level of monitoring**	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	**Example of Alternative indicators**
Lighting Power Density	W/m^2	Lighting power installed to meet illumination needs per unit of area Indications • Lumens per m^2 is a good technical indicator, but the environmental performance should be measured in terms of W/m^2. • It can vary within the site (per zone) and during the day (per period).	Per site or equivalent Per zone and per day period, where appropriate (linked to lighting plans)	Energy efficiency	Specific energy consumption for lighting Specific lighting planning (y/n)
Water Monitoring	%	Percentage of building zones or units with separate water monitoring and/or relevant process for water consumption	Per process (dishwashing, swimming pools, refrigeration, etc.) Per zone (e.g. per office) or per unit (e.g. per floor)	Water	
Water consumption	L per occupant/position per day	Volume of water consumed per occupant of the building or per full position (e.g. for office and industrial buildings)	Per process (dishwashing, swimming pools, refrigeration, etc.) Per zone (e.g. per office) or per unit (e.g. per floor)	Water	When relevant, water consumption per square metre per day Sectoral approaches
Water recycling	%	Percentage of available water from rainwater or from grey water treatment being reused in internal processes	Per process Per site	Water	When relevant, installation of grey water treatment and reuse facilities (y/n)

Indicator	Common Units	Short description	Recommended minimum level of monitoring	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	Example of Alternative indicators
BUILDING CONSTRUCTION AND DECONSTRUCTION					
Specific waste generation	Weight per unit of area or representative factor (e.g. km)	Generated waste during construction phase an per square metre	Per waste type Per site	Waste	Waste sent to landfill (%) Reuse of materials and amount of recycled materials
Use of dust suppression techniques (y/n)	Dust is removed according to techniques summarized in Table 5.56	When appropriate, dust generation is avoided.	Per site	-	Estimation of dust weight and prevention efficiency when using the methodology explained in section 5.6.2.5
Use of a comprehensive monitoring system for the construction site, y/n	Site performance is monitored and benchmarked according to monitoring systems as explained in section 5.6.1.2, y/n	A comprehensive list of criteria according to section is used to control site environmental performance	Per site	All	In addition, it is recommended to add the specific water and energy consumption per site and per square metre (or per other relevant unit)
Workers are trained in environmental management aspects, y/n	-	Site workers are trained in the EMS of the company.	Per site	-	

Indicator	**Common Units**	**Short description**	**Recommended minimum level of monitoring**	**Related core indicator** according to Annex IV of the 1221/2009 EMAS regulation (Section C.2.)	**Alternative indicators**
CONSTRUCTION PRODUCTS					
Use of ecolabeled materials according to type I ecolabel (ISO 14024)	y/n	Use of materials bearing an ecolabel or equivalent (third party verified) can be proved.	Per material category	Materials	Percentage (w/w, EUR/EUR) of ecolabeled materials in one product category
Hazardous products are avoided	y/n	It is proved that hazardous materials to be avoided regarding to recognised third party verified schemes (e.g. ecolabel, GPP, etc) are avoided.	Per site Per material category	Materials	Degree of compliance with GPP criteria, Ecolabels or other third party verified schemes
Percentage of wood with certificates of chain of custody	%	Percentage of wood bearing a certificate of chain of custody	Per site Per wood element	Materials	

11.2.3 Benchmarks of excellence

A benchmark of excellence is a front-runner performance, which can be used to compare organisation current performance and their progression. They do not constitute environmental criteria to be verified according to current performance and cannot be a reason to prevent the EMAS registration to an organisation.

Organisations may report their performance using benchmarks of excellence as reference points against which an organisation can compare in order to identify improvement potentials. The document should be understood in the same way by verifiers when checking the requirements according to Article 18 of the EMAS regulation.

The list of benchmarks of excellence was agreed by the technical working group in the meeting of November 2011. More specific benchmarks can be found in the technical ° of best environmental management practices.

- Building design
  - The building (new) is designed according to the Passive House standard or equivalent, with a consumption value less than 15 kWh/m^{2}yr for heating and cooling and less than 120 kWh/m^{2}yr of primary energy demand according to the methodology described in the relevant chapter.
  - The building (existing) is retrofitted according to the Passive House standard or equivalent, with a consumption value less than 25 kWh/m^{2}yr for heating and cooling and less than 120 - 132 kWh/m^{2}yr of primary energy demand according to the methodology described in the relevant chapter.
  - The building final installation for heating or cooling is less than 10 W/m^2, according to the definition of the Passive House standard or equivalent.
  - A integrative concept is used to cover building energy requirements with renewable energy sources
  - All relevant water consuming process are monitored in all building units
  - Water consumption is less than a relevant benchmark for building typology.
  - Building is designed out to prevent waste during design and for best recycling and reuse at deconstruction, using the concepts of section 3.4.7
- Building construction
  - Less than 5 % of recyclable material is sent to landfill or incineration without energy recovery
  - Dust prevention efficiency is higher than 90 % according to the methodology defined in operational data of section 5.6.2.5
  - Water use is monitored at construction sites (per source) and water drainage is properly controlled according to the practices described in section 5.6.2.5
  - Site environmental management is checked comprehensively and monthly according to a semiquantitative method across all processes
  - Environmental criteria are used in public private and private-private consents in an environmental management plan
  - All site foremen are trained according to an environmental management system
- Construction products
  - More than one product category is 100 % compliance with ecolabel criteria (type 1 ecolabel or equivalent)
  - 100 % of wood chain of custody is certified
  - Hazardous materials are 100 % avoided according to GPP or other ecolabel criteria

12 GLOSSARY

ENGLISH TERM	MEANING
Achieved environmental benefits	main environmental impact(s) to be addressed by the technique (process or abatement), including emission values achieved and efficiency performance. Environmental benefits of the technique in comparison with others
A-value	Airtightness [m^3/(h*m)]
A1	Fire classification: no contribution to fire
A2	Fire classification: negligible contribution to fire
AMR	Automatic meter reading
B	Fire classification: very minor contribution to fire
BMS	Building Management System
BREF	Best Available Technique Reference Document
C	Fire classification: minor contribution to fire
CAFM	Computer Aided Facilities Management
CDD	Cooling Degree Days [°C *d/a]
CFC	Chlorofluorocarbons
CFL	Compact fluorescent lamp
CHP	Combined Heat and Power Systems
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora, also known as the Washington Convention
CO	Carbon Monoxide
CO$_2$	Carbon Dioxide
COP	Coefficient of Performance
CRI	Colour Rendering Index
cross-media effects	the calculation of the environmental impacts of water/air/soil emissions, energy use, consumption of raw materials, noise and water extraction
D	Fire classification: acceptable contribution to fire
db	decibels
ε or e	Emissivity
E	Fire classification: acceptable reaction in fire
DEC	Desiccant and evaporative cooling systems
Deconstruction	The selective dismantlement of building components, aiming at their direct reuse, recycling, or more generally at mono-fractional separating of waste already at the source
DENA	Deutsche Energie Agentur (German Energy Agency)
DfD	Design for Deconstruction
DIN EN	Standard of the German Institute for Standardisation (German: Deutsches Institut für Normung, Englisch)
DRI	Deconstruction/Demolition Recovery Index
EMAS	the Community Eco-Management and Audit Scheme
EMICODE	product classification system for flooring installation materials
EMS	Energy Management System
EN	European standards for products and services by European Committee for Standardization
Environmental aspect	An element of an organisation’s activities, products or services that has or can have an impact on the environment
Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation’s activities, products or services
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declarations
ETA	European Technical Approval
EU	European Union
EU-15	Member States of the European Union before 1 May 2004
EU-25	Member States of the European Union from 1 May 2004 until 31 December 2006
EU-27	Member States of the European Union from 1 January 2007
EUR	Euro – European currency
EURO	European emission standards

ENGLISH TERM	MEANING
F	Fire classification: no requirements
FGD	Flue-gas desulphurization
FSC	Forest Stewardship Council
G-value	Solar energy transmittance through windows [-]
GBP	Great Britain Pound – British Currency
GDP	Growth Domestic Product
GHG	Greenhouse Gas
H_2O	Water
HD	hydrocarbons
HDD	Heating Degree Days [°C *d/a]
HID	high-intensity discharge
HCHO	Formaldehyde
HMA	Hot Mix Asphalt
HQE	High Quality Environmental standard (French standard for green building : Haute Qualité Environnementale)
HSPF	Heating seasonal performance factor
HVAC	heating, ventilation and air conditioning
ICT	Information and Communication technologies
IEQ	indoor environmental quality
IR	Infrared
IT	Information Technology
KIT	Karlsruhe Institute of Technology
kVA	Kilo volt ampere
kWh	kilowatt-hour (1 kWh = 3600 kJ = 3.6 MJ)
LCA	Life cycle Assessment
LED	Light-Emitting Diode
LENI	Lighting Energy Numeric Indicator
LiBr	Lithiumbromide
lm	Lumen, unit of luminous flux
lux	Unit of illuminance and luminous emittance.
MDF	Medium-density fibreboard
MFH	Multi Family House
MPa	Mega – Pascal
N. A.	Not Available
NACE	Statistical Classification of Economic Activities in the European Community (in French : Nomenclature des activités économiques dans la Communauté Européenne)
NCV	Net calorific value (MJ/kg)
NH_3	Ammonia
NiMH	nickel – metal hydride
Nm^3	Normal cubic metre (101.3 kPa, 273 K)
NO_x	Nitrogen Oxides
NO3-	Nitrate
NUA	Niederösterreichische Umweltschutzanstalt (Institute for Environmental Protection of Lower Austria)
O&M	operation and maintenance
ÖNORM	Standard of the Austrian Standards Institute
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated Biphenyles
PCM	Phase Change Material
PEFC	Programme for the Endorsement of Forest Certification
PET	Polyethelene terephthalate
PM	Particulate Matter
PPM	Parts per million
ProVIG	Production Methods for Vacuum-Insulating-Glass
PVC	Polyvinyl Chloride

ENGLISH TERM	MEANING
Ref1, Ref2, Ref3	Insulation qualities: building code standards from 2003 until 2006 (Ref1), a synonymous with more advanced standards (Ref2) and a standard corresponding to low energy houses (Ref3)
RF	Radiative forcing
RH	Relative humidity
Rw	Sound reduction index [dB]
SCM	supplementary cementitous materials
SFH	Single Family House
SHGC	Solar Heat Gain Coefficient
SME	Small and medium sized enterprise (with less than 250 employees)
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxides
T	Total investment [€/m²]
TiO_2	Titanium dioxide
tkm	tonne-kilometers
TVOC	Total Volatile Organic Compounds
TÜV	Technischer Überwachungsverein (Technical Inspection Agency)
U-value (U, U1, U2)	The heat transfer coefficient U [W/(m²*K)] characterises the ability of an insulation material of a given thickness to transfer heat. The higher the heat transfer coefficient is, the lower the heat protection of an insulating material is.
U_D	Heat transfer coefficient of a door [W/(m²*K)]
U_G	Heat transfer coefficient of the glazing [W/(m²*K)]
U_w	Heat transfer coefficient of the window [W/(m²*K)]
UV	Ultraviolet
US	United States
VIP	Vacuum Insulated Panel
VOC	Volatile Organic Compounds
W (kW, MW, GW)	Watt (kilo-, Mega-, Giga-)
Wh (kWh, MWh, GWh, TWh)	Watt-hours (kilo-, Mega-, Giga-, Tera-)
WMA	Warm Mix Asphalt
WP	Work Package
wt. %	Weight percent
µ-factor	Water vapour resistance factor [-]

13 ANNEXES

13.1 Lifetime of building parts

Table 13.1: Lifetimes of building

Building Structures / Components		Life expectancy [years]	Average life expectancy [years]
Load-bearing structure	1. Concrete foundations	80 – 150	100
	2. Exterior walls/ -columns		
	- Concrete, reinforced, aired	60 – 80	70
	- Natural stone, aired	60 – 250	80
	- Brick, clinkers, aired	80 – 150	90
	- Concrete, concrete stone, brick, limestone with facing	100 – 150	120
	- Light concrete with facing	80 – 120	100
	- Pointed brickwork, fair – faced brickwork	30 – 40	35
	- Steel	60 – 100	80
	- Softwood, aired	40 – 50	45
	- Softwood, panelled; hardwood, aired	60 – 80	70
	- Hardwood, panelled	80 – 120	100
	3. Interior walls, internal supports		
	- Concrete, natural stone, brick, clinker, sand-lime brick	100 – 150	120
	- Light concrete	80 – 120	100
	- Steel	80 – 100	90
	- Softwood	50 – 80	70
	- Hardwood	80 – 150	100
	4. Ceilings, stairs, balconies		
	- Concrete, aired outside	60 – 80	70
	- Concrete with external or internal facing	100 – 150	100
	- Vaults and caps made of brick, - clinker	80 – 150	100
	- Steel interior	80 – 100	90
	- Steel exterior	50 – 90	60
	- Load-bearing structures:		
	○ internal wooden stairs, softwood	50 – 80	60
	○ internal wooden stairs, hardwood	80 – 150	90
	○ external wooden stairs, softwood	30 – 50	45
	○ external wooden stairs, hardwood	50 – 80	70
	5. Stairway treads		
	- Natural stone, hard, - external/internal	80 – 150	100
	- Natural stone soft, artificial stone, exterior	30 – 100	70
	- Natural stone soft, artificial stone, interior	50 – 100	80
	- Treads, hardwood, interior	30 – 50	45
	- Treads, hardwood, exterior	20 – 40	35
	6. Roofs, roof structures		
	- Concrete	80 – 150	100
	- Steel	60 – 100	80
	- Timber roof structures	80 – 150	70
	- Glued truss	40 – 80	50
	- Nailed truss	30 – 50	30
Non-load bearing structures, exterior	7. Exterior walls, facings, infill walling		
	- Concrete		
	○ aired	60 – 80	70
	○ dressed	100 – 150	120
	- Natural stone, weathered	60 – 250	80
	- Brick, clinker		
	○ aired	80 – 150	90

Building Structures / Components		Life expectancy [years]	Average life expectancy [years]
	○ dressed	100 – 150	120
	- Sand-lime brick		
	○ aired	50 – 80	65
	○ dressed	100 – 150	120
	- Light concrete, dressed	80 – 120	100
	- Pointed brickwork	20 – 50	40
	- Softwood, aired	40 – 50	45
	- Hardwood, aired	60 – 80	70

N.B. *Source*: BBSR, 2009