French-German Institute for Environmental Research (DFIU), Karlsruhe Institute of Technology (KIT)

Final document

Collection of background information for the development of EMAS pilot reference sectoral documents: The Construction Sector

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GLOSSARY OF TERMS AND ABBREVIATIONS

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 [m³/(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 re-use, 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

ENGLISH TERM	MEANING
EUR	Euro – European currency
EURO	European emission standards
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	Lifecycle 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	ton-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 [-]

1 GENERAL INFORMATION ABOUT SECTOR STRUCTURE 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 activities are therefore recognised to 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 strategic sectors. In the EU, the construction sector as a whole represents approximately 10% of GDP and is also the largest industrial employer (30% of industrial employment), with an estimated number of 14.8 million employees and 3.1 million enterprises in 2007.

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 added 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 precedent version, related to the development of building projects and the assembly and installation of self-manufactured buildings of metal on site[1].

The construction sector is covered by Section F of the NACE Classification[2], 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).

1.1.1 Economic relevance of construction sector

In 2007, the EU-27 construction sector[3] (NACE section F[4]) counted 3.1 million enterprises that together generated a combined value added of EUR 562 billion. This corresponds to 10.7% of the GDP and 51.5% of Gross Fixed Capital formation

The construction sector is also, with 14.8 million persons employed in the EU-27 in 2007, the largest industrial employer in the EU, providing 30% of the industrial employment. Among this workforce, only 81.1% were paid employees, which reveals a relatively high rate of self-employment in the construction sector.

Repartition by size of employment[5]: The construction sector is almost exclusively composed of SMEs (small and medium sized enterprises with less than 250 employees), most of which are

[1] http://epp.eurostat.ec.europa.eu/portal/page/portal/nace_rev2/introduction

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

[3] Estimates for the EU-27 in 2007 based on the (Structural Business Statistics) SBS main indicators. Malta not included.

[4] Since most of the structural business statistics data in NACE Rev.2 will only be available starting from July 2010, the data refers to precedent NACE version.

micro-enterprises with less than 10 employees. In 2007, in the EU-27, 92% of the enterprises in construction were micro organisations, 7% small organisations between 10 and 49 employees, 1% between 50 and 249 employees and 0.2% large organisations.

Geographical repartition: Like shown in Table 1-1, the construction sector is particularly significant in five member states (Italy, Spain, France, UK and Germany), which together account for 73.6% of the value added of the sector, for 63.7% of the number of enterprises and for 64.4% of the employees. Italy hast the highest number of enterprises and Spain the highest number of persons employed (19.5% of the EU-27 total). In terms of value added, the UK has the largest construction sector, with a share of 19.2% of the EU-27.

Table 1-1: Structural profile of the five Member States with the largest construction sector, 2007 (Source: SBS main indicators, undersection European business-selected indicators for all NACE activities (2007). Malta not included.)

	Number of enterprises			Value Added			Number of persons employed		
	Country	(thousand)	% EU-27	Country	(EUR million)	% EU-27	Country	(thousand)	% EU-27
1	Italy	616	19,9	UK	108.062	19,2	Spain	2.881	19,5
2	Spain	456	14,8	Spain	101.149	18,0	Italy	1.964	13,3
3	France	435	14,1	France	75.768	13,5	France	1.724	11,7
4	UK	240	7,8	Italy	70.713	12,6	Germany	1.522	10,3
5	Germany	221	7,1	Germany	57.966	10,3	UK	1.431	9,7
	EU-27	3.090	100,0	EU-27	561.992	100,0	EU-27	14.788	100,0

1.1.2 Environmental impacts of the construction sector

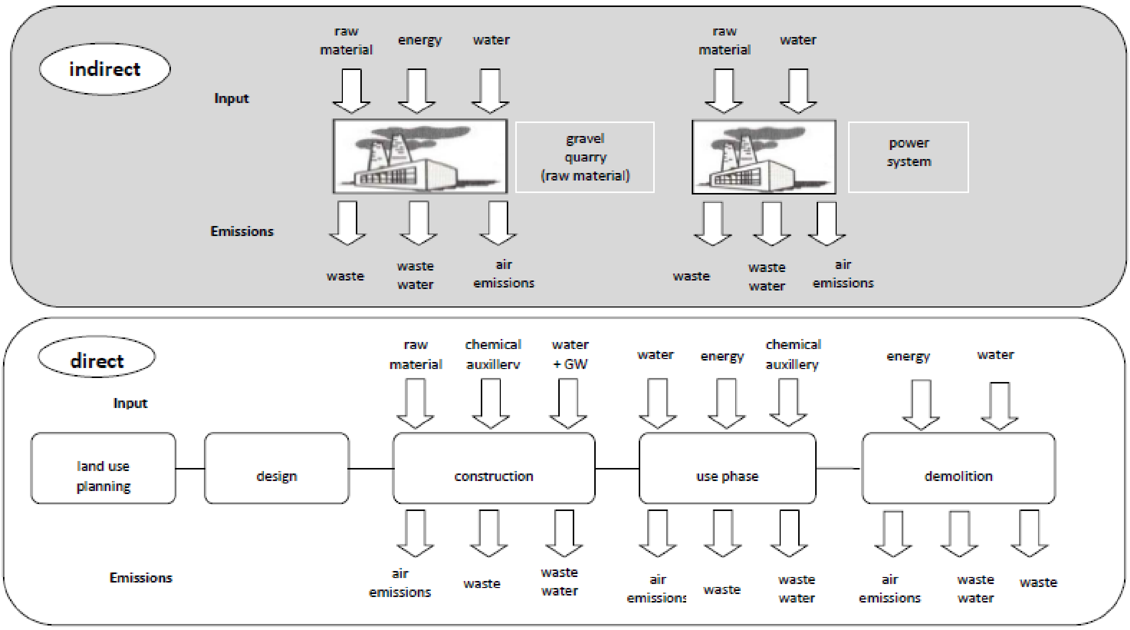


Figure 1-1: Direct and indirect environmental aspects of the construction sector

The construction sector has not only a significant role in the EU economy, but it is also a major contributor to the EU energy consumption and greenhouse gas emissions. Construction activities and buildings are related to 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

[5] http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database#

greenhouse emissions, about 50 wt. % of extracted materials and 22 wt. % of waste generation is related to buildings (ECTP, 2005; EC, 2007).

Environmental aspects are present during all life cycle phases of a building, from the construction to the demolition phase, but also during its operation, maintenance and refurbishment with the importance of the environmental aspects differing during the life cycle phases. The phases construction, use of the building and recycling and disposal are in general important. Due to the long service lifetime of buildings which is often above 100 years, aspects associated with the use phase are in general very important. During the planning of a building (selection of site, design of the building including choice of materials/components etc.) a large part of the environmental aspects are determined highlighting the key role of planning when aiming at improving the environmental performance of the construction sector. To realise the planned performance throughout the entire service lifetime good maintenance and operation are necessary. Regular refurbishment allows increasing the performance further and may also extend the service lifetime. Due to important environmental aspects associated with demolition and new construction, extending the service lifetime and avoiding this way new construction is in general considered as environmentally advantageous, even though the environmental performance of a new building during the use phase is in general better than that of the refurbished existing building.

The strength and relativ relevance of individual environmental aspects differ largely depending on the activity (Table 1-2), the building type and its life cycle phase and performance as well as the natural environment like climate and finally the environmental soundness of applied techniques.

Table 1-2: Overview of major environmental aspects of the construction sector. Grey shading marks processes leading to indirect aspects.

		Up-stream		Plan-ning		Realisation				Use phase	End of life	
		Pre-stages, e.g. quarrying	Manufacture of construction materials & products	Project development	Design / Planning	Transport	F43.1.2 Site preparation	Construction of - F41.2: residential & non-residential buildings - F42.1: roads & railways - F42.2: utility projects - F42.9: civil engineering projects	- F43.2 Electrical, plumbing & other construction installation activities - F43.3 Building completion & finishing - F43.9 Other specialised construction activities	Use / Occupation Facility Management Maintenance Refurbishment	Deconstruction	Recycling / Disposal
Consumption	Energy	++	+++			++	+	++	+	+++	+	+
	Water	+	++					+		+++		
	Raw materials	+	+++					+++	+	++		
	Land/space	++					+++	+				+
Emissions to/of	Water	+	+				+	+				
	Soil	+						+			+	
	Air	++	+++			++	+	++	++	+++	++	+
	Odour		+			+		+		+	+	+
	Noise	++	++			++	++	++		+	++	+
	Vibrations	+++	+			+	++	++			++	+
Waste	Inert solid	+++	+				+++	++		+	+++	+
	Municipal	+	+				+	++	+	+++	++	+
	Hazardous	+	+					++	++	++	++	+
	Wastewater	+	++				++	++		+++		+
Other	Use of chemicals	+	++					++	++	++		

1.1.2.1 Direct environmental aspects

In the initial phase of a construction project, the choice of the construction site is capital and has a direct influence on land use. Due to an uninterrupted urban and rural development, land is becoming a scarce resource in Europe. Between 1990 and 2000, 800.000 ha of Europe's land cover were converted to artificial surfaces. The choice of a building site also has an influence on the mobility of inhabitants and on the surrounding infrastructure. Each constructed parcel has to be connected to transportation, water, sewage, gas, and electricity networks. A more compact system is less costly and requires also less energy for maintenance. In the perspective of urban sprawl, construction activities cause environmental impacts not only as damage to landscapes but also as a loss of biodiversity as well as contributing to depletion of fossil energy resources and climate change. These impacts can be reduced through a more sustainable land use management and a densification of the constructions.

The construction phase is also source of noise pollution, dust, and emission of hazardous materials. In order to reduce these negative environmental aspects during the construction phase, the choice of materials is a complex process which must take into account many factors: the origin of the product, the life cycle costs, impacts during the construction, emissions during their production and use phase, the amount of maintenance required, and the possibilities for recycling or valorisation.

During their operation phase, buildings consume large quantities of energy, mainly for heating, air-conditioning, warm water preparation and electricity. Buildings account for the largest share of greenhouse gas emissions in Europe (about 40%). Large quantities of water are also required for the operation of the built environment. In the last years, considerable improvements in energy efficiency techniques have been realised which allow drastic cuts in the energy consumption of new buildings stock.

Moreover, the construction sector is also the largest single producer of waste in Europe. Measured by weight, construction and demolition activities respectively account for 40% and 50% of EU total waste. The different types of waste produced are various: inert waste from construction works, excavation and demolition material, hazardous waste, e.g. asbestos, batteries, fluorescent light tubes, oily sludge, aerosols, chemical waste including paints and solvents, contaminated glass, plastics, wood and packaging. Several measures can be implemented in order to reduce construction and demolition waste, including prevention during the construction phase and the use of selective deconstruction to increase the recycling and revalorisation of waste.

1.1.2.2 Indirect environmental aspects

Environmental aspects related to up-stream processes include material extraction and production of building products and components as well as their transport but also the supply of energy, in particular electricity and water. These activities are not part of the construction sector but are strongly influenced by it resulting in indirect aspects. Electricity and water are consumed mainly during the use phase of the building. Construction activities require a large amount of raw material resources, like clay, gravel, stone or wood. These materials can either be used directly or transformed for the construction. They consume more raw materials by weight (as much as 50%) than any other industrial sector. The environmental aspects include the consumption of natural resources, which are becoming scarce in some regions, as well as the negative effects related to their production (energy consumption, emissions).

Indirect environmental aspects may be influenced in several ways: One option is to reduce the input to achieve the same function. One example is a better lighting system leading to the same or a better illumination at lower electricity consumption and thus less indirect environmental aspects related to electricity production. Another option is to purchase products with less indirect environmental aspects, e.g. in case of the lighting example electricity from renewable energy. In this field, a number of labels as well as environmental product declarations (EPD) might be useful when selecting products for purchase. Finally, often alternatives exist, e.g. the use of natural illumination. In case of concrete the options could be: use of high-strength concrete requiring less concrete, more environmental friendly produced concrete, e.g. with recycling aggregates or ashes, and alternative design.

1.1.3 Subsector NACE F41: Construction of buildings

This subsector concerns the general construction of buildings of all kinds. It includes new work, repair, additions and alterations, the erection of pre-fabricated buildings or structures on the site and also construction of 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

1.1.4 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 temporary nature. Included is the construction of heavy constructions 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.

1.1.5 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 therefore, 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 like 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 operator is classified with 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.

1.2 EMAS implementation in the construction sector

1.2.1 Repartition of EMAS in the European construction sector

All sectors included, the repartition of EMAS in the EU-27 is not completely homogeneous. There are 4429 EMAS registrations in the EU-27 of which 172 organisations of the construction sector representing a total of 257 sites and 18.765 employees in 2008[6].

The geographic repartition of EMAS records across the European construction sector is not homogeneous. Only 10 out of 27 Member States are represented and 85% of the registered organisations are concentrated in 3 Member States (Spain, Italy, Germany) and the remaining 9% are dispersed between 6 countries (the Czech Republic, Greece, United Kingdom, Austria, France, Poland). More than half of the registered organisations are located in Spain. Although unevenly distributed, this repartition reflects partially the structure of the European construction sector and its importance in the different member states.

Like shown in Table 1-3, Spain, Italy and Germany have the most significant construction sectors in terms of employment and regarding the number of enterprises. Although also being in the top-five members of the European construction sector, the UK and France count few EMAS registrations. The Czech Republic has the largest number of employees in EMAS registered organisations in the EU since 90% of the organisations have more than 250 employees.

[6] ec.europa.eu/environment/emas

Table 1-3: Structural repartition of EMAS in the EU construction sector (Source: EMAS Statistics, 2008)

	Number of organisations			Number of persons employed		
	Country	number of organisations	% EU-27	Country	number of employees	% EU-27
1	Spain	93	54.1	Czech Republic	6158	32.8
2	Italy	37	21.5	Spain	4215	22.5
3	Germany	17	9.9	Greece	3879	20.7
4	Czech Republic	10	5.8	Italy	1500	8.0
5	Greece	5	2.9	UK	1057	5.6
6	UK	4	2.3	Germany	909	4.8
7	Austria	3	1.7	Austria	558	3.0
8	France	1	0.6	Poland	320	1.7
9	Hungary	1	0.6	Hungary	153	0.8
10	Poland	1	0.6	France	16	0.1
	EU-27	172	100%	EU-27	18765	100.0

85% of the registered organisations are SMEs (less than 250 persons employed), including 42% small enterprises with 10 to 42 persons employed. 12% of the registered organisations are large organisations with more than 250 employees. This repartition is not representative of the European construction sector, which is composed by around 99% of SMEs. Especially micro enterprises with less than 10 employees, which account for 93% of European construction companies, are underrepresented by EMAS with a share of only 21% of the organisations registered by EMAS. This relatively low share of SMEs in the EMAS registers reveals burdens for SMEs, especially micro-enterprises. In terms of employment, only one third of the employees of EMAS registered organisations are working in a SME, whereas the remaining two third are working for large organisations.

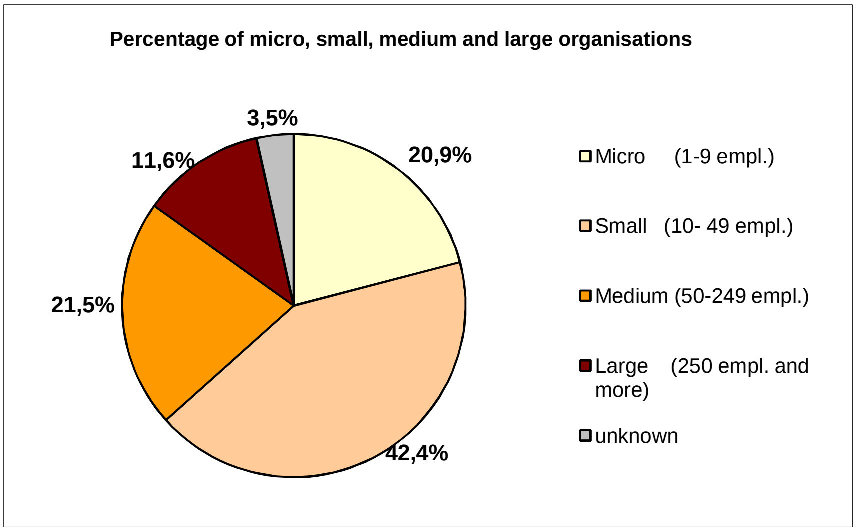


Figure 1-2: Employment size of EMAS registered organisations in the construction sector

Table 1-4: EMAS registered organisations by country and employment size

Country	Share of SMEs	Including:			Large enterprises (%)	Number of registered organisations
	%	Micro-enterprises (%)	Small enterprises (%)	Medium enterprises (%)		
Spain	92,5	28,0	47,3	17,2	4,3	93
Italy	94,6	21,6	45,9	27,0	-	37
Germany	94,1	11,8	64,7	17,6	5,9	17
Czech Repub	10,0	-	-	10,0	90,0	10
Greece	80,0	-	-	80,0	20,0	5
UK	-	-	-	-	75,0	4
Austria	66,7	-	-	66,7	33,3	3
France	100,0	-	100,0	-	-	1
Hungary	100,0	-	-	100,0	-	1
Poland	-	-	-	-	100,0	1
EU-27	84,9	20,9	42,4	21,5	11,6	172

As shown in Table 1-4, the share of SMEs severely varies from country to country. The underrepresentation of SMEs is strongest in the Czech Republic, where 9 out of 10 EMAS registered organisations are large with 250 to 2.000 employees. Participation of SMEs incl. micro enterprises is much higher in Spain and Italy, where respectively 92.5 and 94.6% of the registered organisations are SMEs.

1.2.2 EMAS implementation in the construction sector by NACE code

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 building; 23% in the sector of civil engineering; and 69% in specialised construction activities.

Like shown in Table 1-5 and figure 2-2, the greatest number of organisations is to be found in the Specialised Construction section (F43), especially in the subsections F43.21 - Electrical installations and F43.22 - Plumbing, heat and air-conditioning installation (also see Table 1-5). The second highest share of registered organisations is active in the construction of residential and non-residential buildings (F41.2). Both subsections concern the energy efficiency of a building, and new techniques have been developed offering great potential for reducing energy consumption during the use phase of a building.

Table 1-5: EMAS registrations in the construction sector according to NACE Code

NACE Code	Construction of buildings (F41)	Civil Engineering (F42)	Specialised construction (F43)	Total
Number of EMAS registered organisations	64	50	103	172
% of EMAS registered organisations	37%	29%	60%	

Note: About 30% the registered organisations belong to several subsectors at a time.

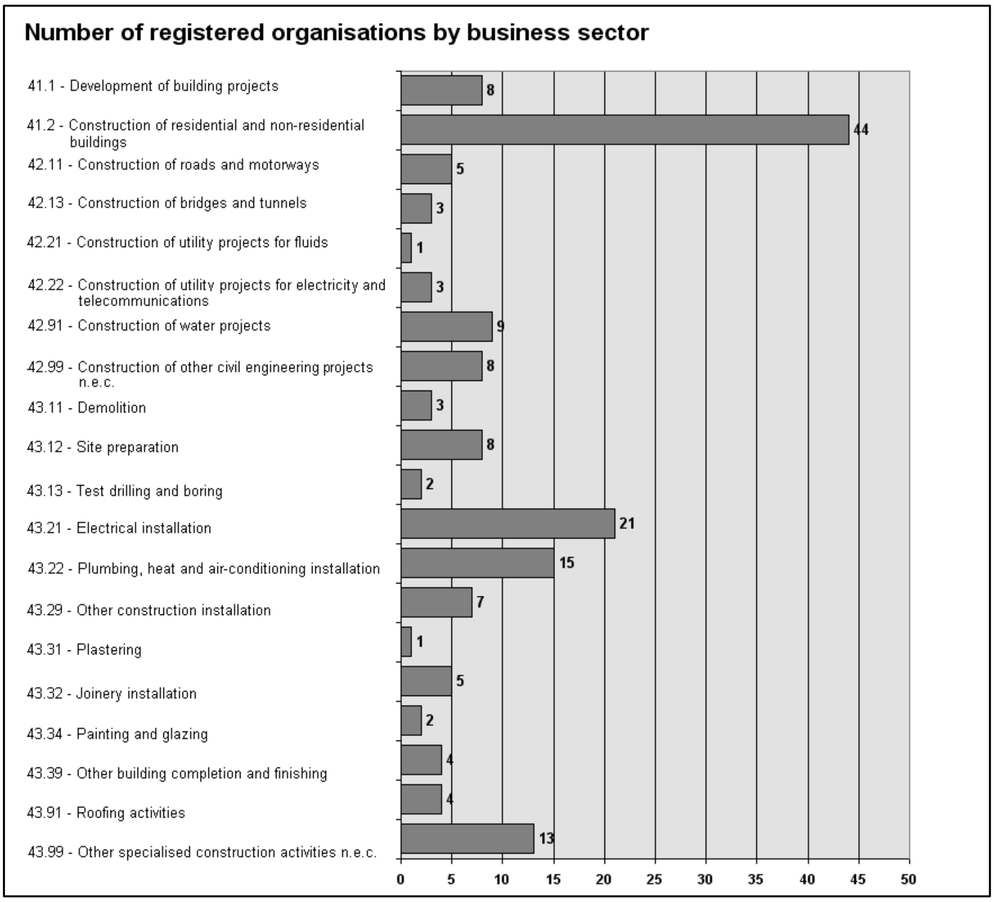


Figure 1-3: Repartition of EMAS registered organisations by NACE code

2 BUILDING DESIGN

2.1 Introduction: Building design, environmental effects and performance indicators

2.1.1 Site selection and land consumption/area efficiency

Land consumption refers to the conversion of open space or farmland to residential, commercial, office, traffic or other developed land uses. Land consumption has various impacts on the environment depending on the ecologic value of the land beforehand (for which there are a number of assessment approaches) and how the land is used afterwards. Land consumption is also a problem of loosing future use options. Whereas arable land can be easily converted to more valuable ecosystems or other uses when the use changes, there are only few examples for renaturation of built land.
In general, land consumption leads to a degradation of soil, in particular if sealed, and compromises its functions as there are (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.

Other aspects of land consumption are habitat fragmentation, by roads for example, leading 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, biodiversity.

Land consumption is also often associated with urban sprawl, i.e. the spreading of cities towards its outskirts with low population density, high car-dependency and high segregation of land uses. Urban sprawl contributes to increase 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 2-1). 150; NEWMAN and KENWORTHY, 1999].

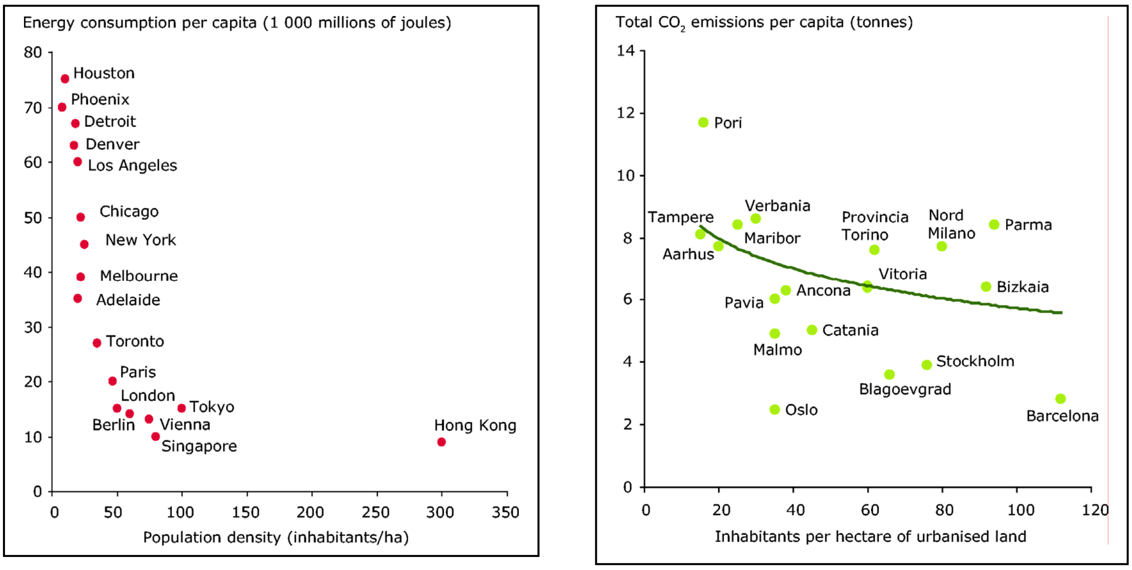


Figure 2-1: Population density and CO_2 emissions, selected cities [61, EEA, 2006]

Sustainable land use management aims at reducing land consumption and protecting 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 doesn't require investments 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[7]:

- revitalisation of brown-fields (this allows to remediate polluted resp. abandoned areas and reduces land consumption; brown-fields areas are often in central position making them interesting for investors)
- 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[8]
- discussion with building owners about their willingness to sell parts of their building plot
- internet tool to foster a market for spaces between buildings etc.
- sensibilisation of both building owners and parties interested in constructing a building about advantages of densification

For new building zones the following shoud be considered

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

Table 2-1: Indicators and recommendations for sustainable land management [56, DDE, 2010].

Indicators	Recommendation
Minimal density (taking into account public equipment and tertiary activities)	In communes: at least 40 habitations / ha
	In dense cities: at least 60 habitations / ha
Lot dimensions	200m² for 40 habitations/ha and 20% public space
Floor space index (FSI)	Set a FSI of at least 0.5 and try to tend to a FSI of 1.
Density of territory regularly served by public transport	No construction further than 300m from a public transport station
Percentage of public infrastructure (roads and public spaces)	between 20 % and 50%

Recommendations regarding density and types of habitations for different levels of sustainable urban settlement (cf. Figure 2-2):

- Minimum density of 25 habitations/ha for individual houses (grouped, row or twin houses).

[7] http://www.uvm.baden-wuerttemberg.de/servlet/is/53375/1_Broschuere_Kleine_Luecke.pdf?command=downloadContent&filename=1_Broschuere_Kleine_Luecke.pdf

[8] http://www.raum-plus.info/

- 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 functional mixture.

Figure 2-2: Left: Eco housing estate [25-40 habitations/ha], Center: Eco-district [50-80 habitations/ha], Right: Sustainable city [min. 100 habitations/ha]

References

[56] DDE Haut-Rhin (2010) : Guide méthodologique pour une intégration possible des objectifs de développement durable dans le projet urbain et les documents réglementaires locaux, Direction Départementale des Territoires du Haut-Rhin, AAtelier Cité Architecture, Ministère de l'écologie, de l'Energie, du Développement durable et de l'Aménagement du Terriotoire. http://www.haut-rhin.equipement.gouv.fr/professionnels/guide%20methodologique.pdf

Further reading

- Database with publications on management of land consumption (in German): http://www.flaecheninfo.de/
- Brochure on management of land consumption addressing municipalities (in Gerrman): http://www.lubw.baden-wuerttemberg.de/servlet/is/11111/kommunales_flaechenmanagement.pdf?command=downloadContent&filename=kommunales_flaechenmanagement.pdf
- Several publications of State Environmental Ministry of Baden-Württemberg (Germany) on management of land consumption: http://www.uvm.baden-wuerttemberg.de/servlet/is/11146/

2.1.2 Orientation of the building

The position and orientation of a building is important in terms of heat loss and solar gains as well as impacts on micro-climate. Building orientation depends on the local climate but also on e.g. shading by other buildings, trees etc. The town of Graz has published a map[9] giving detailed advice on orientation and form of buildings in their area. Simulation of insolation may help finding the best orientation in a given situation. In general, to maximize solar gain, roof areas and main rooms should be oriented south +-30° to minimize heating demand in temperate climate. However, if heat demand for cooling is important other orientations might be preferable.

2.1.3 Ecodesign

[9] http://www.graz.at/cms/dokumente/10023905_1604103/fd27edd4/klimatologie.pdf

2.1.3.1 Rules of Ecodesign

In ecodesign the whole life-cycle of a product or building is considered. From different guidelines and handbooks ten generic golden rules can be identified, which need to be implemented and concretised for a certain application. In the following the ten rules are listed, the order is not fixed [134]:

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

2. By effective housekeeping the consumtion of energy and resources is to minimize for transport and in the production/construction phase.

3. Whenever possible and when there are no negative effects on flexibility, strength and other functional qualities, product weights should be minimized by using high quality materials and structural features.

4. In the usage phase energy and resource consumption should be minimised and especially for those products, which have the major influence in this phase.

5. The repair 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 improtant, especially for products with major environmental influences outside of the usage 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 is to promote by avoiding alloys and using simple, recycled, not blended materials in a small amount.

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

2.1.3.2 Systems to evaluate and communicate the environmental performance of structures

Several systems have been developed to measure, evaluate and certificate the performance of buildings regarding certain sustainable and especially ecological aspects. Some of these systems can be applied in the design phase, they provide guidelines for sustainable and especially environmental design of different building types, and others are also applicable in the usage phase and make environmental performance of buildings, such as energy efficiency, transparent. The following table gives an overview of existing building rating systems applied in Europe.

Table 2-2: 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, Austria
HQE	France	France
LEED	USA	Several European countries
Minergie	Switzerland	Switzerland, France

Other initiatives and support projects focus on single environmental aspects. For instance, the open house project aims at establishing a common European basis, in form of a technical platform and open assessment methodology, to make planning and construction of sustainable buildings transparent and applicable [157, OH, 2010]. Similar intentions have the Sustainable Building Alliance (SBA) on an international level [183, SBA, 2010]. The Energy Efficiency in European Social Housing (E3SoHo) project intents 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) [68, E3SOHO, 2010]. Energy efficiency is also the focal point of the dena efficient house quality mark, making energy-efficient houses recognizable in Germany [58, DENA, 2010].

References

[58] DENA (2010b): Deutsche Energie-Agentur- Zukunft Haus: http://www.zukunft-haus.info/de/verbraucher/dena-guetesiegel-effizienzhaus.html, accessed 08.06.2010

[68] E3SOHO (2010): Energy efficiency in European social houses: http://www.e3soho.eu/, accessed 08.06.2010.

[134] LUTTROPP (2006): Luttropp, Conrad; Lagerstedt, Jessica: Ecodesign and the ten golden ruels: generic advice for merging environmental aspects into product development, Journal of Cleaner Production, 14, pp. 1396-1408.

[157] OH (2010): Open House - 7 framework program: http://www.openhouse-fp7.eu, accessed 08.06.2010.

[183] SBA (2010): Sustainable Building Alliance: http://www.sballiance.org/, accessed 08.06.2010.

2.1.4 Design for deconstruction and reuse

Deconstruction is the selective dismantlement (in contrast to demolition, cf. 5.1) of building components, aiming at their direct re-use or recycling of components and materials ("construction in reverse"). Design for deconstruction DfD and reuse is a way of designing a building to maximize its flexibility (to adapt to multiple owners and enlarge its lifespan avoiding wasteful renovations) and ensure a building can be disassembled (and parts reused for "closing the loop) after becoming obsolete. For achieving an optimal re-use of the building and designing it so that it can be efficiently mined as a source of reusable materials, several preconditions exist. 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 extend a building's useful life time. Measures for achieving this are for example simple construction methods with accessible separable joints (mechanical fasteners instead of glue), durable high-grade materials, standardized materials and documentation of construction methods. In summary, DfD is a design approach aiming at environmentally responsible buildings by accounting for the future deconstruction of a building.
[107, HURLEY, 2005]

As a summary of DfD principles, the following list gives some general strategies[10], for more information see list of references:

- construction design:
  - maximize clarity and simplicity
  - minimize building complexity
  - provide access to components/assemblies (windows, etc.)
  - ensure that buildings are conceived as layered according to their anticipated life spans.
  - design buildings to be adaptable to different occupancy patterns in plan, 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
  - minimize number of different materials
  - avoid composites of dissimilar materials
  - minimize toxic materials, parts containing hazardous materials should be easy to remove
  - code and mark all materials
- assemblies:
  - minimize number of components (fewer, larger elements)
  - minimize 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

[107, HURLEY, 2005], [216, UBA-A, 2006] [197, SHELL, 2006]

Layers of buildings: One issue relevant for several of these specific advices is the representation of a building as composed of different layers, which are in a constant change (see Figure 2-3). The faster changing layers as the space plan are contained by the less flexible layers like the structure, which can create friction 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 [36, 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.

[10] N.N.: Design for deconstruction, Chartwell School, Seaside, California, http://www.chartwell.org/UserFiles/File/Design_for_Deconstruction.pdf

- services (utility, HVAC systems, elevators): major replacement every 7-15, their embedded-ness can cause demolition of a building
- space plan (division of space, cabinetry, interior finishes): changes vary from commercial settings being overhauls every 3 years to much longer life in residential buildings
- stuff (furniture, appliances): can change daily to monthly.

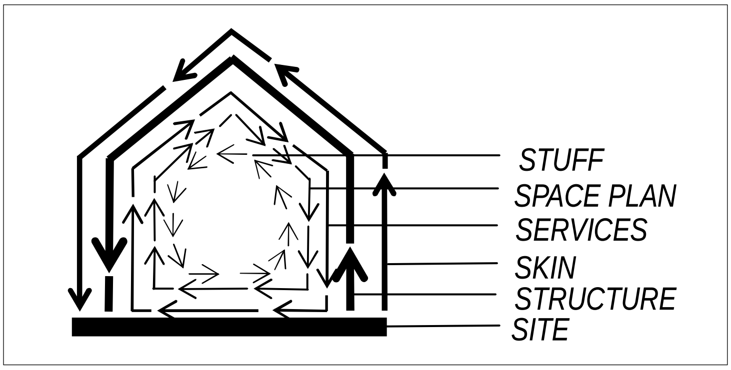


Figure 2-3: Stewards Six S's showing the layers of a building [36, BRANDT, 2005]

References

[36] BRANDT (2005): Brandt, S.: How Buildings Learn: What Happens After They're Built, Penguin, 1994 as cited in Guy, B., Ciarimboli, N.: DfD Design for Disassembly in the built environment: a guide to closed-loop design and building, Hamer Center for Community Design, The Pennsylvania State University

[107] HURLEY (2005): James Hurley & Gilli Hobbs: UK Country Report on Deconstruction, in: Deconstruction and Materials Reuse – an International Overview, International Council for Research and Innovation in Building Construction (CIB) Publication 300, Final Report of Task Group 39 on Deconstruction, Edited by Abdol R. Chini, University of Florida, www.cce.ufl.edu/affiliations/cib

[143] N.N. (2005): DfD Design for Disassembly in the built environment: a guide to closed-loop design and building, Hamer Center for Community Design, The Pennsylvania State University

[197] SHELL (2006): Scott Shell, Octavio Gutierrez, Lynn Fisher, et al for U.S. Environmental Protection Agency: Design for Deconstruction: The Chartwell School Case, Chartwell School, Seaside, California, http://www.chartwell.org/UserFiles/File/Design_for_Deconstruction.pdf

[169] PULASKI (2004): Pulaski, M., Hewitt, C., Horman, M., Guy, B.: Design for deconstruction, in: Modern Steel Construction, June 2004, p.33-36

2.1.5 Building envelope

The building envelope encompasses exterior walls, floors, ceilings or roofs, windows, and exterior doors. Theses components will be described in the follwing sections. Special aspects concerning public and retail buildings, as automatic doors, are not considered.

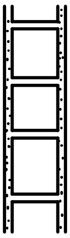
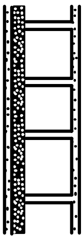
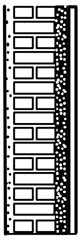
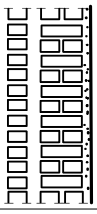
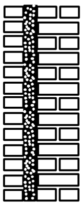
2.1.5.1 Exterior walls

Functions and requirements: Wall constructions can be differentiated into interior and exterior as well as structural and nonstructural walls. In most cases exterior walls have to absorb loads caused by building components, building use, snow, wind or seisms and transfer the resulting forces into the fundament. 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 encompass with respect to surface area the majority of the building envelope and therefore influence highly the energy performance of the building. Moreover walls have to provide moisture proofing, noise protection, fire protection and compatibility with human health. [48, CRTE, 2009; 133, LÜNSER, 2005; 140, MÖTZL, 2000]

Building materials: The use of building materials depends on the building techniques, i.e. 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 can be used. [148, NEUMANN, 2002]

2.1.5.1.1 Solid construction

Table 2-3 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 air layer and heat insulation.

	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 x plaster
	Single-layer wall of small-sized bricks with interior heat insulation layer, plastered on both sides Construction materials: Bricks + mortar + heat insulation + 2 x plaster
	Double-layer wall with air layer Construction materials: 2 x Bricks + 2 x mortar + plaster
	Double-layer wall with core insulation Construction materials: 2 x Bricks + 2 x mortar + heat insulation + plaster

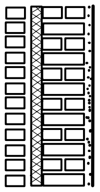
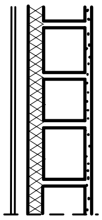
	Double-layer wall with air layer and core insulation Construction materials: 2 x Bricks + 2 x mortar + heat insulation + plaster
	Masonry with core insulation and rear ventilated curtain wall Construction materials: Curtain wall + heat insulation + bricks + mortar + plaster

Table 2-3: Typical solid wall constructions

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 2-4 provides a comparison of selected building materials used in solid construction in a life cycle oriented manner. With respect to the energy efficiency of the building the **thermal conductivity** is of major importance, whereas the **energy demand** for the production of the building materials should also be taken into account. It should be taken notice of the **Energy Performance of Buildings Directive** (Directive 2010/31/EU), which has to be implemented full into the laws of alle EU member states. The environmental aspects related to the **transport** of the high-density solid wall materials require a special consideration of the local availability of the ingredients and adequate production plants.

Table 2-4: Characteristics of selected solid wall building materials [48, 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			
Ingredients	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 SOx-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 life-time in yrs	120	100	100	100	90-120	-	70-120
Material-specific remarks	-	Possibly fungicides	Emission of eco-relevant materials by washing out		-	-	Emission of eco-relevant

		by surface treatment	and leaching, elevated radio activity (pumice)			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 (re-use / utilization)	Recycling in production process, construction waste	Re-use, concrete aggregate		Re-use, gravel, concrete aggregate, mostly deposited	Recycling (separation of steel and concrete)	Re-use, concrete aggregate

General recommendations [48, CRTE, 2009]

- use of material with high recycling 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

2.1.5.1.2 Frame construction

In contrast to solid construction 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. Advantages of frame construction in contrast to solid construction are: [48, CRTE, 2009; 148, NEUMANN, 2002]

- better use of solar radiation by transparent exterior and interior walls
- higher flexibility with respect to indoor space utilization
- reduction of permanent loads

General recommendations [48, 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

References

[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

[133] LÜNSER (2005): Lünser, H.: Energieeinspaarung im Hochbau, Innenministerium Baden-Württemberg, Stuttgart, 2005.

[140] MÖTZL (2000): Mötzl, H.; Zelger, T.: Ökologie der Dämmstoffe, Springer-Verlag, Wien, 2000.

[148] NEUMANN (2002): Neumann, D.; Weinbrenner, U.: Frick/Knöll – Baukonstruktionslehre 1, B.G., Teubner Verlag, 33. Auflage, ISBN-13: 978-3519452508, 2002.

2.1.5.1.3 Plaster

Plaster is a layer put 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 used adhesive agents into mineral and organic. [48, CRTE, 2009; 204, STARZNER, 2000]

Besides prerequisites concerning functionality, building physics, building chemistry, indoor climate and fire protection, a thorough comparison of environmental aspects should be performed. Table 2-5 provides a comparison of selected plasters in a life cycle oriented manner. Especially in the case of 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.

Table 2-5: Characteristics of selected plasters [48, 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 SOx-equivalent/kg	+++++	++++	+	+++	++++	+++++	+++++
Photosmog in kg ethene-equivalent/kg	++++	+++++	+	++++	++++	+++++	+++++
Construction							
Density in kg/m³	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 life-time 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, odor-absorbing, moisture regulating, disinfectant, mold repellent	Diffusion resistant, long drying time	Diffusion resistant	Low diffusibility, moderate moisture character-istics, long drying time	Breathable, moisture regulating, high diffusibility	Breathable, partially moisture regulating	Breathable, odor-absorbing, moisture regulating
Deconstruction / dismantling							
Recyclability	Con-struction waste	Con-struction waste	Energetic recovery	Con-struction waste (if purely mineral)	-	-	Re-use after addition of water

General recommendations [48, CRTE, 2009]

- utilization of premixed mortar in order to avoid incorrect mixing and the intake of contaminant loads at the construction site
- utilization of plaster which is made of secondary raw materials
- avoidance of small packagings by delivery in silos or containers
- electrical installation: utilization 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 facade protection systems against weathering

References
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.
[204] STARZNER (2000): Starzner, S.; Wurmer-Weiß, P.: ECOBIS – Ökologisches Baustoffinformationssystem, Bundesministerium für Verkehr, Bau- und Wohnungswesen, CD-ROM, 2000.

2.1.5.2 Floors and ceilings

2.1.5.2.1 Ceilings

Ceilings consist of different layers and can be constructed of precast components. They have to meet static requirements and should provide noise, fire and heat protection.

Besides prerequisites concerning functionality, building physics, building chemistry, indoor climate and fire protection, a thorough comparison of environmental aspects should be performed. With respect to the energy efficiency of the building the **thermal conductivity** of the ceilings of non-heated basements is of major importance, 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 materials should also be considered.

General recommendations [48, CRTE, 2009]
- use of material with high recycling fraction
- alleviation of dismantling by reduction of material variety
- avoidance of composite construction materials
- avoidance of risky additives as anti-freezing agents
- avoidance of cutting scrap

References
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

2.1.5.2.2 Floor screed

Screed can be amended by a floor cover or it serves as topmost floor layer. It has to meet the following general requirements: Wear resistance, heat protection, noise protection as well as planeness and gradient respectively. Screed can be classified according to the corresponding binding agent. [48, CRTE, 2009; 148, NEUMANN, 2002]

General recommendations [48, CRTE, 2009]
- re-use of packagings and utilization of silos at the construction site
- return of construction waste by the supplier into the production process [204, STARZNER, 2000]
- delivery of basic materials in silos or containers, avoidance of small packagings

- use of of polyethylene interlayers with a thickness of 0.5 mm as moisture barrier, which can be re-used or recycled after the dismantling

References
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.
[148] NEUMANN (2002): Neumann, D.; Weinbrenner, U.: Frick/Knöll – Baukonstruktionslehre 1, B.G., Teubner Verlag, 33. Auflage, ISBN-13: 978-3519452508, 2002.
[204] STARZNER (2000): Starzner, S.; Wurmer-Weiß, P.: ECOBIS – Ökologisches Baustoffinformationssystem, Bundesministerium für Verkehr, Bau- und Wohnungswesen, CD-ROM, 2000.

2.1.5.3 Roof

2.1.5.3.1 Steep 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.

With respect to the energy efficiency of the building the **thermal conductivity** is of major importance, whereas the **energy demand** caused by the production of the building materials should also be taken into account. The corresponding data can be found in CRTE [48, CRTE, 2009].

General recommendations [48, CRTE, 2009]
- use of material with high recycling fraction
- avoidance of composite construction materials
- alleviation of dismantling by reduction of material variety
- preference of mechanical fixing to adhesives

References
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

2.1.5.3.2 Flat roof

Flat roofs have their origin often in aesthetic considerations. It should be checked if a roof garden or a roof terrace could be installed. Steep roofs often provide longer life-times. Flat roofs can be constructed with or without protective layer, e.g. gravel. The lack of a protective layer requires a waterproofing which is able to resist high loads.

With respect to the energy efficiency of the building the **thermal conductivity** is of major importance, whereas the **energy demand** caused by the production of the building materials should also be taken into account. The corresponding data can be found in CRTE [48, CRTE, 2009].

General recommendations [48, CRTE, 2009]
- utilization of water as solvent in black painting of bitumen
- utilization of solvent-free paints
- avoidance of the use of herbicides by performing inspection walkways every 2 years

- utilization of solvant-free coatings
- only outdoor utilization of bitumen

References
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

2.1.5.4 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, are manifold: [48, CRTE, 2009; 149, NEUMANN, 2008]

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

Windows, exterior walls and the connection joints constitute with respect to heat protection requirements a common system. The weakness of one component causes disadvantages of 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** $\mathbf{U_w}$ [W/(m²*K)] characterises the heat protection of a whole window (including the frame). The higher $\mathbf{U_w}$ is, the lower the **heat protection** of a window is.
- The **heat transfer coefficient of the glazing** $\mathbf{U_g}$ [W/(m²*K)] characterises the heat protection of a glazing. The higher $\mathbf{U_g}$ 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 that radiant heat originating from indoors in winter is reflected back inside.
- The **airtightness A** [m³/(h*m)] 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.

A thorough comparison of environmental aspects of different frame materials should be performed. With respect to the energy efficiency of the building the **thermal conductivity** and the **airtightness** is of major importance, whereas the **energy demand** caused by the production of the building materials should also be taken into account.

Table 2-6 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. [121, KREIßIG, 1998]

Table 2-6: Characteristics of windows with different frame materials [48, CRTE, 2009; 121, KREIßIG, 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 SOx-equivalent/window	+++++	+	++++	+++
Photosmog in kg ethene-equivalent/window	+++++	+++++	+	++
Use				
Average life-time 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 (re-use / utilization)	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 valorization is possible, need for flue gas purification plant depends on finishing	Aluminium is recyclable, energetic recovery of wood is possible

References

[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.

[121] KREIßIG (1998): Kreißig, J.; Baitz, M.; Betz, M.; Straub, W. et al.: Ganzheitliche Bilanzierung von Fenstern und Fassaden, Institut für Kunststoffprüfung und Kunststoffkunde, Uni Stuttgart, 1998.

[149] NEUMANN (2008): Neumann, D.; Hestermann, U.; Rongen, L.: Frick/Knöll – Baukonstruktionslehre 2, B.G., Teubner Verlag, 33. Auflage, ISBN-13: 978-3519552512, 2002.

2.1.5.5 Exterior doors

Exterior Doors are necessary for access and often for ventilation and illumination too. They can consist of different materials (wood, aluminium, PVC, steel, insulation material) and can 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** [W/(m²*K)] 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** [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/(m²*K) and A-values of about 1.07-2.25 m³/(h*m) at a pressure difference of 100 Pa.[11,12]

[11] Passive House Institute: http://www.passivehouse.com/, accessed 18.08.2010.

[12] Gürlich & Wöller GmbH: http://www.fenster-passivhaus.de/Passivhaustur/passivhaustur.html, accessed 18.08.2010.

2.1.6 Heating, ventilation, air conditioning

Indoor air quality requirements state humidity rates of 40-55% to be 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 regarded to lie between 19 and 25°C, which requires heating in winter times and cooling in summer times and increasing needs for badly isolated houses.

This chapter will start with techniques for heating, as heating is the main concern in terms of energy requirements and an area of large improvement potential for most of Europe. Afterwards 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 like passive houses. Therefore the reader has to be careful, when choosing one of the described techniques, as it will have a severe influence on the other parts of the house and especially on further installed heating, ventilation and air conditioning (HVAC) techniques.

2.1.6.1 Heating

The heating system itself consists of several separate units, which altogether 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, certain attention should 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 to choose a larger system, thereby obtaining scale effects in monetary (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 load heat demand. As this does not apply for single households, the heat generator is designed for peak demand and consequently 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.

2.1.6.1.1 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 shall 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 is 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 shutdowns, 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 shall 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.

2.1.6.1.2 Heating cycle

With growing centralisation, the heat medium has to be transported for longer distances from generation via storage to the individual radiator. Therefore, efficient transport mechanisms, pumping technology and minimum heat and pressure losses are main indicators of an environmentally-friendly 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 shall 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. One available and environmentally-friendly technique, the adjustable high-efficiency circulation pump is described in the chapter of available techniques to represent the field of possible improvements at the heating control and pumping 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.

2.1.6.1.3 Heating control system

The scope of a heating control mechanism is to serve demand by steering heat production rates and storage tank level. 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 shall be maximised, periods of suboptimal generation and amounts of heat loss minimised.

An upcoming 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 shall be drawn upon the integration of renewable sources like solar thermal and geothermal heat generation, their supply characteristics (solar thermal as being dependent on sunshine hours and geothermal as being a 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.

2.1.6.1.4 Radiators

Optimising the heating cycle includes optimising radiators as well. One important aspect is to locate radiators at places, where heat can be distributed well into the room and stays in the room. This is rather a planning task, whereas technological aspects can influence system efficiency, as efficient radiators have to be selected. New radiator products are designed for low temperature use, which means they can heat rooms with hot water temperatures of as low as 65°C and not as much as 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 a better heat transmission.

Further on, technologies like 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.

2.1.6.1.5 Heat generation

Heat generation principles largely depend on the energy source used. A general split 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, which 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 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 selected type. For general LCA information regarding these mass and energy flows of heat generators, reference can be made to 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"[13] and "EcoInvent".

2.1.6.1.6 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 have been provided for the consumer market to gain electricity as well as heat in form of hot water in order to meet their demand. As solar energy is freely available, this type of technique only requires investment and maintenance cost.

For heat generation, solar thermal collectors are installed at sunlight exposed places, usually at the southward roofs (in the northern hemisphere), which absorb the sunlight and pass the absorbed energy onto 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 upon 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 collector effectiveness (degree of absorption, heat medium flow, sunlight exposure). Theoretical foundation and detailed discussion on each parameter can be found in many standard textbooks, for example in [34 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 like evacuated tube collectors with additional reflectors or solar parabolic dishes are more expensive. A decision, 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. In the section of "available techniques for heating, ventilation and air conditioning", we will give an exemplary technique description of evacuated tube collector rooftop installations, since it is an efficient and widely installed type of solar thermal heat generation.

Solar thermal systems in general 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.

2.1.6.1.7 Geothermal heat generation

Basic principle of geothermal heat generation systems is to use the heat, which is stored in the soil, to warm up the heat medium. Heat medium ducts are being installed in depth with a heat exchanger at the bottom, in which the soil passes heat onto the medium. As the amount of heat for household systems to be delivered is comparatively small to the "reservoir of heat in the soil", such type of heat generation is classified as being renewable.

Air and surface temperatures change along the year, whereas the temperature in the ground varies in a smaller amount, as it 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 middle European climate. Additionally, soil temperature

[13] The Global Emission Model for Integrated Systems GEMIS, freely available at www.oeko.de/service/gemis.

starts to increase from a certain depth onwards, which is why geothermal systems reaching deep into the ground achieve relatively high temperatures. Equipment and installation costs generally increase with deeper systems. Therefore, two different types of geothermal heat generation principles are dominating the market for household applications: horizontal ground heat exchanger, an exchanger just below the surface with a total duct length of 100 - 200 meters, and vertical ground heat exchanger, a number of ducts reaching down to as far as 100 meters below 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 medium circulation as well as for temperature and pressure regulation. Ground heat exchangers need feeding temperatures well below soil temperature and allow a certain maximum reachable temperature, which is usually below required demand levels. Pumps can be driven by electricity as well as 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 "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 energy. "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 horizontal ground heat exchanger in combination with heat pumps is an efficient way of heat generation for households, this type of installation is described in the chapter of available techniques.

2.1.6.1.8 Combustion based heat generation

Combustion based systems can be categorised according to the state of the fuels into solid, liquid and gaseous fuels. Fuels generate energy mainly by oxidising carbon to carbon dioxide and hydrogen to water. Further components of fuel mostly end up as bottom ash and emissions to air, which is why the cleanest fuels only contain hydrocarbons like methane. Regarding dust and other emissions due to incomplete combustion, the general trend can be observed that the best fuel-air mixing reaches the lowest emissions in partially oxidised substances. Consequently, recent developments have been made to provide solid fossil fuels in small pieces, such as wood pellets and wood chips, rather than log wood to improve the fuel-air mixing.

Gaseous fuel burning: 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% (NCV)[14] and very low emissions with respect to all pollutants. For description of the available technique "Gas fired condensing boilers" please refer to the section "Available techniques for heating systems, ventilation, air conditioning".

Liquid fuel burning: Common liquid fuel for domestic heating is light fuel oil. Analogous to gas, light fuel oil is a product underlying legal standards with regard to composition, especially with regard to sulphur content. Market share of oil fired heating systems decreased for many

[14] As NCV (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.

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 efficiency performances of gas fired condensing boilers. Oil is being delivered in trucks and stored in the households, therefore larger storage space is required instead of a connection to public distribution systems.

Solid fuel burning: 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 minority shares with decreasing influence. Biomass like straw, etc. is rarely used in households due to reasons of availability and low heating value. As described in the introducing text, solid fuel combustion develops towards combustion of small pieces, since surface area is maximised and hereby 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, but is fragile to low load performance, as the embodied mechanism only works for high loads [16 BAUER (1984)].

Modern solid fuel combustion in household appliances concentrates mainly on wood burning, hereby especially wood pellet and wood chip burning. These techniques are highlighted in the section “available techniques for heating systems, ventilation, air conditioning”.

2.1.6.1.9 Local and district heating systems

All heat generation systems discussed so far are producing the heat at the consumer, i.e. the dwelling. The special feature of local and district heating systems is a centralised heat production for many consumers at one single place. This heat is going to be 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 release of industrial waste heat, such as in steelmaking, cement production and oil-refining. These heat sources 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, overall system efficiency of the industrial processes can be raised in combination with covering heat demand. Main disadvantage of most distribution networks is high investment for the network duct. These high investments lead to the development, that German local authorities can rule a compulsory network connection for households, which have the possibility of connecting. This ruling shall raise the acceptance, lower overall emissions and guarantee an 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 of up to several hundred (e.g. district heating network Duisburg with a network length of approximately 500 km and 1,100 GWh of energy delivered[15]). In contrast, large local heating networks have a network length of less than 10 km and less than 10,000 MWh energy delivered[16]. Many arising

[15] From Info-Brochure „Industrielle Abwärmenutzung“, Amt der oberösterreichischen Landesregierung, October 2008.

[16] 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 [35 BÖNISCH (2001)].

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 like industrial plants or fossil fuel power stations and in addition separate small cogeneration plants for peak times.

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.

As types and forms of these local and district heating networks vary largely in size, heating capacity and type of heat generation (fossil, mixed regenerative-fossil, etc.), the example technique highlighted in the section of available techniques represents one possible form. Which type and form proofs to be the best is highly site specific and depends on the operator's requirements, hence general recommendations are hardly derivable.

2.1.6.1.10 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 is compulsory in general, costs for installing additional other heat generation techniques would outweigh possible cost advantages in most cases.

2.1.6.1.11 Emerging heating techniques

- **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% to 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 decreases with growing installation size[17].

- **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. As it generally forms an environmentally-friendly approach of thermal energy production, overall emissions will be reduced. Two different types of gas-fired heat pumps have been developed, heat absorbing and adsorbing pumps. Further information can be obtained at producers and associations websites, like www.igwp.de and www.heatpumpcentre.org.

- **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 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 numbers. Additionally, the compressibility of CO_2 facilitates very good performance numbers 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 is still at high levels.

- **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 CO2 on a specific level. 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 shall provide 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 [141 MÜLLER-STEINHAGEN (2005)]. High investment for the storage installation requires a local heating system and an additional heat generation principle like thermal combustion or additional heat supply by district heating. A summary of two feasibility studies for geothermal heat storage of solar heat energy gives Reuß in [177 REUß (2001)].

2.1.6.2 Ventilation and Air Conditioning:

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

[17] Information obtained from http://www.so.ch/fileadmin/internet/bjd/bumaa/pdf/luft/staubabscheider.pdf.

tasks to 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 especially modern construction requires ventilation systems due to air-tight walls and low heating requirements due to low heat losses.

2.1.6.2.1 Ventilation

Ventilation has been a concern in office buildings for many years, but has started for dwellings since several years 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 like 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 (see chapter in heating), but uses the air as medium. Air heat pumps do not achieve 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.

In the chapter of available techniques for ventilation, two new but accepted and already installed techniques, the earth-to-air heat exchanger and air collectors are described. Waste heat recovery is such an elementary technique for minimising energy losses, so that it is regarded as being basis for all other environmentally-friendly ventilation systems.

2.1.6.2.2 Air conditioning

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 feature highest calculated emission rates. Natural and thermal assisted systems have the ability to use excess or geothermal heat, thereby being more environmentally-friendly. As a consequence, the section of available techniques focuses on an overview of naturally and thermally assisted air conditioning systems herein and in the chapter of available techniques.

For thermally assisted air conditioning, two different process types are existing, open and closed systems. In open systems, cooling energy is directly “produced” at the air, i.e. 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.

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 prevalent open system, combining tasks of ventilation, humidity control and temperature regulation and especially designed for smaller installations like 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 exchanger, 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 have been trying 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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2.1.7 Lighting

2.1.7.1 Building lighting and its environmental aspects

Lighting of buildings has to fulfil practical and aesthetical effects that strongly depend on the building's and the lighting's (task lighting, accent lighting, and general lighting) purpose, it includes use of both artificial light sources such as lamps and natural illumination from daylight. Artificial lighting represents a major component of a building's 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 over 90 percent of lighting energy consumed is due to over-illumination. According to www.ecolabel.com, 10 percent of global electricity could be saved by switching to entirely efficient lighting systems and carbon dioxide emissions saved by such a switch would dwarf cuts so far achieved by adopting wind and solar power. Table 2-7 shows the share of lighting in total electricity consumption for the example of Germany.

Table 2-7: Share of lighting in electricity consumption for different sectors [233, WUPPERTAL, 2006]

	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

Comprehensive lighting design requires consideration of the amount of functional light provided, the energy consumed, as well as the aesthetic impact supplied by the lighting system. The following table 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 2-8 Typical illuminances of buildings and daylight [125, LFNUV, 2010]

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

Important design and technology choices concerning lighting mainly refer to the type of light source and optimal control strategies, i.e. on one hand installation of high efficiency lighting systems and on the other hand interior and exterior lighting control systems with sensors that integrate daylighting strategies and occupancy to conserve energy.

In the following, issues related to the quality of interior lighting and its energy consumption are summarized.

- Firstly, of illumination requirements for each given use-area have to be defined. This should be done together with space planning and interior architecture (including choice of interior surfaces and room geometries) for avoiding poor design choices. Especially in facilities like schools and shopping centres, where a large amount of energy is consumed by lighting, a good lighting concept is crucial.[18]
- Daylighting can be combined with intelligent lighting control and in many cases completely obviates the need for interior artificial lighting for many hours of the day.
- For artificial lighting, the fixture and lamp types should be selected in a way to reflect best available technology for energy conservation (see types of light bulbs).
- Training of building occupants can ensure to use lighting equipment in most efficient manner.
- Beside the use of modern light bulbs, regular maintenance at constant intervals is important. Pollution of reflectors for example can cause efficiency losses of up to 30%.

2.1.7.2 Bulbs

The use of efficient lighting technology can lead to significant reductions of electricity consumption, especially in office buildings with shift operation or in buildings where a lot of old lamps can be replaced by a smaller quantity of new ones.

[18] Cf. http://www.energyglobe.com/en/building-renovation/praktischer-leitfaden/innengestaltung/optimale-lichtplanung/

In European legislation regulating on efficiency requirements and on bans on inefficient lamps, a distinction is made between “household”-bulbs (standard incandescent and halogen bulbs, compact fluorescent lamps with integrated ballast) and fluorescent lamps with separated ballast, regulated by 2000/55/EC. These regulations set minimum energy efficiencies (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. Regarding the whole lifecycle 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.
The main types of light bulbs are described in 2.5.1.

2.1.7.3 Environmental indicators for light bulbs

- Luminous efficacy [lm/W]
- Alternatively: Efficiency class [A-G for household lamps and A1-D for other discharge lamps]
  - Other technical quality/performance parameters
  - Light output [lm]
  - Lifetime [h]
  - Lumen maintenance [% remaining after X hours]
  - Light colour/”temperature” [K]
  - Colour rendering index (CRI): a quantitative measure of the ability of a light source to reproduce the colours faithfully (100 best, 0 worst)
  - Mercury content [mg]
- EU Ecolabel: Light bulbs bearing the EU-Ecolabel fulfil the following criteria (for a detailed list cf. [70, EC, 2010], www.ecolabel.com):
- life span of between 5 and 9 years (10,000 hours), i.e. ten times longer than incandescent light bulbs
- It will consume five times less electricity than an incandescent light bulb
  - It will not flicker when switched on
  - It contains very little mercury
  - It uses at least 65% recycled packaging
  - It is guaranteed to light at 70% or 90% after 10,000 hours depending on type of bulb

2.1.7.4 Fixtures, avoiding glare

Lighting fixtures serve as a holder for the light source, to provide directed light and to avoid visual glare. An important property of light fixtures is the luminous efficacy, meaning the amount of usable light emanating from the fixture per used energy quoted as the percentage of light passed from the bulb to the surroundings.[19]
The combination of light sources and surface materials used in buildings should in general avoid glare and strong variations of light density, which both causes eye stress and general exhaustion. For general lighting, lamps should be distributed evenly throughout the room. An arrangement of lights parallel to the line of the window is of advantage here. Work-stations are to be arranged so that lighting or lighted surfaces will not produce a glare, and so that reflections onto the monitor will be avoided as much as possible.

2.1.7.5 Use of daylight

The best option for maximizing visual comfort and to reduce energy use is to use as much natural light as possible. Some studies suggest that productivity increases by 6 – 16 percent

[19] A database of residential energy-efficient lighting fixtures can be found at http://www.e-ster.be/enerlin/

when natural light is added to a workplace, with 1 percent productivity increase equalling the total energy cost in offices [81, EDWARDS, 2002].
Daylighting[20] is the practice of placing windows, skylights, translucent wall panels or sunlight transport devices and reflective surfaces so that during the day natural light provides effective internal lighting. Good daylighting technique depends on the proper placement of windows and performance characteristics such as visible light transmittance and solar heat gain coefficient (measures how well a window blocks heat from sunlight) not having large amounts of glass. If a building is well conceived and well designed in the first place, users have access to copious amounts of natural light through well-placed openings. Even without skylights and bay windows, architects can make light reflect deep into an interior space through strategic design and placement of windows.
With the increasing proportion of glass surfaces in building facades, the heat input 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 mechanical cooling. Possibilities of "redirecting light" should be fully applied.
The correct use of natural daylight saves energy (lighting energy reduced by up to 80%) and is beneficial for health of the building's users (more circadianly-attuned lives). A successfully daylit 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. Main design issues are illuminance levels, contrast ratios, window to wall ratios, ceiling to skylight area percentages, and reduction in unwanted glare.

Environmental indicators for daylighting

- Annual energy consumption (or absolute/relative energy savings) for lighting per square meter [kWh/m²a]
- Other technical quality/performance parameters
    - Room illuminance [lux]

Sunlight shading and over-illumination

Efficient methods for keeping unwanted sunlight out of a building are important for several reasons. Firstly, direct sunlight can lead to glare. This and heat in summer leads to discomfort for building occupants. Increased cooling demand is another issue that can be avoided by simple solar control techniques like exterior solar control (overhangs, fins), window blinds, solar filters (e.g. spectrally selective glazings), angular selective façades, etc. Especially when concepts like passive cooling or daylighting are applied, controlling possibly interfering sunlight is important.

Over-illumination is the presence of (artificial) lighting intensity beyond what is required for a specified activity. Over-illumination was commonly ignored in past decades, especially in office and retail environments. It can contribute to light pollution, where stray light illuminates the outdoors or others' property, where it is unwanted. The two main concerns of over illumination are the related consumption of energy (especially when rooms are unoccupied, e.g. office buildings illuminated overnight and on weekends) and negative health effects (migraine headaches, fatigue, stress, circadian rhythm effects) depending on the brightness and spectrum of the light. Solutions in response to these concerns are a greater use of indirect sunlight in modern buildings and the control of lighting in unoccupied spaces, either by manual switches or by occupancy sensors.

Besides overlooking opportunities for skylights, the lack of coordination of interior light banks with indirect sunlight is an even more common error. At a minimum, the building design should offer sufficient independent light banks so that building occupants may select the most suitable combination of natural to augmented light. Very frequently entire floors of existing office

[20] For more information see for example http://www.daylighting.org/what.php, http://www.iea-shc.org/task21/publications/index.html

buildings are designed with only one switch, so that perimeter areas near natural light are illuminated with the same level of artificial light as the dimmest interior zones. This lack of independent controls also requires an entire office floor to be fully illuminated if one office worker stays late for evening work. Often "designed in" over-illumination can be corrected by simple actions of building managers, following an illumination survey like removing a fraction of the lights or fixtures from a ceiling lighting system.

2.1.7.6 Automatic control

Occupancy sensors for artificial lighting are currently used primarily for bathrooms and storage areas, their use can extended to many other types of rooms like offices, hallways etc. Their payback time is in the range of two to five years.
Besides artificial lighting, the control of window blinds according to the occupants' demand (room illumination and temperature) can further improve comfort and reduce energy consumption. Besides artificial illumination, air conditioning can be reduced by such measures, for example by completely shading unattended rooms.

For more information on lighting control systems, please refer to section 2.5.4.

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http://www.greenlabelspurchase.net/de-green-procurement-downloads.html

2.1.8 Electric installations

Beyond scope of project; potential issues (should be mentioned in the final document, however not a core topic of the construction sector):

- Environmentally friendly cables/materials or bus systems for reducing cable needs
- Flexibility for future uses (cable tubes for power, computer networks etc)
- Smart Homes
- Use of residual current devices and smoke detectors
- Energy-efficient elevators escalators

2.1.9 Water system

Water consumption during operation refers to four different types of use:

- 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 being 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 have impacts on users' health. Due to the scarcity of water resources, it has become necessary to adopt water efficient practices in building operation.

Main parameters

The quantity of water consumed strongly depends on 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's households (Portsmouth Water, 2005).

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 regions, 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 around 380 l/hh/d, with a range of 247-511 l/hh/d [62DG ENV, 2009]. This corresponds to a daily water demand of 153 litres per person. The most demanding water using products in households are usually water taps, toilets, and showers. Table 2-9 illustrates the most common water using products in residential buildings and their corresponding average daily water consumption.

Table 2-9: Water consumption of commonly used water using products in residential buildings in Europe [62, DG Env, 2009]

WuP	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	6.0 - 9.5 l/flush	7.0 - 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 - 47.0 l/use	0.5 - 0.7	24.3	15.1 - 33.4
Outdoor use[8]	0 - 48.5 l/use	0 - 0.89	21.8	0 - 43.5

Water demand can be mastered by metering the consumption (see section 2.6.1) by installing water leak detection systems (section 2.6.2), or by retrofitting existing equipment using water-saving plumbing devices (section 2.6.3) and recycling waste water (section 2.6.4).

Water wastage through leaky piping systems is frequent and can raise a buildings' water consumption significantly. By avoiding these problems, maintenance plays a key role in water management.

Another issue of water consumption, particularly in residential buildings, is water heating, which typically accounts for 10 to 20% of the energy used in households. Most of this energy is generally lost as wastewater is eliminated through the drain. However, it is nowadays possible to install a hot water heat recycling system to recover that energy (see section 2.6.5).

References
[62] DG ENV (2009): European Commission; Study on water performance of buildings, 2009. SustainableBuild (http://www.sustainablebuild.co.uk)

2.1.10 Finishings, facilities, interior fitting

2.1.10.1 Indoor air quality

According to some studies, European citizens spend over 90 % of their time in buildings. Health and comfort-related problems and illnesses occur in more than 40% of these enclosed spaces [80, 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, some of the most important parameters are:

- 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 by many laws and regulations, fewer regulations for indoor air quality exist. An exception are working areas, in which air pollution arises from technical production processes and which are regulated by provisions of industrial law. Pollutants from different sources are often present in interior rooms, partly carried in by the outside air partly from sources within the buildings. Table 2-10 gives an overview of possible indoor air pollutants which may be caused by building products and equipment.

Table 2-10: Common indoor air pollutants and their sources (adapted from [20, BBSR, 2009a])

Substance	Source (building products and equipment)
Dusts	Abrasion of floors, insulating materials, processing of building products
Carbon monoxide	Defective or poorly ventilated heating equipment
Radon	Subsoil
Formaldehyde (HCHO)	Wooden materials (fibreboards), acid-hardening varnishes
Volatile organic compounds including • alkanes • aromatic compounds • aldehydes (o. HCHO), ketones • ester • alcohols • terpenes • glycols • chlorinated/brominated/fluorated 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

Assessment scales are available for only a few of the numerous substances which lead to indoor air pollution. The following table lists guideline values (data from 1999) and provides orientation for the assessment of indoor air pollutants.

Table 2-11: Guideline values for maximum levels of indoor air pollutants (proposed by the Indoor Air Hygiene Commission IRK/AOLG1 in 1999; adapted from [20, BBSR, 2009a])

Substance	Immediate measures to be taken (mg/m³)	Target value for remedial works (mg/m³)	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/m³	0.1 µg/m³	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/m³	0.035 µg/m³	Link, B.: Guideline Values for Indoor Air: Mercury. Federal Health Department Bulletin. Health Research - Health Protection 42 (1999) 168 - 174

Other recommended limit values for indoor air [20, BBSR, 2009a]:

- TVOC (Total Volatile Organic Compounds) [195, SEIFERT, 1999]:
  - 10-25 mg/m³ temporarily
  - 1-3 mg/m³ longer stay
  - 0.2-0.3 mg/m³ 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/m3 are considered to be tolerable long-term levels.
  - Where indoor air concentrations between 300 ng/m3 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, to some extent such solvents are also released to indoor air from (new) products like 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. They are typically not acutely toxic but have chronic effects. Exposure to VOCs can worsen asthma symptoms and cause nose, skin and eye irritation, headaches, nausea, respiratory problems. Concerning their sources, neurotoxic toluene often comes from polyurethane foam insulation, other potentially carcinogenic and respiratory-irritant VOCs 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 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 priorities of clean air can be considered depending on the use of the building: 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) stay in these buildings for up to 24 hours per day. Second priority buildings for clean indoor air are other buildings with permanent occupancy like 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. [48, CRTE, 2009]

2.1.10.2 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 concentrations can reach high levels.

Many different kinds of paints exist; in section 2.7.2 an overview of 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 several more environmentally friendly options are available than conventional paints with rather high environmental and health impacts. Section 2.7.2 gives information on characteristics of different kinds of paints, environmental and health issues of conventional paints and available techniques for reducing these, namely low-VOC paints and paints from natural ingredients.

Selecting products with a generally accepted ecolabel (see 2.7.1) is recommendable, as these paints are checked for hazardous ingredients and low VOC content.

2.1.10.3 Wood Preservatives

Wood preservation includes all measures that ensure a long life of wood and wood products, in generally by increasing the 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 exterior use of wood products, several design decisions can avoid permanent moisture of wood parts (e.g., leaving air space for ventilation). For wood parts in buildings that are already affected by insects (like the house longhorn beetle), thermal treatment (heating the room/attic to 80°C-100°C) is an environmentally friendly option.

Wood product applications are divided in different risk classes (for example German DIN 68800-3), with several naturally durable woods (for example black locust) being suited for quite high risk classes without chemical treatment.

Table 2-12: Risk categories of timber following DIN 68800-3 [48, CRTE, 2009]

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

As most chemical wood preservation products contain substances with possible negative health effects, wood products for interior use (wall panels, floor covering, furniture) should not be treated at all with those products, especially in case of residential or other permanent occupancy buildings (cf. section on general indoor air quality). As all chemicals for wood preservation have negative environmental impacts (emission of VOC, hazardous salts that can be washed out, biocides that are slowly released to the environment) their use should be limited as much as possible and several general measures should be respected:

- Wood should only be utilized for construction when it is fully dry; protection against moisture during use phase is advisable.
- The risk class of the wood to be protected has to be determined beforehand.
- Some substances like chromates should be avoided.
- Skin contact should be avoided during application, spraying is not recommended.
- The used products should be documented for supporting later deconstruction and recycling.
- Organic products should not be used for interior application.[21]

[48, CRTE, 2009]

[21] http://www.bayern.de/lfu/umwberat/data/chem/stoff/holzschutz_1996.htm

2.1.10.4 Adhesives

In general, adhesives used in construction activities can be divided in the main types dispersion adhesives, (wheat) paste, solvent-based adhesives, polyurethane adhesives and epoxy resin adhesives. Especially the differences between dispersion adhesives and solvent-based adhesives are important for environmental and health issues. Wheat past is an old adhesive with special application areas, polyurethane and epoxy resin adhesives are new adhesives also rather for special applications. Table 2-13 summarizes the major characteristics of these groups of adhesives.

Table 2-13: Properties off different types of glues [48, CRTE, 2009]

<table>
<tr><th></th><th>Dispersion glue</th><th>(Wheat) paste</th><th>Solvent-based glue</th><th>Polyurethane glue</th><th>Epoxy glue</th></tr>
<tr><td>Hardening mechanism</td><td colspan="3">physical</td><td colspan="2">chemical</td></tr>
<tr><td>Binding agent</td><td>various</td><td>starch/cellulose</td><td>various</td><td>polyurethane</td><td>epoxide</td></tr>
<tr><td>Binding type</td><td colspan="5">cold binding</td></tr>
<tr><td>Form of delivery</td><td colspan="3">one-part adhesive</td><td>one or multi-part adhesive</td><td>multi-part adhesive</td></tr>
<tr><td>Mechanical properties</td><td colspan="3">basically plastomer</td><td colspan="2">plastomer, duromer and elastomer</td></tr>
<tr><td>Application in construction</td><td>universal</td><td>breathable wallpapers</td><td>increased demands</td><td>increased demands</td><td>special applications</td></tr>
</table>

The choice of a suited adhesive depends on the material (e.g. floor covering) to be glued to a surface and this 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. 2.7.1):[22]

The emission class is determined by the summed TVOC emission, for which medium and low volatility compounds shall be measured. These slowly evaporating compounds are the main determinants for the long-term emission characteristics and indoor air pollution.

Check list:

- 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 installation of flooring, countertops, trim, wall coverings, panelling and tub/shower enclosures.

[48, CRTE, 2009], www.buildgreennow.org

[22] www.klebstoffe.com

2.1.10.5 Other interior finishing materials

Material selection and cleaning efforts: 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: Relevant environmental and health issues for wallpapers are the environmental effects during production (e.g. preference for recycled paper products) and the content of pollutants, like heavy metals or formaldehyde. Choosing products bearing a recognized ecolabel (cf. 2.7.1) is recommended for assuring quality and sustainability of the product (recyclability, absence of problematic chemicals, etc.).

Wood: In general, wood products should be certified by the Forest Stewardship Council (FSC) or other generally recognized organizations (cf. 2.7.1) for its assuring sustainable production and tropical woods should be avoided (cf. 2.7.3). 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 chemical 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 a very ecological option for non-structural parts saving natural resources. In general, wood products (including furniture) treated with natural materials or made from untreated wood is recommendable for environmental and health reasons.
The use of different kinds of engineered wood (also called composite wood) can increase 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 as strong as, but 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 taterials like straw-based MDF and bamboo plywood or laminate are durable alternatives to wood-based MDF and solid wood for interior trim that reduce pressure to harvest forests. Bamboo is as durable as most hardwoods.
However, for all composite materials the used glues and chemical 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).
www.buildgreennow.org

Furniture: For furniture that requires cushioning, foamed material is not the best option, as foam off-gases over time. For beds, sofas etc. recommendable options are cotton padding, latex, or kapok or furniture designed ergonomically reducing the necessity of using foam. Buying furnishings assembled with toxic epoxies, stains, paints and varnishes or fabrics (perfluorated hydrocarbons) should in general be avoided.

2.1.10.6 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). Important properties of floor coverings are density, hardness and fire classification as wells as noise and thermal conductivity. Table 2-14 shows different wear classes for floor coverings.

Table 2-14: Wear classes for floor coverings [48, CRTE, 2009]

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

Environmental performance indicators, as well as more details (application, operational data…) about different types of floor covering are given in table Table 2-55.

General recommendations for selecting floor coverings [48, CRTE, 2009], [78, EC, 2010c]:

- Prefer domestic (European) woods. Select wood from sustainably managed forests (FSC or PEFC certification).
- Choose floor covering 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 a way, that a destruction-free reopening and reuse is possible
- Apply surface treatment as far as possible already at factory level, because the factory is better equipped to collect the emissions.
- For elastic floor coverings a high traceable product quality should be ensured, which normally leads to low emissions during the utilization phase.
- Cleaning and care of floor covering during the utilisation phase can produce emissions; environment-friendly processed should be applied here (cf chapter on maintenance).

Recommendations for specific floor covering types:

- **Linoleum floor coverings**: The portion of renewable and mineral raw materials should amount to at least 98 percent[23]. No persistent organic pollutants which accumulate in the body of the person, animals and plants should be added.
- **Floor covering (textile):** The requirements of the EMICODE label (see 2.7.1, www.emicode.de) give some guidelines for selecting textile floor covering installation material, these include:
  - The flooring installation product meets all the legal requirements, especially the chemical law and its specifications.
  - The flooring installation product is 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.
  - The classification into the EMICODE classes is performed, for product labelling the matching EMICODE class is used.

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2.2 Available Techniques for Design for Deconstruction

2.2.1 Application of design for deconstruction techniques during design and construction

Description

Waste from demolition of constructions can be reduced by increasing the rates of reuse and recycling of building materials and components. Material reuse considerations do not start when a building reaches the end of its life; improving material reuse starts when a building is designed. Many construction parts that are sent to the landfills have a reuse value or can be recycled. One obstacle to reuse is that 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 much 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, health hazards (asbestos). [107, HURLEY, 2005]

According to practitioners, the following building characteristics can simplify the dismantling, reducing the time and expense of salvaging the building materials [224, WEBSTER, 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.

- 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 are important 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 life time 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, modularization, 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 spayed products for fire protection may mean that removal and disposal of potentially hazardous materials make deconstruction uneconomic.

[107, HURLEY, 2005], [216, UBA-A, 2006] [197, SHELL, 2006]

<u>Achieved environmental and health benefits</u>

- Reduced amounts of deconstruction wastes
- Recyclability of components reduces number of parts that have to be built

- Flexibility for future uses of whole buildings avoids impact from newly constructed buildings

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.

Cross-media effects
None

Operational data
Recycling and reusing opportunities and barriers of specific building materials:
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, 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 however there is a market. Cement mortar of modern buildings cannot be cleaned off bricks and blocks so if they are to be deconstructed at all their use can only be aggregate. [107, HURLEY, 2005]
Some of the main issues for DfD of masonry bricks are:

- 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 to be used 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.

[224, WEBSTER, 2005]

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. [224, WEBSTER, 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 (See 5.2.3 and 5.2.5). [107, HURLEY, 2005]

Some of the main issues for DfD of concrete parts are:

- 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.

[224, WEBSTER, 2005]

Many products can never be reused in their original form and can only be recycled as aggregate, such as:

- 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)
- reinforcement corrosion can occur
- coatings (either cosmetic or protective) can deteriorate due to ageing, weathering and mishandling

[107, HURLEY, 2005]

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[24]), 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 build or renovation with little modification required. For example large timber beams, railway

[24] For example handheld denailer Nail kicker v20, Price one-driver kit, about 400 €, www.nailkicker.com

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. [107, HURLEY, 2005]
Some of the main issues for DfD of timber parts are:

- 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 panelized 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.

[224, WEBSTER, 2005]

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. [107, HURLEY, 2005]
Some of the main issues for DfD of steel parts are:

- 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.

[224, WEBSTER, 2005]

<u>Applicability</u>
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 2-15 shows the relevance of DfD aspects for different groups of stakeholders

Table 2-15 Relevance of design principles for different project players (adapted from [169, PULASKI 2004])

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 standardize 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
Minimize 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				

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. However, no exact data is available.

Driving force for implementation

Reduction of deconstruction waste (increase of the construction materials recycling quota)

- Increasing legislative pressure for high recycling quotas and bans for landfilling waste

Reference organizations

- International Council for Research and Innovation in Building and Construction, Task Group 39 on Deconstruction, http://www.cibworld.nl
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2.3 Available techniques for building envelope

2.3.1 Higher thickness of insulating material

Description

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. [105, HIETE, 2008]

Technically, the best way to insulate a building component is on the outside as this reduces problems with thermal bridges and does not lessen the useful floor area. 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. [211, THUNSHELLE, 2005]

The most important insulating materials with respect to the business volume in Germany are:[25]

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

From a thermal point of view, insulation materials are highly important for the energy efficiency of a building. Increasing the thickness of insulation material and the utilization of insulation material with low thermal conductivity improves the thermal quality of the building envelope. Generally, the thickness 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. [211, THUNSHELLE, 2005]

Achieved environmental and health benefits

- reduction of heating or cooling energy demand

[25] Gesamtverband Dämmstoffindustrie GDI: http://www.gdi-daemmstoffe.de/produkte/, accessed 18.08.2010.

- enhancement of noise protection
- stabilization of the indoor temperature
- summertime excessive heating protection

The reduction in final energy demand and the adequate 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, depending on the outdoor temperature. The division was made according to the number of heating degree days[26] (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.

Table 2-16 and Table 2-17 provide HDD (year 2005) for 25 EU member states [94, GIKAS, 2006]. In an analogous way cooling degree days (CDD) can be considered. A detailed map is availabe in BOERMANS [33, BOERMANS, 2007]. [33, BOERMANS, 2007]

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

Table 2-16: Heating degree days in EU member states, year 2005 (Part I) [94, GIKAS, 2006]

State	BE	CZ	DK	DE	EE	EL	ES	FR	IE	IT	CY	LV	LT
HDD [Kd/a]	2669	3564	3233	3137	4319	1625	1937	2457	2633	2051	644	4184	4014
Climatic zone	mod-erate	mod-erate	mod-erate	mod-erate	cold	warm	warm	mod-erate	mod-erate	mod-erate	warm	cold	cold

Table 2-17: Heating degree days in EU member states, year 2005 (Part II) [94, GIKAS, 2006]

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	mod-erate	mod-erate	warm	mod-erate	mod-erate	mod-erate	warm	mod-erate	mod-erate	cold	cold	mod-erate

The reduction in cooling energy demand by insulation measures has been investigated for a single family house (SFH) and a multi family house (MFH) with 120 m² and 1600 m² useful floor area, respectively.

Table 2-18 provides the results of this investigation. [33, BOERMANS, 2007]

Table 2-18: Cooling energy demand savings by insulation in reference house in Seville and Marseille [33, BOERMANS, 2007]

	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/(m²*a)] (useful energy/useful floor	SFH: 4 MFH: 2		SFH: 13 MFH: 6		SFH: -4 MFH: -2	

[26] Heating degree days (HDD) express the severity of the cold in a specific time period taking into consideration outdoor temperature and room temperature. EUROSTAT [94, GIKAS, 2006] 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

area)			
	SFH: 14 MFH: 7		
Marseille (427 cooling degree days)			
Cooling energy demand savings [kWh/(m^2*a)] (useful energy/useful floor area)	SFH: 1 MFH: 0	SFH: 4 MFH: 2	SFH: -3 MFH: -1
	SFH: 3 MFH: 1		

For Germany, the achievable savings in annual heating energy demand per m^2 component area by the improvement of the insulation of existing buildings have been investigated. The results depend on construction details. An overview without those details is provided in Table 2-19. [98, GRE, 2002]

Table 2-19: Achievable savings in annual heating energy demand (useful energy) by insulation measures for existing buildings in Germany [98, GRE, 2002]

Application area	U old [W/(m^2*K]	U new [W/(m^2*K]	Recommended (2002) insulation thickness [cm]	Achievable reduction in useful energy demand [kWh/(a*m^2)] (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

Environmental indicators

As environmental indicator serves the **heat transfer coefficient U [W/(K*m^2)]** of the insulation layer, as it influences the heating or cooling demand of a building. As overall environmental indicator serve the **annual savings in heating or cooling energy demand per square meter useful floor area or component area [kWh/(a*m^2)]**. Whereas the heat transfer coefficient depends only on the insulation layer, the latter energy demand savings depend on the building type the indoor temperature, the outdoor temperature etc. Furthermore, in the case of integrated measures as combined improvement of building envelope and heating system, the contribution of the improved building envelope to final energy savings isn't clear-cut.

Cross-media effects

The selection of an insulating material is a multi-criteria problem. Whereas ceteris paribus costs, primary energy demand for production and thickness should be low, specific heat capacity should be high. Generally (if U isn't fixed) the primary energy demand for the production should be regarded in contrast to the reduction in heating demand, which is strongly influenced by the useful life of an insulating material. 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 examined with special attention. Furthermore the limited availability of resources and the possibility of recycling, re-use and energetic valorization after the use phase of the insulating material should be already considered during the decision 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: [133, LÜNSER, 2005; 140, MÖTZL, 2000; 178, REYER, 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 as well of importance, as the thermal conductivity increases, if the insulating material becomes humid.
- **Heat transfer coefficient**: The heat transfer coefficient [W/(m^2*K)] 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.[27]
- **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 merrier the **airborne sound insulation** is.
- **Dynamic stiffness:** The dynamic stiffness [MN/m^3] describes the dynamic-elastic characteristics of an insulating layer as intermediate layer in multilayer constructions. The lower the dynamic stiffness is, the merrier 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/m^3] of the insulating material is as well of importance, as the heat capacity (per volume) increases, if the density of the insulating material increases.

Table 2-20: Application areas (ÖNORM B600) as well as performance indicators of selected insulating materials, fire classification according to DIN EN 13501-1 [140, MÖTZL, 2000]

			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

[27] Armacell Enterprise GmbH: http://www.armacell.com/www/armacell/INETFAQ.nsf/vFrame1/9B07DE2D77C5EBB7802571A8007289D0, accessed 18.08.2010.

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 indicators								
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		

In selecting adequate insulating materials environmental aspects during production and end-of-life stage as well as health impacts, e.g. by hazardous fibre length or formaldehyde loads, and indoor climate should also be considered. Because of the increasing resource consumption insulating materials, which consist of **renewable resources**, should be preferred. With respect to the admission of insulating materials national rules and standards as well as European ones as the **European Technical Approval** (ETA) have to be taken into account. With respect to energy-efficiency it should be taken notice of the **Energy Performance of Buildings Directive**, which has to be implemented full into the laws of alle EU member states. Exemplarily, Table 2-20 provides in detail the application areas of selected insulating materials as well as performance indicators – including 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 plethora of insulating materials can be found in MÖTZL [140, MÖTZL, 2000].

Table 2-21: U=0.4 W/(m²*K); Cost and operational data of selected insulating materials in Germany, fire classification according to DIN EN 13501-1 [120, KÖNIG, 2008]

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 classific ation	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-	18	10	0.84	A1/A2/	1-2

			0.05				B/E	
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
Exruded 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

Table 2-21 and Table 2-22 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/(m²*K). The selection of an insulating material is a multi-criteria problem. Whereas ceteris paribus costs, primary energy demand for production and thickness should be low, specific heat capacity should be high. Generally (if U isn't fixed) the primary energy demand for the production should be regarded in contrast to the reduction in heating demand, which is strongly influenced by the useful life of an insulating material. Usually, the reduction in heating demand should by far exceed the required energy for the production of the insulating material. The compressive strength is only important if the insulation layer will be loaded, e.g. as in the case of parking levels. On the one hand a higher density of the insulating material causes an increase of the thermal mass and thus a reduction of temperature variations. On the other hand it causes an increase of the insulation layers' weight and thus different requirements regarding mounting etc. The dehumidification capacity is of importance, as the heat transfer coefficient increases, if the insulating material becomes humid. Thus 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 examined with special attention. Furthermore the limited availability of resources and the possibility of recycling, re-use and energetic valorization after the use phase of the insulating material should be already considered during the decision process.

Table 2-22: 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); [48, CRTE, 2009; 120, KÖNIG, 2008]

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

<u>Applicability</u>

Technically, the best way to insulate a building component is on the outside as this reduces problems with thermal bridges and does not lessen the useful floor area. 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. [211, THUNSHELLE, 2005]
Example installations: common technique in Europe

Application areas for selected insulation materials are provided in Table 2-20 and Table 2-22.

General recommendations [48, CRTE, 2009]:

- utilization of renewable insulating materials as the elevated requirements of heat protection raise the insulating material consumption
- 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 utilization 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 packagings

Economics

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 2-23 provides heat transfer coefficient recommendations from an economic point of view for walls, roofs and floors in new construction and retrofit 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. If 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. [33, BOERMANS, 2007]

Table 2-23: Heat transfer coefficient recommendations for walls, roofs and floors in selected cities of the EU [33, BOERMANS, 2007]

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

Investment data for the insulation of walls, roofs and floors in existing residential buildings, built before 1975 is provided in Table 2-24. The investments include labour and material and are provided in € 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 synonymous with more advanced standards (Ref2) and a standard corresponding to low energy houses (Ref3). [83, EICHHAMMER, 2009]

Table 2-24: Investments for the insulation of walls, roofs and floors in existing buildings [83, EICHHAMMER, 2009]

Cold climate zone									
	Walls			Roofs			Floors		
	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3	Ref1	Ref2	Ref3
U-value before [W/(K*m²)]: U1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.5
U-value after [W/(K*m²)]: U2	0.18	0.17	0.15	0.15	0.13	0.11	0.18	0.17	0.15
Labour [€/m²]	66.0	66.0	66.0	37.8	39.1	44.9	21.8	21.8	21.8
Material [€/m²]	88.9	92.9	99.0	18.9	19.6	22.3	29.3	30.7	32.7
Total investment [€/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/(K*m²)]: U1	1.50	1.50	1.50	1.50	1.50	1.50	1.20	1.20	1.20
U-value after [W/(K*m²)]: U2	0.41	0.38	0.20	0.25	0.23	0.20	0.44	0.41	0.28
Labour [€/m²]	50.6	50.6	50.6	20.6	22.3	24.4	13.8	13.8	13.8
Material [€/m²]	36.9	38.3	49.4	10.3	10.6	21.1	15.3	16.1	19.2
Total investment [€/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/(K*m²)]: U1	1.97	1.97	1.97	2.46	2.46	2.46	2.46	2.46	2.46
U-value after [W/(K*m²)]: U2	0.59	0.48	0.25	0.50	0.43	0.30	0.50	0.43	0.30
Labour [€/m²]	30.4	30.4	30.4	13.2	13.6	15.6	10.0	10.0	10.0
Material [€/m²]	31.9	35.3	45.6	6.6	6.8	7.8	6.6	6.8	7.8
Total investment [€/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

In the case of unheated and unused top floors with steep roofs, the insulation of the topmost ceiling is from an economic point of view in general the most reasonable insulation measure. [98, GRE, 2002]

Further cost data is provided in Table 2-21.

Driving force for implementation

- reduction of heating or cooling energy demand
- legal requirements concerning the energy efficiency of buildings

Reference organizations

- European Insulation Manufacturers Association: http://www.eurima.org
- German Insulation Manufacturers Association: http://www.gdi-daemmstoffe.de/

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[133] LÜNSER (2005): Lünser, H.: Energieeinspaarung im Hochbau, Innenministerium Baden-Württemberg, Stuttgart, 2005.

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[178] REYER (2001): Reyer E.; Schild, K.; Völkner, S.; Kompendium der Dämmstoffe, Fraunhofer IRB Verlag, ISBN 978-3-8167-4732-1, 2001.

[211] THUNSHELLE (2005): Thunshelle, K. et al.: Bringing Retrofit Innovation to Application in Public Buildings – D16 Handbook of design guidelines, tools and strategies for low energy refurbishment of public buildings, Norwegian Building Research Institute, 2005, available under http://edit.brita-in-pubs.eu/fundanemt/files/DesignGuidelines/BRITA_in_PuBs_D16_Handbook_of_guidelines_complete_submitted_31_07_08_sq.pdf, accessed 18.08.2010.

Further information:

[163] PETERSDORFF (2004): Petersdorff, C.; Boermans, T.; Stobbe, O.; Joosen, S; Graus, W.; Mikkers, E.; Harnisch, J.: Mitigation of CO2 Emissions from the Building Stock - Beyond the EU Directive on the Energy Performance of Buildings, ECOFYS GmbH, 2004, available under http://www.eurima.org/uploads/pdf/puttingHouseInOrder/ecofys_repoft_final_160204.pdf, accessed 18.08.2010.

2.3.2 Walls

2.3.2.1 Transparent thermal insulation

Description

Transparent insulation reduces heat losses and increases solar gains in comparison with opaque insulation (see Figure 2-4). In the case of opaque insulation solar radiation is absorbed at the outside of the heat insulation. Therefore, the insulation avoids the intrusion of heat caused by solar radiation. In the case of transparent insulation, 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. The heat transfer is reversed, if the solar gains exceeed the heat losses. In this case the transparent thermal insulation can be interpreted as heating system and the time delay of the heat transfer from outside to inside depends on the thermal capacity of the inner shell of the wall. [211, THUNSHELLE, 2005]

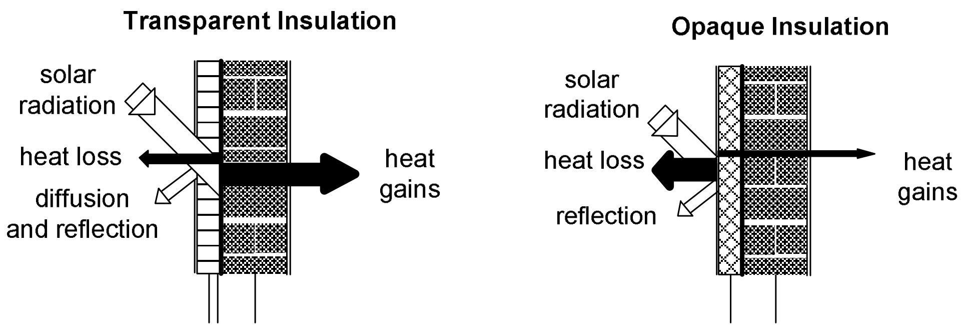

Figure 2-4: Functional principle of transparent insulation in comparison with opaque insulation [211, THUNSHELLE, 2005]

Achieved environmental and health benefits

- reduction of heating energy demand
- use of solar energy
- higher comfort through warmer inner surfaces

The useful energy saving potential of transparent thermal insulation materials compared to conventional insulation material of the same thickness ranges from 13 to 71 kWh per m² component area and from 1 to 21 kWh per m² useful building floor area. [175, REIß, 2005; 211, THUNSHELLE, 2005]

Environmental indicators

As environmental indicators serve the annual savings in heating energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature, the solar radiation etc.

Cross-media effects

During summertime cooling energy demand can increase, but this effect can be reduced by reflection. This is possible as the angle of incidence of the solar radiation differs from winter to summer[28]. Furthermore, see chapter 2.3.1 Higher thickness of insulating material.

Operational data

Technical data, as standard formats, available thicknesses, the adequate integration into a thermal insulation composite system, etc., is provided under http://www.sto.de.[28]

Applicability

The transparent thermal insulation can be used instead of conventional external insulation for solid masonry walls and concrete walls.[28]

Example installations:

- multi-family house in Munich [211, THUNSHELLE, 2005]
- two-catcher in Basel[29]

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. [175, REIß, 2005; 211, THUNSHELLE, 2005]

[28] Sto AG: http://www.sto.de, accessed 18.08.2010.

[29] Fachverband Transparente Wärmedämmung e.V.: http://umwelt-wand.de/newsletter/nl9-1/scobalit.html, accessed 18.08.2010.

Driving force for implementation
- reduction of heating energy demand
- legal requirements concerning the energy efficiency of buildings

Reference organizations
- Association for Transparent Insulation: http://umwelt-wand.de/
- Sto AG: http://www.sto.de

References
[175] REIß (2005): Reiß, J.; Wenning, M.; Erhorn, H.; Rouvel, L.: Solare Fassadensysteme, Energetische Effizienz-Kosten-Wirtschaftlichkeit, IRB-Verlag, Stuttgart, Germany, 2005, ISBN 3-8167-6433-9.
[211] THUNSHELLE (2005): Thunshelle, K. et al.: Bringing Retrofit Innovation to Application in Public Buildings – D16 Handbook of design guidelines, tools and strategies for low energy refurbishment of public buildings, Norwegian Building Research Institute, 2005, available under http://edit.brita-in-pubs.eu/fundanemt/files/DesignGuidelines/BRITA_in_PuBs_D16_Handbook_of_guidelines_complete_submitted_31_07_08_sq.pdf, accessed 18.08.2010.

Further information:
[124] LEONHARDT (1996): Leonhardt, H.; Sinesbichler, H.: Hybrid Transparente Wärmedämmung, IBP-Mitteilung 304, 23 (1996), Fraunhofer Institut für Bauphysik, available under http://www.ibp.fhg.de/literatur/ibpmitt/304.pdf, accessed 18.08.2010.

2.3.2.2 Vacuum insulated panel

Description
The thermal conductivity of vacuum insulated panels is about 0.004 W/(m*K) and therefore much smaller than the thermal conductivity of conventional insulation materials (see chapter 2.3.1 Higher thickness of insulating material) [135, MAINKA, 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. [211, THUNSHELLE, 2005]

Gas leakage causes an increase of the thermal conductivity of 0.0015 W/(m*K) 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 about the protection during use has to be provided. [135, MAINKA, 2005]

Achieved environmental and health benefits
- reduction of heating or cooling energy demand
- thinner constructions
- increase in living area in the case of internal insulation

The useful energy saving potential of vacuum insulated panels compared to conventional insulation materials of the same thickness is about 26 kWh per m² component area and about 7.3 kWh per m² useful building floor area. [175, REIß, 2005; 211, THUNSHELLE, 2005]

Environmental indicators
As environmental indicators serve the annual savings in heating or cooling energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature etc.

Cross-media effects

See introduction chapter 2.3.1 Higher thickness of insulating material.

Operational data

Various product data sheets for vacuum insulation panels are available under http://www.va-q-tec.com/[30]. For example, the a VIP, namely va-Q-vip, provides a density of 180-210 kg/m³, a thermal conductivity of less than 0.005 W/(m*K), temperature stability between -70 an +80 °C, a thickness of 10 to 40mm, standard dimensions of 1000 mm x 600 mm or 500 mm x 600 mm, and an internal gas pressure o fless than 5 mbar at delivery. Other technical data concerning the influence of the gas pressure on the thermal conductivity, an overview of different layer constructions as well as the comparison of vacuum insulated panels and conventional polystyrene layers is available in MAINKA [135, MAINKA, 2005]. Furthermore, two different VIP layer constructions are compared with respect to extra energy losses by thermal bridges ranging from 10% to 43%.

Applicability

Vacuum insulated panels are applicable for insulations of walls, ceilings, floors etc. Especially, they are adequate for applications with spatial restraints.[30]

Example installations:

- two-catcher in Basel[31]
- three single family houses in Germany [95, GINTARS, 2007]

Economics

In Germany, additional gross investments for vacuum insulated panels compared to conventional insulation materials of the same thickness are about 105 € per m² component area and about 29 € per m² useful building floor area. [175, REIß, 2005; 211, THUNSHELLE, 2005]

Driving force for implementation

- reduction of heating and cooling energy demand
- spatial restraints requiring slim insulation layers
- legal requirements concerning the energy efficiency of buildings

Reference organizations

- Va-Q-tec AG: http://www.va-q-tec.com/
- VARIOTEC GmbH & Co. KG: http://variotec.de/

References

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[211] THUNSHELLE (2005): Thunshelle, K. et al.: Bringing Retrofit Innovation to Application in Public Buildings – D16 Handbook of design guidelines, tools and

[30] Va-Q-tec AG: http://www.va-q-tec.com/, accessed 18.08.2010.

[31] Fachverband Transparente Wärmedämmung e.V.: http://umwelt-wand.de/newsletter/nl9-1/scobalit.html, accessed 18.08.2010.

strategies for low energy refurbishment of public buildings, Norwegian Building Research Institute, 2005, available under http://edit.brita-in-pubs.eu/fundanemt/files/DesignGuidelines/BRITA_in_PuBs_D16_Handbook_of_guidelines_complete_submitted_31_07_08_sq.pdf, accessed 18.08.2010.

2.3.2.3 High performance plaster systems

Description
The integration of glass bubbles into plaster layers, e.g. on bricks, causes, that the absorption of the sun and the convective heat transfer to the outside air are not longer on the same layer. Thus, the useful gains from direct and diffuse radiation increase, whereas the convective heat losses decrease. This principle is known from transparent insulation. In comparison to conventional plaster systems energy losses decrease by 15 to 25 %. [211, THUNSHELLE, 2005]

The combination of IR-coatings, highly absorbtive colours and the lotus effect in external plaster systems reduces heat losses and raises solar gains. The protection against weathering by similar surfaces as the lotus plant 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. [211, THUNSHELLE, 2005]

Achieved environmental and health benefits
- reduction of heating energy demand
- use of solar energy

The useful energy saving potential of high performance plaster systems (phase change materials included) compared to conventional insulation materials of the same thickness range from 3 to 10 kWh per m² component area and from 0.9 to 2.8 kWh per m² useful building floor area. [175, REIß, 2005; 211, THUNSHELLE, 2005]

Environmental indicators
As environmental indicators serve the annual savings in heating energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature, the solar radiation etc.

Cross-media effects
The risk of microorganisms contaminating outside surfaces is significantly reduced by higher surface temperatures. During summertime cooling energy demand can increase.

Operational data
Product data sheets are available under http://www.sto.de[32].

Applicability
The high performance plaster systems can be used instead of conventional external plaster.

Economics
In Germany, additional gross investments for high performance plaster systems (phase change materials included) compared to conventional insulation materials of the same thickness range from 60 to 80 € per m² component area and from 18 to 23 € per m² useful building floor area. [175, REIß, 2005; 211, THUNSHELLE, 2005]

Driving force for implementation

[32] Sto AG: http://www.sto.de, accessed 18.08.2010.

- reduction of heating energy demand
- legal requirements concerning the energy efficiency of buildings

Reference organizations
- Sto AG: http://www.sto.de

References

[175] REIß (2005): Reiß, J.; Wenning, M.; Erhorn, H.; Rouvel, L.: Solare Fassadensysteme, Energetische Effizienz-Kosten-Wirtschaftlichkeit, IRB-Verlag, Stuttgart, Germany, 2005, ISBN 3-8167-6433-9.

[211] THUNSHELLE (2005): Thunshelle, K. et al.: Bringing Retrofit Innovation to Application in Public Buildings – D16 Handbook of design guidelines, tools and strategies for low energy refurbishment of public buildings, Norwegian Building Research Institute, 2005, available under http://edit.brita-in-pubs.eu/fundanemt/files/DesignGuidelines/BRITA_in_PuBs_D16_Handbook_of_guidelines_complete_submitted_31_07_08_sq.pdf, accessed 18.08.2010.

Further reading:
http://www.ibp.fraunhofer.de/wt/berichte/2003/jb_03_20.html[33].

2.3.2.4 Emerging technique: 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 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 stabilized without mechanical cooling. The core of the PCM is a microcapsule, which contains a special wax mixture as 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 in a phase change. Thus, a 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.[34]

Achieved environmental and health benefits[35]
- reduction of cooling energy demand
- quiet air conditioning without the occurrence of draughts and transference of noise
- stabilization of the indoor temperature in the healthy temperature zone, that is between 21°C and 26°C
- summertime excessive heat protection

Enviromental indicators
As environmental indicators serve the annual savings in cooling energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature, the solar radiation, etc.

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[33] Fraunhofer Institut für Bauphysik, Abteilung Wärmetechnik: http://www.ibp.fraunhofer.de/wt/berichte/2003/jb_03_20.html, accessed 18.08.2010.

[34] BASF AG: http://www.highglosspaint.com/portal/basf/ien/dt.jsp?setCursor=1_290868, accessed 18.08.2010.

[35] BASF AG: http://www.micronal.de/portal/streamer?fid=443847, accessed 18.08.2010.

No data for environmental indicators is available.

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 2-25. The higher the latent heat capacity [kJ/kg] and the overall heat capacity [kJ/kg] are, the lower the cooling energy demand is.

Table 2-25: Operational data of Micronal® PCM[35]

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 surface cooling system (21°C), summertime excessive heat protection (26°C) and stabilizing 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. 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. can be used without 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. Therein 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).[35]

In general, the following application areas for PCM in buildings exist: [30, BINE, 2009c]
- integration into the building structure (ceiling, wall)
- integration in other building elements (e.g. façade elements)
- utilization in separate heat and cold storage devices

Further information can be found under http://www.ise.fraunhofer.de[36] and http://www.deutscher-zukunftspreis.de/content/nominierte-2009[37].

E.g. in the gypsum wallboard 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 of certain low weight building materials.[34]

Further products integrating Micronal® PCM are[38]

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[36] Fraunhofer Institute for Solar Energy Systems ISE: http://www.ise.fraunhofer.de, accessed 18.08.2010.
[37] Büro Deutscher Zukunftspreis: http://www.deutscher-zukunftspreis.de/content/nominierte-2009, accessed 18.08.2010.

[38] BASF AG: http://www.micronal.de/portal/basf/ide/dt.jsp?setCursor=1_290222, accessed 18.08.2010.

- Ilkazell Isoliertechnik GmbH's Ilkatherm® System (ceiling panels, http://www.ilkazell.de/)
- Maxit clima® machine-applied plaster from maxit Deutschland GmbH (plaster, http://www.maxit.de)
- H+H Deutschland GmbH's CelBloc Plus® (aereated concrete blocks, http://www.hplush.de/home)

Example installations:

- office construction for Engelhardt & Bauer, Karlsruhe[35]
- new school building for the state of Luxembourg, Diekirch[35]
- Solar Decathlon House[35]
- new office construction of Badenova, Offenburg[38]
- DSC of LUWOGE/Fortisnova, Ludwigshafen[38]

Economics

- No specific cost data is available, but aggregated data is available in SCHMIDT [186, 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 organizations

- BASF AG: http://www.micronal.de
- Knauf Gips KG: http://www.knauf.com
- Saint-Gobain Weber GmbH: http://www.maxit.de/
- H+H Deutschland GmbH: http://www.hplush.de/home
- Ilkazell Isoliertechnik GmbH: http://www.ilkazell.de/

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[186] SCHMIDT (2005): Schmidt, M.: 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.

2.3.3 Roofs

2.3.3.1 Cool roofs

Description

In summer, cities heat up about one to three degrees Celsius more than rural regions. The main cause for this is the built environment, which absorbs more heat, especially streets and roofs as they are often made of dark materials.

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 used materials, which reflect the solar radiation (solar reflectance or albedo) and release the heat they have absorbed (infrared emissivity).

Achieved environmental and health benefits

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. [5, AKBARI, 2009]

By immediately reflecting solar radiation back into the atmosphere and reemitting 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 [5, AKBARI, 2009] calculates the following performance indicators:

- 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.

Environmental indicators

The performance of building products is 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.[39]

[39] Environemntal Protection Agency, United States: http://www.epa.gov/heatisld/resources/glossary.htm, accessed 18.08.2010.

- The emissivity of a material (usually written ε or e) 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.

The EU research project COOLROOFS offers an online calculator for determining energy saving potentials by cool roofs technology.[40]

Cross-media effects
Reduced maintenance and extended roof life is claimed, reducing solid waste. Increased heating in colder periods reduces energy savings depending on climate (see Applicability).

Operational data
A cool roof is one that reflects the sun's heat and emits absorbed radiation back into the atmosphere. The roof stays cooler and reduces the amount of heat transferred to the building below, keeping the building at cooler and more constant temperature. However, a cool roof need not be white. Many "cool colour" products exist which 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 research project COOLROOFS develops a database of cool materials.[41]

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 http://www.coolroofs-eu.eu/.[41] 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

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

The benefit of the reduced solar heating of buildings is however 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 [159, OLESON, 2010], global space heating increased more than air conditioning decreased. The researchers note that the benefits of white roofs will grow as the use of air-conditioning around the world grows.

Example installations: common technique.

Economics

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[40] Calculator of energy savings, EU research project COOLROOFS: http://pouliezos.dpem.tuc.gr/coolroof/coolcalcenergy_eu.html, accessed 18.08.2010.

[41] EU Cool Roofs Project: http://www.coolroofs-eu.eu/, Intelligent Energy Europe, accessed 18.08.2010.

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

Driving force for implementation

- In some regions (California), all new buildings have to be equipped with cool roofs as part of the government's climate strategy.
- reduction of cooling energy consumption in hot climate zones

Reference organizations

- Abolin: http://www.abolincoolpaints.com/

References

[5] AKBARI (2009): Akbari, H., Menin, S., Rosenfeld, A.: Global cooling: increasing world-wide urban albedos to offset CO2, Climatic Change, Vol. 94: 275-286, 2009.

[159] OLESON (2010): Oleson, K.; Bonan, G.; Feddema, J.: Effects of white roofs on urban temperature in a global climate model, Geophys. Res. Lett., Vol. 37, L03701, doi:10.1029/2009GL042194, 2010.

Further reading:
EU Cool Roofs Council: http://www.coolroofs-eu-crc.eu/, accessed 18.08.2010.
Cool Roofs Rating Council: http://www.coolroofs.org/, accessed 18.08.2010.
Baulinks.de: http://www.baulinks.de/webplugin/2010/1frame.htm?0346.php4, accessed 18.08.2010.

2.3.3.2 Brown and green roofs

Description

The overriding aim in designing a **brown roof** is to encourage biodiversity, e.g. by compensating for loss of brownfield habitat or by providing protected habitats on the roof. Soil and rubble caused by new building construction 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. The flexible concept of brown roofs should 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.[42]

Figure 2-5 shows a typical example for the layer build-up of brown roofs. The brown-roof comprises the following four layers:[42]

- The **substrate layer** consists of a varied range of growing mediums (local soil and spoil, aggregates etc.), usually selected to maximize 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 doesn't, a separate root barrier layer will be needed.

[42] BrownRoofs.co.uk: http://www.brownroofs.co.uk/brown-roof-habitats.php, accessed 18.08.2010.

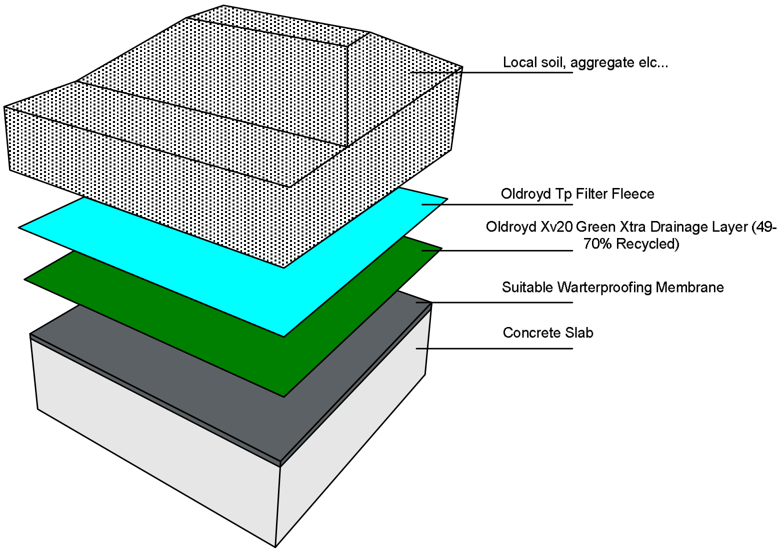

Figure 2-5: Typical layer build-up of brown roofs[43]

Green roofs provide a plethora of environmental benefits. As insulation layer they stabilize temperatures during the summer and the winter and provide urban heat island mitigation benefits. Furthermore, storm water runoff 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.[44]

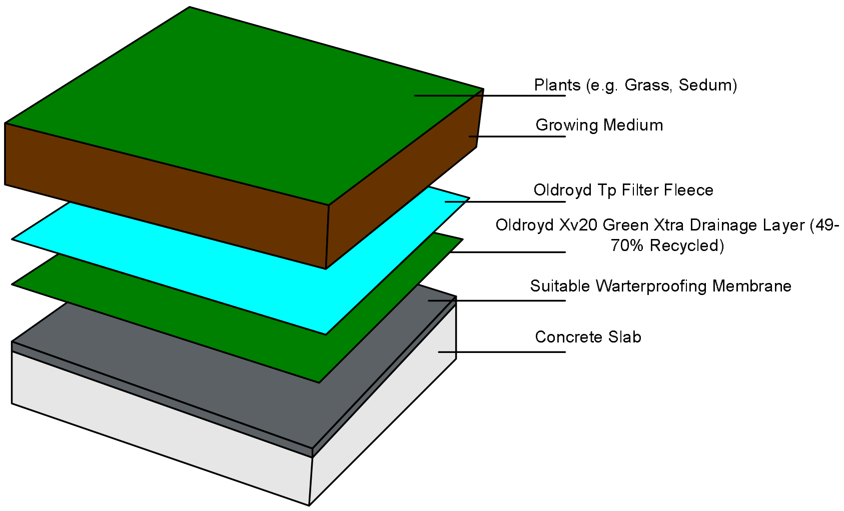

Figure 2-6: Typical layer build-up of flat green roofs[44]

Figure 2-6 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. After a **filter layer** soil loading and plantings are added.[44]

Achieved environmental and health benefits[45,46]

[43] Safeguard Europe Ltd.: http://www.safeguardeurope.com/applications/biodiverse-roofs.php, accessed 18.08.2010.

[44] Safeguard Europe Ltd.: http://www.safeguardeurope.com/applications/green_roofs.php, accessed 18.08.2010.

[45] BrownRoofs.co.uk: http://www.brownroofs.co.uk/brown-roof-habitats.php, accessed 18.08.2010.

[46] CIRIA Building Greener: http://www.ciria.com/buildinggreener/index.html, accessed 18.08.2010.

- attractiveness of visual appearance
- encouragement of biodiversity
- enhancement of roof insulation properties
- enhancement of roof lifespan by protecting underlying waterproofing system
- improvement of air-quality in cities
- providing green space in urban areas
- reduction of rainwater runoff
- reduction in urban heat island effect
- stabilization of temperatures throughout the year

Environmental indicators

As environmental indicators serve the annual savings in heating and cooling energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature etc. Furthermore, the number of species (biodiversity) living on the rooftop can be used.

No data for environmental indicators is available.

Cross-media effects

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Operational data

Fixing guides for green roofs are available in SAFEGUARD [180, SAFEGUARD, 2010a; 181, SAFEGUARD, 2010b] and OLDROYD [158, OLDROYD, 2010]. In Barking, East London, (http://www.brownroofs.co.uk/brown-roof-case-study-hackney.php, BrownRoofs.co.uk, accessed 18.08.2010) 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. Further example installations are referenced in the following section.

Applicability

The concept of green roofs is applicable at flat roofs [181, SAFEGUARD, 2010b] and at steep roofs [180, SAFEGUARD, 2010a] with low pitch. The required loadbearing capacity has to be provided.[43] Furthermore, concepts for green walls also exist. The concept of brown roofs is applicable on flat roofs and on steep roofs with low pitch. The required loadbearing capacity has to be provided.[43]

Example installations for green roofs: Construction of a sloping green roof on an oak-framed garage/summerhouse[47].

Example installations for brown roofs:

- brown roof case study, Hackney, London: http://www.brownroofs.co.uk/brown-roof-case-study-hackney.php, BrownRoofs.co.uk, accessed 18.08.2010
- brown roof in Barking, East London: http://www.brownroofs.co.uk/brown-roof-case-study-barking.php, BrownRoofs.co.uk, accessed 18.08.2010
- retrofit brown roof in Tower Hamlets, East London: http://www.brownroofs.co.uk/brown-roof-case-study-tower-hamlets.php, BrownRoofs.co.uk, accessed 18.08.2010
- retrofit brown roof with disabled access, Toxteth, Liverpool: http://www.brownroofs.co.uk/brown-roof-case-study-toxteth-tv.php, BrownRoofs.co.uk, accessed 18.08.2010

Economics

[47] Safeguard Europe Ltd.: http://www.safeguardeurope.com/case_studies/sloping-green-roof.php, accessed 18.08.2010.

No cost data for brown and green roofs is available. Low level maintenance is required, e.g in order to avoid monocultures and to assess the condition of the waterproofing layer.

Driving force for implementation

- Encouragement of biodiversity, e.g.
  - 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)
- Furthermore, see chapter *achieved environmental and health benefits*

Reference organizations

- Oldroyd AS: http://www.oldroyd.com/
- Safeguard Europe Ltd.: http://www.safeguardeurope.com/
- Wild Flower Turf: http://www.wildflowerturf.co.uk

References

[158] OLDROYD (2010): Oldroyd AS: Creating Effective Drainage for Green and Turf Roofs, available under http://www.safeguardeurope.com/pdf_datasheets/oldroyd_turf_roofs.pdf, accessed 18.08.2010.

[180] SAFEGUARD (2010a): Safeguard Europe Ltd.: Pitched Green Roof Fixing Guide, available under http://www.safeguardeurope.com/pdf_datasheets/pitched_green_roof_guide.pdf, accessed 18.08.2010.

[181] SAFEGUARD (2010b): Safeguard Europe Ltd.: Flat Green Roof Fixing Guide, available under http://www.safeguardeurope.com/pdf_datasheets/flat_green_roof_guide.pdf, accessed 18.08.2010.

2.3.3.3 Emerging technique: integration of titanium dioxide in roof tiles

Description

Nano-crystalline titanium dioxide (TiO_2) can be integrated in a concrete surface of roof tiles. TiO_2 is a semiconductor which accelerates under illumination by daylight or solar radiation as a photocatalyst the speed of a chemical reaction, without being consumed. 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 converts them into nitrates. [53, 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 is being depleted per m² of roof area during one year. [53, DACHZENTRUM, 2004]

Environmental indicators

As environmental indicator serves the quantity of NO_x that is being depleted per m² of roof area during one year [g/(a*m²)]. [53, DACHZENTRUM, 2004]

Cross-media effects

Environmental assessment of nanoparticles is still ongoing.

Operational data

Product data sheets are available under http://www.nelskamp.de[48]:

- 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, approximately on 500 multi-family houses with a roof area of about 500,000 m² roof tiles with TiO_2 have been installed [53, DACHZENTRUM, 2004]. Further example installations are referenced in the following section.

Applicability

Generally, all products 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 surrounding [115, JUSCHKUS, 2008]. The photocatalytic feature is not visible and does not influence other durability properties. No special measures are necessary.

Example installations:

- The roof tiles with titanium dioxide have been installed in eight residential buildings in Duisburg, Germany. [228, WIRTSCHAFTSWOCHE, 2008]
- Further example installations exist in Bremen, Barsinghausen, Duisburg, Essen, Braunschweig, Münster, Darmstadt, Leinfeld-Echterdingen, Greifswald, Fulda and other German cities.[48]
- The de-soiling and de-polluting abilities of titanium dioxide by the introduction in the building matrix or surface coatings have been investigated in the PICADA EU project.[49]

Economics

Nano-crystalline titanium dioxide is a very expensive raw material, but only small amounts of TiO_2 are required for the roof tile production, as only the surface contains TiO_2 [115, JUSCHKUS, 2008]. Therefore the economics of TiO_2-containing roof tiles is comparable to conventional roof tiles [228, WIRTSCHAFTSWOCHE, 2008]. The prices of these roof tiles range from 4.2 €/m² to 6 €/m².[50]

Driving force for implementation

A driving force is the enhanced living quality through better air conditions especially in alive cities.

Reference organizations

- Dachziegelwerke Nelskamp GmbH: http://www.nelskamp.de/

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[48] Dachziegelwerke Nelskamp GmbH: http://www.nelskamp.de , accessed 18.08.2010.

[49] Photocatalytic Innovative Coverings Applications for Depollution Assessment (PICADA), official web site: http://www.picada-project.com/, accessed 18.08.2010.

[50] Modach Baushop GmbH: http://www.baustoffe-modach.de/, accessed 18.08.2010.

References
[53] DACHZENTRUM (2004): Deutsches Dachzentrum e. V.: 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.
[115] JUSCHKUS (2008): Juschkus, U.: 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.
[228] WIRTSCHAFTSWOCHE (2008): Wirtschaftswoche, 2008, number 8, page 92.

2.3.4 Windows

2.3.4.1 Triple-glazed windows with high-solar gain low-e glass, filled with argon/krypton gas

Description
From a thermal point of view, glazings are highly important for the energy efficiency of a building. Conventional double glazings have insulation values of, at best, U_g = 1.1 W/(K*m^2). Triple-glazed windows with high G-value, low-e glass and krypton filling have heat transfer coefficients of U_g=0.5-0.7 W/(K*m2) and provide a better heat protection and high solar gain. [187, SCHNEIDER, 2008]

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 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 the noise protection can be enhanced remarkably. [104, HENSLER, 2009]

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 doesn’t fall by more than 2-3°C below room temperature and furthermore, building owners and architects are able to arrange windows and heating device in a more flexible manner because of the, by the elevated surface temperature, prevented water condensation. [104, HENSLER, 2009]

Triple-glazed windows with high G-value, low-e glass and krypton filling [for comparison double-glazed windows with argon filling] provide the following corresponding data: [187, SCHNEIDER, 2008]
- U_g = 0.5-0.7 W/(m^{2}K) [1.1-1.4 W/(m^{2}K)],
- U_W = 0.7-0.8 W/(m^{2}K) [1.2-1.5 W/(m^{2}K)] and
- G = 0.47-0.55 [0.53-0.63].

The achievable reduction in annual transmission losses per square meter window surface ranges from 42% in comparison to double-glazing up to 88% in comparison to single-glazing [104, HENSLER, 2009]. Based on annual transmission losses (useful energy) of 460 kWh/(a*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 (compare chapter 2.3.1 Higher thickness of insulating material) without consideration of solar gains and improved airtightness. [37, BRANDT, 2007]

Environmental Indicators
As environmental indicators serve the annual savings in heating or cooling energy demand per square meter component area and useful building floor area [kWh/(a*m²)]. The energy demand savings depend on the building type, the indoor temperature, the outdoor temperature, the solar radiation, etc. Specific data is not available.

In a technical sense, as environmental indicators serve the heat transfer coefficient of the glazing U_g and the window U_W [W/(m²K)], the G-value [-] and the emissivity, as they influence the heating or cooling demand of a building.

Cross-media effects
The replacement of windows in existing buildings could contribute to mould built-up, if the ventilation isn't performed 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 performed. Furthermore, the insulation of walls, roller shutter casings etc. should accompany the replacement of windows, as elevated surface temperatures avoid the condensation of water.[51]

Operational data
No information available.

Applicability
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 elevated humidity, so that intensified venting could be necessary. This could be performed by an automatic ventilation device with integrated heat recovery. [104, HENSLER, 2009]

The areas of application encompass:[52]

- highly-insulating glazings for new buildings (ideal for low-energy and passive houses)
- energy-efficient building renovation (huge potential for saving energy considering the 400 million old, poorly insulated windows in buildings in Germany alone)

Example installations: Common technique in Europe. The best performers provide an U_g of 0.5-0.7 W/(m^{2}K), an U_W of 0.7-0.8 W/(m^{2}K) and a G-value of 0.47-0.55. [187, SCHNEIDER, 2008]

Economics
The extra charge of triple-glazing in comparison to double-glazing is about 15-70 €/(m² of glass). In 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

[51] J. Zink BAU-Kommunikation, Schimmel-Beratung Nord: http://www.schimmel-beratung.de/html/neue_fenster_und_schimmel.html, accessed 18.08.2010.

[52] 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.

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 incl. 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 attractivity of the building. [104, HENSLER, 2009]

The benefit of the reduced heating or cooling of buildings depends on the climate zones. Table 2-26 contains reference prices of 1.3m x 1.3m triple-glazing windows in Germany (2009) for different frame materials. [104, HENSLER, 2009]

Table 2-26: Reference prices of 1.3m x 1.3m triple-glazing windows in Germany (2009) [104, HENSLER, 2009]

Frame	Net price [€]	Installation [€]	Value added tax [€]	Total [€]
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

Energy and CO_2 savings can be calculated with an online calculator, which is available under http://www.energiesparen-mit-glas.de/sparrechner/.[53]

Driving force for implementation

- reduction of heating or cooling energy demand
- enhancement of indoor climate and living comfort
- noise protection
- legal requirements concerning the energy efficiency of buildings

Reference organizations

- Federal German Association of Flat Glass: http://www.bundesverband-flachglas.de/
- German Quality and Control Association for Windows and Doors: http://www.window.de/

References

[37] BRANDT (2007): Brandt, A.: In neuem Licht: Studie zur energetischen Modernisierung von alten Fenstern, Federal German Association of Flat Glass, 2007, available under http://www.gre-online.de/bilder/File/VFF%20BF_Modernisierung_alter_Fenster_23-01-2008.pdf, accessed 18.08.2010.

[104] HENSLER (2009): Hensler, G.; Scheider, M; Miehle, P.: Energiesparen mit 3 Scheiben – Heizkosten senken und Lärm vermindern, Bayerisches Landesamt für Umwelt, 2009, available under http://www.lfu.bayern.de/umweltwissen/doc/uw_102_energiesparfenster.pdf, accessed 18.08.2010.

[187] SCHNEIDER (2008), Schneider, B.: 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.

Further reading:

[53] Federal German Association of Flat Glass., Aktionszentrale "Energiesparen mit Glas": http://www.energiesparen-mit-glas.de/sparrechner/, accessed 18.08.2010.

[222] WAGNER (2007): Wagner, A.; Herkel, S.; Kohne, W.: Energieeffiziente Fenster und Verglasungen, BINE Informationsdienst, FIZ Karlsruhe, Berlin, Germany, 2007.

2.3.4.2 Shading of windows

Description

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 thermal barrier. [202, STACK; 203, STANDAERT, 2006]

Achieved environmental and health benefits

- reduction of cooling (and heating) energy demand
- stabilization of the indoor temperature
- enhancement of indoor climate and living comfort
- summertime excessive heat protection

The reduction in cooling energy demand by external shading has been investigated for a single family house (SFH) and a multi family house (MFH) with 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 m² of useful floor area and in MFH of 4-5 kWh useful energy per m² of useful floor area. [33, BOERMANS, 2007]

Furthermore, the reductions in heating and cooling energy demand have been simulated for a room with 25 m² useful area in a MFH and a SFH. Thereof Table 2-27 provides selected results. [203, STANDAERT, 2006]

Table 2-27: Simulation results for the reduction in useful energy demand in SFH and MFH caused by shading [203, STANDAERT, 2006]

City	Building type	Reduction in heating energy demand [kWh/(a*m²)] (useful area)			Reduction in cooling energy demand [kWh/(a*m²)] (useful area)			
		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

Environmental indicators

As environmental indicator serve the annual savings in cooling energy demand per square meter living space or useful floor area [kWh/(a*m²)]. The energy demand saving depends on the building type, the cooling system, the intensity of solar radiation, the indoor temperature, the outdoor temperature etc.

Cross-media effects

Reduction in daylighting: See chapter 2.5.2

Operational data

No representative operational data is available.

Applicability

Shading devices are applicable for almost every type of window.

Example installations: Common technique in Europe.

Economics
No representative cost data is available.

Driving force for implementation
Reduction of cooling energy demand

Reference organizations
European Solar Shading Association: www.es-so.com

References
[33] BOERMANS (2007): Boermans, T.; Petersdorff, C.: U-Values for Better Energy Performance of Buildings, ECOFYS GmbH, 2007, available under http://www.eurima.org/uploads/pdf/EURIMA-ECOFYS_VII_report_p1-65.pdf, accessed 18.08.2010.
[202] STACK (2010): Stack, A.; Goulding, J.; Lewis, J.: Shading Systems – Solar shading for the European climates, Energy Research Group, University College Dublin, on behalf of the European Commission, available under http://www.es-so.com/documents/EurCommOnSolarShading.pdf, accessed 18.08.2010.
[203] STANDAERT (2006): Standaert, P.: Energy Savings and CO2 Reduction Potential from Solar Shading Systems and Shutters in the EU25, European Solar-Shading Organization (ESSO), 2006, available under http://www.es-so.com/documents/ESCORP-EU25.pdf, accessed 18.08.2010.

2.3.4.3 Emerging technique: 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 realized 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[54] and is to be realized by the end of 2012. Figure 2-7 illustrates the structure of vacuum insulation glass in double-pane design.[55] [187, SCHNEIDER, 2008]

[54] Grenzebach Maschinenbau GmbH, page of the network project ProVIG (Production Methods for Vacuum-Insulating-Glass): www.vig-info.de/, accessed 18.08.2010.

[55] 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.

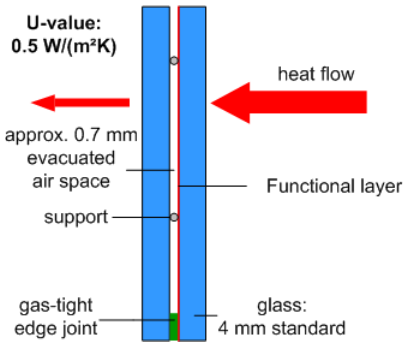

Figure 2-7: Structure of vacuum insulation glass[55]

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 the 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". [104, HENSLER, 2009]

Vacuum insulation glass in double-pane design reaches heat transfer coefficients of U_g = 0.5 W/(m^{2*}K).[55]

Environmental indicators

As environmental indicators serve the heat transfer coefficient of the glazing U_g and the window U_W [W/(m²*K)], the G-value [-] and the emissivity, as they influence the heating or cooling demand of a building.

Cross-media effects

See chapter 2.3.4.1.

Operational data

Advantages of vacuum insulation glass in double-pane design are: [55]

- 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 organizations

No information is available.

References
[104] HENSLER (2009): Hensler, G.; Scheider, M; Miehle, P.: Energiesparen mit 3 Scheiben – Heizkosten senken und Lärm vermindern, Bayerisches Landesamt für Umwelt, 2009, available under http://www.lfu.bayern.de/umweltwissen/doc/uw_102_energiesparfenster.pdf, accessed 18.08.2010.
[187] SCHNEIDER (2008), Schneider, B.: 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.

2.3.5 Integrative concepts (low energy buildings)

Description
The term low energy building usually indicates a building with better energy efficiency than the standard energy efficiency requirements of the corresponding building code, but an EU-wide definition doesn't exist. The reduction of heating and cooling energy demand is typically achieved by the utilization of energy efficient windows, high insulation levels, heat recovery ventilation and airtightness. 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. Concepts labeled as green building or eco-building doesn't focus only on the energy demand as low energy buildings and account therefore for more parameters. Furthermore, the energy use, which is taken into account in all concepts, isn't consistent. Whereas often only space heating is considered, ideally water heating, air conditioning and the consumption of electricity should be included as well. If the primary, final or useful energy demand is regulated, is a further inconsistency. [75, EC, 2009c]

Until 2009, a definition of a low energy building has been introduced in seven EU member states (AT, BE (Flanders), CZ, DE, DK, UK, FI, and FR). Generally, these definitions target new buildings, but in AT, CZ, DE, and DK they also include existing buildings. In almost all cases they cover nonresidential and residential buildings. LUX, RO, SE, and SK plan to define low-energy buildings as well. The required reduction in energy demand with respect to the standard technology defined for new buildings ranges usually from 30 to 50%. The labeling of low-energy buildings has been introduced in some countries, e.g. Switzerland (MINERGIE) and France (Effinergie). [75, EC, 2009c] According to the Energy Performance of Buildings Directive[56] all EU member states have to introduce energy performance certificates for buildings.

Passive house: In central Europe (Germany etc.), a low energy building without a need for a conventional heating system is called passive house, if solely post-heating or post-cooling of the fresh air mass is necessary to achieve thermal comfort. Technologies as super glazing, passive solar gain (also through south orientation), thermal bridge free construction, airtight building envelope are typically included. Annual primary energy demand for space heating is reduced to 15 kWh/(a*m²), i.e. about 15% of the limit for total primary energy use being 120 kWh/(a*m²). [75, EC, 2009c]

Zero energy house: A house is called a zero energy house, if its energy needs summed up over the year are entirely covered with renewable resources. As renewable energy resources are often seasonal, usually an interaction with the electricity grid is necessary. [75, EC, 2009c]

[56] Directive 2010/31/EU of 19 May 2010 on the Energy Performance of Buildings.

Plus energy house: A house is called a plus energy or positive energy house, if it imports less energy from external sources than it produces from renewable energy. This is enabled by the combination of low energy building techniques (passive solar building design, insulation etc.) with small power generators and careful site selection and placement. [75, EC, 2009c]

Achieved environmental and health benefits

- reduction of primary/useful/final energy demand for space heating/cooling, water heating, air conditioning as well as consumption of electricity [75, EC, 2009c]

Table 2-28 provides definitions and specific energy demands for low energy builidings in selected EU member states.

Table 2-28: Examples of definitions for low energy building standards [84, ENGELUND THOMSEN, 2008; 75, EUROPEAN COMMISSION, 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/(a*m^2) per useful area (Styria) and per heated area (Tyrol)
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/(a*m^2) • **Very low energy class:** below 51 kWh/(a*m^2), also **passive house standard** of 15 kWh/(a*m^2) 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 (a*m^2) where A is the heated gross floor area, and for other buildings = 95 + 2200/A (a*m^2) (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 has 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 (60kWh/(m²*a)) or KfW40 (40 kWh/(m²*a)) maximum primary energy demand • **Passive house** = KfW40 buildings with an annual useful energy demand for space heating lower than 15 kWh//(m²*a) and total primary energy demand lower than 120 kWh//(m²*a)
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)

Environmental Indicators

As environmental indicators serves the (annual) primary/useful/final energy demand per square meter useful or gross area [kWh/(a*m²)], whereas the included energy use (space heating/cooling, water heating, air conditioning, consumption of electricity) varies.

Cross-media effects

- protection against climbing energy prices
- benefits from increased security and self-sufficiency

Operational data

No information is available.

Applicability
These concepts are typically applicable in new buildings (residential and nonresidential ones), but in modified forms they can also be applied in existing buildings. In the case of existing buildings the requirements will be lower because of the limitation concerning flexibility. [75, EC, 2009c]

Example installations:
- A lot of built passive house examples are provided under http://www.passivhausprojekte.de/[57] and http://www.cepheus.de/[58].
- Passive house examples for new construction and retrofit are provided in http://download.nachhaltigwirtschaften.at/hdz_pdf/messprojekt_leitfaden.pdf [223, WAGNER, 2010].

Economics
In all cases additional costs for low energy buildings depend on specific conditions, but the extra upfront investments are about 10% with 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, as Germany, to countries with a beginning diffusion seems misleading. However, in general, the additional investment will be in the range of 100 EUR/m² [123, LENORMAND, 2006] (more if expensive solutions are used) with returns of less than 20 years[59]. [75, EC, 2009c]

Because of the reduction in energy demand with respect to standard new constructions low energy buildings offer considerable savings in energy costs. E.g., a passive house brings a substantial reduction of total costs at around 15 kWh/(a*m²), as a traditional heating system is no longer needed. Therefore no radiator system has to be installed at all and the gains from energy savings will be significant. [75, EC, 2009c]

Driving force for implementation
Reduction of energy demand for space heating/cooling, water heating, air conditioning as well as consumption of electricity

Reference organizations
Passive House Institute: http://www.passiv.de/

References
[84] ENGELUND THOMSEN (2008): Engelund Thomsen, K.; Wittchen, K.: European national strategies to move towards very low energy buildings, SBI (Danish Building Research Institute), 2008, available under http://www.rockwool.com/files/rockwool.com/Energy%20Efficiency/Library/European NationalStrategiesToMoveTowardsVeryLowEnergyBuildings.pdf, accessed 18.08.2010.
[75] EC (2009c): European Commission: Low Energy Buildings in Europe: Current State of Play, Definitions and Best Practice, 2009, available under http://ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf, accessed 18.08.2010.

[57] Database of Passive House projects as common project of the Passive House Institute, the Passivhaus Dienstleistung GmbH, the IG Passivhaus Deutschland and the iPHA (International Passive House Association), accessed 18.08.2010.

[58] Passive House Institute, Cost Efficient Passive Houses as European Standards (CEPHEUS), accessed 18.08.2010.

[59] Passive-On Project, funded within the Intelligent Energy for Europe SAVE programme: http://www.passive-on.org, accessed 18.08.2010.

[123] LENORMAND (2006): Lenormand, P.; Rialhe, A.: Very Low Energy Houses, AERE, 2006, available under http://www.leonardo-energy.org/webfm_send/413, accessed 18.08.2010.

[223] WAGNER (2010): Wagner, W.; Spörk-Dür, M.: Leitfaden, Ergebnisse der messtechnischen Begleituntersuchungen von "Haus der Zukunft" – Demonstrationsbauten, AEE – Institut für Nachhaltige Technologien, available under http://download.nachhaltigwirtschaften.at/hdz_pdf/messprojekt_leitfaden.pdf, accessed 18.08.2010.

2.4 Available Techniques for heating, ventilation, air conditioning

2.4.1 Heating

2.4.1.1 Technique: Solar thermal evacuated tube collector

Description

Solar thermal systems with evacuated tube collectors are a common and highly efficient form of simple solar heat collectors. Sunrays pass 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 best isolation and hence best absorbing efficiency.

The operating cycle of such a system consists of the collector itself, 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.

Achieved environmental and health benefits

As emissions of households are reduced to zero with respect to heat generated by solar thermal collectors, local air quality will not be harmed. Overall and in the long term, widespread use of solar thermal collectors shall raise the ambient air quality in residential areas and cut down the demand for fossil fuel resources.

Though emitting zero pollutants in the operating phase, production of collectors is energy- (hence CO_2-) and especially material-intensive. Therefore, the total energy balance becomes positive after two to three years usually, depending upon site specific issues like type of collector, solar intensity, etc., which determine the amount of heat produced each year.

Environmental indicators

Collectors do not emit any substances, hence the operation of solar thermal heat generation systems does not affect the environment. Since solar thermal systems can only supply parts of overall heat demand, other systems have to be installed additionally, which might emit polluting substances. Therefore a suitable indicator might be energy saving (kWh/year) or CO_2-saving (CO_2/year).

Though operation times are without emissions (except for indirect emissions due to power consumption), the production of collectors is sophisticated and requires a large amount of energy and metal resources. Hence, a proper evaluation on environmental effects should include all LCA stages, not only the operating phase.

Cross-media effects

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Operational data

The 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%. Detailed test results for many types of solar thermal collectors for household installations can be found on www.solarenergy.ch.

Proper systems use efficient circulation pumps, as inefficient pumps reduce overall efficiency and 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%.[60]

Applicability

In general, solar thermal collectors can be installed everywhere. But since 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.

Economics

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-persons household (excluding installation costs). In general, flat plate collectors are in the lower price range, whereas evacuated tube collectors find themselves in the upper price range.[61] Economic payback depends largely on the use of solar thermal collectors 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 literature, 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.

Driving force for implementation

Environmental awareness and governmental funding has been the reason for growing demand of solar thermal collectors. Evacuated tube collectors in special are popular, since economic gains rise stronger with growing energy prices than other systems due to higher efficiency.

Reference organisations

Wagner & Co.: www.wagner-solar.com
Viessmann: www.viessmann.de
Wolf: www.wolf-heiztechnik.de
Paradigma: www.paradigma.de
Junkers: www.junkers.com

References

[27] BINE (2008b): Thermische Solaranlagen, BINE basisEnergie 08/2008, FIZ Karlsruhe, Germany, available under http://www.bine.info.

www.solarenergy.ch
Solaranlagen test 03/2008, Stiftung Warentest, 2008.

[60] 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.

[61] Stiftung Warentest, Solaranlagen, test 03/2008.

2.4.1.2 Technique: Horiziontal ground heat exchanger with heat pump

Description

Horizontal ground heat exchangers usually are polyethylene ducts, which are installed at 1-2 m below 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 pressure increase and peak level heating.

Special attention shall be drawn to an efficient heat pump, a proper storage and especially proper operation of the heating system. Experts highlight, that no other systems' efficiency (or here: heating seasonal performance factor (HSPF[62])) 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.

Achieved environmental and health benefits

A general increase of using renewable energy for household energy consumption will be supported by a wide application of ground heat exchangers with heat pumps. Though still powered by electricity, it is a hybrid technique towards increasing resource efficiency. Material developments in heat exchanger material to improve heat transfer and in high efficiency pumps as well as in powering with other sources than electricity are concrete fields for further developments. As operational data shows, operations are environmentally-friendly compared to fossil fuel firing, but due to higher power needs still CO_2-intensive. As the future tends towards integration of renewable sources, this shall be done with geothermal heat production systems as well, improving their CO_2-balance strongly.

A general indicator is the HSPF, but it is a rather 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[63], 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.

Environmental indicators

The HSPF and the amount of energy consumed in kWh/year are appropriate environmental indicators. The difference of energy consumed and heat supplied to the system is the amount of energy saved due to installing the heat pump.

Cross-media effects

Installation of ground heat exchangers might affect groundwater.

Operational data

Pressure levels, peak temperatures and energy needed for circulation determine the overall energy demand, usually in form of electricity. Energy provided by the system (heat pump and ground heat exchanger) to the household is the total energy provided. The coefficient of energy

[62] Please bear in mind that anglo-american calculations divide heating output in BTU by energy consumed in Wh, leading to different HSPFs, usually between 8 and 10 for efficient systems.

[63] Development of the specific CO_2 emissions of the German electricity mix, March 2010, www.umweltbundesamt.de.

provided by energy needed averaged over the year is the so called heating seasonal performance factor (HSPF)). German DENA standards[64] define a heat pump to be "efficient" if it has a HSPF above 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 the summer, most hot water required is tap-water, which needs higher temperatures than hot water for room heating. As the soil temperature with at maximum 14°C in Germany limits the maximum achievable temperature, further increases have to be done with the use of electricity. Hence more power is required and the HSPF is decreasing. 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. This difference is reason for extracting the yearly average, the HSPF.

Applicability
Ground heat exchangers need uncovered soil to be installed, which is usually the soil below a garden. Therefore, this type of installation is only applicable to households who have a garden with the required area.

Economics
Installation work is costly, since it requires a lot of manpower or heavy machinery, especially larger installations and installations in higher 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[65].

As heat pumps consume electricity and electricity costs are expected to rise, these systems may lose economic attractiveness.

Driving force for implementation
The development towards heat production with renewable energy led governmental fundings rise. Heat pumps and especially new developments within the system of heat pumps show the possibility to cover large shares of overall heat demand with geothermal heat pumps and thereby increasing the share of renewable energy use and resource efficiency.

Reference organisations
www.erdwaerme-zeitung.de lists 27 producers and seller of ground source heat pumps[66].
Bundesverband Wärmepumpe (BWP) e.V.

References
[31] BINE (2010): Erdgekoppelte Wärmepumpen für Neubauten, BINE Themeninfo III/2010, FIZ Karlsruhe, Germany, available under http://www.bine.info.

http://wp-im-gebaeudebestand.de
www.energiesparen-im-haushalt.de

2.4.1.3 Technique: Gas-fired condensing boiler

Description
Gas-fired condensing boilers are current state-of-the-art gas combustion installations for domestic use. In general, burning gas is the cleanest fossil fuel combustion technology, since

[64] German Energy Agency.

[65] http://www.energiesparen-im-haushalt.de/energie/bauen-und-modernisieren/modernisierung-haus/heizung-modernisieren/heizkosten-gas-oel-pellets.html

[66] http://www.erdwaerme-zeitung.de/waermepumpen/herstellervonwaermepumpen/index.html on 22.07.2010.

virtually no dust and SO_2 emissions are released. Gas-air mixing is far less complicated than solid fuel-air mixing, therefore combustion is usually near completion. Complete combustion means maximum thermal efficiency and no CO emissions. Gas-fired condensing boilers are usually installed with an additional heat storage tank.

Condensing boilers outperform classical gas-fired boilers in efficiency terms, because they use the energy released by flue gas condensation. Flue gas is cooled to approximately 40°C; water condensates at that temperature on the duct walls and condensation energy can be transferred to the heat delivery medium. This effect is the reason, why condensing boilers have net calorific value efficiencies of above 100%, since the net calorific value does not account for condensation energy. Gas-fired appliances can reach up to additional 11 percentage points, giving a theoretically achievable maximum value of approximately 109.7% (NCV). Actual efficiency depends on return temperature (ideally 40°C) and the gas-air mixing, but can reach 109% (NCV) in certain test bench cases.

Condensing effects in the flue gas duct result in higher additional stack requirements. They need to be airtight, resistant against corrosion and against permeation by moisture. These requirements usually are much too expensive for retrofitting, hence merely used for new buildings. Common retrofitting policy is to introduce a stainless steel flue gas duct into the stack and thereby separating the wet flue gas from the old stack walls.

Achieved environmental and health benefits

The additional heat gained by condensation energy recovery leads to an overall reduced fuel demand and consequently to lower overall CO_2 emissions. Since the combustion process itself is very clean, i.e. close to zero emissions with respect to SO_2, volatilised organic compounds and dust, and relatively low CO and NO_x emissions compared to solid fuel burning, gas-fired condensing boilers represent the cleanest fossil fuel combustion technology for domestic use. These characteristics were reason to certify the best gas-fired condensing boilers in Germany with the “Blauer Engel” (‘blue angel’), which marks very environmentally-friendly products.

Environmental indicators

Since dust, volatilised organic compounds and SO_2 emissions are close to zero due to the nature of domestically available natural gas and the easily achieveable good fuel-air mixing, the only emissions to be accounted for are CO_2, CO and NO_x. CO, a representative of imperfect combustion, has to be below 46 ppm (57.5 mg/Nm³), thereby indicating very high efficiency due to almost complete combustion, in order to fulfil the requirements of “Blauer Engel” certificates. NO_x emission values have to be below 34 ppm (69.7 mg/Nm³). Minimum requirements for overall efficiency depend on the boiler size and vary between 103 and 104%.

As a comparison, “Blauer Engel” values for pellet boilers are 90 and 200 mg/Nm³ for CO (full load/ partial load), 5 mg/Nm³ for volatilised organic compounds, 20 mg/Nm³ for dust and 150 mg/Nm³ for NO_x. Specific CO_2 emissions for gas are calculated at approximately 240 g/kWh[67]. Consequently, suitable environmental indicators might be the pollutant concentrations for comparison to “Blauer Engel” reference values.

Cross-media effects

As gas firing usually replaces solid or liquid fossil fuel firings, overall energy demand may be reduced and especially oil, wood or coal demand.

Operational data

For efficiency and emitted substances, see above.

[67] See EcoInvent Database 1.2

Electricity consumption is close to zero, as fuel feeding and operation regulation do not need much electricity. Space required for installation is quite small, as the boilers can be hung up at the wall. Space required for storage tanks is mainly size dependent, for household appliances it is not expected to be a limiting factor. Static problems due to the overall weight may only arise in cases of large storage tanks.

Applicability
As gas burning usually needs a municipal gas distribution system, it may not be available for all potential users, especially in rural areas. These consumers may use liquefied gas, since it can be delivered in trucks. This solution is expensive and hence rarely used. Another solution is biogas, but since biogas needs to be specially produced at or near the place of demand, it is moreover used at larger installations in rural areas.

Gas-fired condensing boilers can be installed in hybrid renewable/ fossil energy generation systems, as they are a clean, highly efficient technique and are well suited for peak use.

Economics
High efficiency means low fuel use, hence natural gas-fired condensing boilers minimise overall fuel need with respect to heating value. However, as gas is a rather expensive fuel in some EU countries, sensitivity calculations with respect to heat demand should be made.

Equipment and installation costs are relatively low, since the technique is quite simple. Additional costs for stack retrofitting and connection installations to the municipal gas distribution system have to be borne in mind, since it may push total installation costs. Gas-fired condensing boilers are standard products on a competitive market, hence prices are located in a narrow range. Conventional condensing boilers for domestic use can be purchased from 1,400 to 2,000 EUR, advanced boilers with the newest technology and efficiency of 107-109% might double the price[68]. Gas connection and stack retrofitting cost is highly site specific.

Efficient gas-fired condensing boilers are currently subsidised by many environmental schemes. One of these schemes, the EnerCity Fonds in Hannover, Germany, published an extensive list of all gas-fired condensing boilers, of which they regard as being environmentally-friendly[69].

Driving force for implementation
Lowering emissions from combustion sources; enlarging the share of clean energy production and resource efficiency. Governmental incentive schemes have stimulated the demand over the last few years.

Reference organisations
Large producers of gas-fired condensing boilers are, for example Vaillant and Buderus. Selling and installation service is done by local plumbers in most cases.

References
www.heizungsfinder.de
www.blauer-engel.de
www.proklima-hannover.de

2.4.1.4 Technique: Automatically fed wood pellet boiler

Description
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

[68] Price data from http://www.heizungsfinder.de/gasheizung/brennwerttherme/preise-vergleich on 05/20/2010.

[69] The list is available on www.proklima-hannover.de/Produkt-und-Firmenliste.134.0.html.

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.

A continuous and automatic feeding of pellets into the combustion chamber is the key to stable combustion conditions with low emissions. Automated systems can meter 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 in 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 operation 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 shutdown 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.

Achieved environmental and health benefits

Wood burning mainly produces CO_2, CO, NO_x and various 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, shutdown, load variations) and low-load operation.

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 that emissions will be kept at low levels during stable load phases. Air and fuel feeding systems improve combustion performance at loads between 50-100% additionally.

Reducing the number and times of load changes, especially of start-ups and shutdowns, contribute largely to emission reductions. Though not covered by most analyses of combustion performance, these unsteady states with highly imperfect combustion conditions (too much or not enough air, too low temperatures, etc.) are main contributors to pollutants like soot.

Environmental indicators

Suitable environmental indicators are CO_2 emissions and primary energy factor, which determine the amount of non-renewable energy fired and emitted. Pollutant emissions might be suitable aswell.

Cross-media effects

Increasing wood pellet demand enlarges the wood processing industry. As demand for pellets increases, raw wood might be only cut for pellet production. High prices may as well lead to a worldwide sourcing industry, with pellets being produced in South America and Asia for European demand. These effects would counterbalance the environmentally-friendly characteristic of wood pellets.

Fly-ash and old catalyst material may count as special waste.

Operational data

Standardised pellet boilers have been analysed under the Eco-design directive preparatory study for solid fuel combustion. Table 2-29 shows best-performance figures, which have been used to characterise the pellet boiler (reference O_2 content: 13%-vol.).

Table 2-30: EcoDesign performance indicators for pellet boilers [73, EC, 2009a, Task 6, Table 6-6]

Energy efficiency (NCV)	94%
CO emissions [mg/Nm³]	30
PM emissions [mg/Nm³]	10
Organic compounds emissions [mg/Nm³]	1.5

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 type classes 1 (dirtiest class) and 3 (cleanest class) at the levels shown in table 2-31.

Table 2-32: EN 303-5 test stand emission limit values for pellet boilers [[73, EC, 2009a, Task 4, Table 4-35]

	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

Required efficiency herein can vary according to the nominal heat output Q_N in kW. Studies have shown, that optimising the combustion process lead to nearly zero large particle emission, but contrarily create more finest 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 form of fine particles) via flue gas. Therefore, particulate emissions cannot be reduced to zero without further secondary abatement techniques like 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 show 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, which shall represent 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 per DIN standard 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 may range between 350 and 400 g/kWh heat output.

Power demand of pellet boilers is moderate compared to other available heat generation principles. Automatic feeding systems obviously 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. Rather than the boiler itself, pellet storage needs quite a large space. In most cases, outdoor shelters are used. Static issues and nearby storage usually prevent an installation above ground floor.

Applicability
Pellet boilers with heat storage tanks theoretically have no limit of application. The wood pellet market should allow for a Europe-wide access to pellets. Pellet boilers are available at various sizes, but high investments imply large scaling effects, favouring larger installations (> 50 kW/80 kW).

Economics
Various renewable-energy associations estimate investment amounts to EUR 15.000 – 20.000 for modern detached houses (approx. 10 kW net output).

Driving force for implementation
Lowering emissions from combustion sources; enlarging the share of biomass in energy production. Governmental incentive schemes have stimulated the demand over the last few years, especially in Sweden, Germany and Austria.

Reference organisations
German Pellet Organisation DEPV, www.depv.de.
A list of international pellet boiler manufacturer is available on www.euroheat.co.uk and many other websites.

References
[73] EC (2009a): European Commission DG TREN: Preparatory Studies for Eco-design Requirements of EuPs (II) – Lot 15 Solid fuel small combustion installations, 2009.
[118] KLINGEL (2008): Klingel, T.: Detaillierte experimentelle Untersuchung der Schadstoffbildung bei der Holzverbrennung, Universität Karlsruhe, 2008.

2.4.1.5 Technique: Automatically fed wood chip boiler

Description
Automatically fed wood chip boilers are another indirect heating appliance with basically the same working principle as automatically fed pellet boiler. 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. Boiler construction and heat cycle should be equal, a difference can be found in 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, we can resume the superiority of automatic to manual feeding systems and the general importance of heat storage tanks for efficiency maximisation and emission reduction. Boilers with dual fuel use (pellets and chips) exist alongside to boilers 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.

Achieved environmental and health benefits
As wood chips have a lower heating value than wood pellets and contain higher shares of ash and volatile compounds, combustion is not as environmentally-friendly as wood pellet combustion. As bark is rich of minerals, which form large parts of the combustion ash, mineral dust emissions rise. Increased size of wood chips, varying shape and inclusions in bark provide an imperfect combustion environment, hence especially enhancing the formation of CO, carbon

containing dust as well as volatile and condensable organic compounds more than wood pellet combustion does. Additionally, wood chips are usually larger and have a greater size distribution. Therefore, wood chip combustion cannot be as balanced as wood pellet combustion and consequently emits more pollutants, especially pollutants occurring due to imperfect combustion, such as CO and dust.

Overall, wood chip boilers produce slightly more emissions than wood pellet boilers. However, emissions compared to manually fed wood boilers, log wood boilers or brown and hard coal boilers are much lower, which therefore still characterises the automatic wood chip boiler as an environmentally-friendly technique to produce domestic heat by solid fuel combustion.

Environmental indicators

Suitable environmental indicators are CO_2 emissions and primary energy factor, which determine the amount of non-renewable energy fired and emitted. Pollutant emissions might be suitable aswell.

Cross-media effects

Increasing wood chip demand enlarges the reusing rate of wood residues in wood processing industries. If local demand is larger than supply, indicating that trees may solely be cut down for wood chip production, wood chips lose the characteristic of waste reuse. Demand for intensified short-rotation forestry may arise and put pressure onto the natural ecosystem and local biodiversity.

Fly-ash and old catalyst material may count as special waste.

Operational data

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 the table 2-33. In reality CO and organic compound emissions are expected to be higher.

Table 2-34: EcoDesign performance indicators for pellet boilers and combined pellet/ wood chip boilers [73, EC, 2090a, Task 6, Tables 6-6 and 6-7]

	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

According to the authors, these EcoDesign values shall represent current best available technique for these boiler types in the European Union. The table 2-35 reproduces TÜV[70] and NUA[71] test stand 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 has been drawn onto the partial load results, which find themselves on the right side of the full load results.

Table 2-36: Performance comparison of three 300 kW wood chip boilers with EN 303-5 Class 3[72]

	Type 1	Type 2	Type 3	EN 303-5 C3

[70] German Technical Inspection Association (Technischer Überwachungsverein)

[71] Public institution for environmental protection in Lower Austria (Niederösterreichische Umweltschutzanstalt)

[72] Spark Energy, Comparison of modern 300 kW Wood Chip Boilers.

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 outperform the requested EN 303-5 Class 3 values by far and show the tremendous development between 1999 and now in domestic stand-of-the-art solid biomass combustion.

Power demand and space required for the installation and wood chip storage is roughly the same as for pellet boilers.

Applicability
Wood chip boilers with heat storage tanks theoretically have no limit of application. The wood chip market should allow for an Europe-wide access. Wood chip boilers are available at various sizes, but high investments imply large scaling effects, favouring larger installations (> 50 kW/ up to several hundred kW).

Economics
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[73] offers 20/30 kW boilers at GBP 3,200 to 4,350 (excl. VAT) onwards. A German manufacturer[74] 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 strongly, depending on site issues.

Wood chips produced of wood scrap and by-products of the wood processing industry form a type of recycling product and are consequently cheaper than wood pellets.

Driving force for implementation
Lowering emissions from combustion sources; enlarging the share of biomass in energy production. Governmental incentive schemes have stimulated the demand over the last few years, especially in Austria, Germany and Sweden.

Reference organisations
A list of international wood chip boiler manufacturer is available on www.euroheat.co.uk and many other websites.

References
[73] EC (2009a): European Commission DG TREN: Preparatory Studies for Eco-design Requirements of EuPs (II) – Lot 15 Solid fuel small combustion installations, 2009.

Spark Energy, Comparison of modern 300 kW Wood Chip Boilers: www.euroheat.co.uk

2.4.1.6 Technique: District heating network

Description

[73] Comment: Company Perge on www.euroheat.co.uk

[74] Comment: Company HDG on www.euroheat.co.uk

Many local and district heating networks have been built throughout Europe, especially in Germany and the Nordic countries Denmark, Finland, Iceland and Sweden, during the last decades. Herein, we describe the district heating network “Fernwärmeverbund Niederrhein Duisburg Dinslaken”, a network which has its foundations in the beginning of the 20th century. This network has a delivery rate of 800 MW and delivered 1,100 GWh heat to approximately 500,000 persons across its 500 km network in 2007[75].

This network has two different types of sources, one is industrial waste heat of two steelmaking sites and one producer of sulphuric acid, the other is five CHP plants. Heat is available at temperatures up to 600°C, therefore industrial consumers may also be attracted.
First networks for centralised cooling systems started to exist. These cooling networks produce cold water at one single economic source and distribute it to many small and nearby consumers, which otherwise would have had to use inefficient and energy-intensive small-scale cooling systems.

Achieved environmental and health benefits
Out of the 1,100 GWh, 350 GWh (31.8%) is served by industrial waste heat, which accounts for overall CO_2 reduction of approximately 90,000 t CO_2 per year (82 kg CO_2 per MWh). This amount accounts for the needs of roughly 100,000 persons. Consequently, the percentage of non-renewable primary energy resources used according to German EnEV standards (DIN V 18599-1) varies between 18.4% and 36%. Example calculations of the distributor[76] for a household consuming 15,000 kWh per year show CO_2 emission reductions from 4 tons to 1.5 tons per year (-62.5%).

High isolation standards have reduced the overall temperature loss to an average of 5°C, according to the distributor this is a very low figure. Temperature loss is a measure of network efficiency, since energy losses in the ducts reduce overall system performance.

Environmental indicators
District heating networks do not reduce the amount of energy needed directly, but rather reduced the amount of energy produced to serve the demand. Additionally, specific emissions per energy output can be reduced due to higher combustion efficiency and/ or economies of scale in pollutant abatement techniques. Efficiency increase may be regarded as a way of reducing specific CO_2 emissions.

Local and district heating systems with their flexible structure are hardly comparable with respect to emission and energy efficiency (heat is a by-product). The best indicator is the non-renewable primary energy factor, as it represents the use of non-renewable sources. The district heating network Niederrhein Duisburg Dinslaken has a factor of 0.184-0.360 (depending on the location of household). For comparison, pure fossil fuel fired CHP-networks have a factor of at least 0.7.

Due to the flexible input possibilities of local and district heating networks, general specific CO_2 emissions are not possible to calculate as producers vary across the networks and may vary during operation even within a network. Additionally, it is not clearly defined how to account for industrial waste heat reuse with regard to corresponding CO_2 emissions and primary energy factor. The primary energy factor represents the share of non-renewable sources used. This might be a similar factor, but since CO_2 neutral emissions are calculated as emitting zero CO_2, proper values are not predictable.

Cross-media effects

[75] See info brochure of the local supplier “Stadtwerke Duisburg” at: http://www.swdu.dvv.de/privatkunden/partnerfernwaerme.html

[76] See imageflyer of “Stadtwerke Duisburg” at http://www.swdu.dvv.de/privatkunden/partnerfernwaerme.html

As network ducts need to be installed, usually under streets, road construction industry is facing a higher demand.

Operational data
System efficiency depends upon heat and pressure losses between supplier and households. The Duisburg system claims to have an average temperature loss of as low as 5°C across the whole network.

Local and district heating networks require a connection and a transfer apparatus, which have to be installed at the households. No further equipment is needed.

Applicability
In areas with such a network, the use of local and district heat is often compulsory, as sufficient heat demand per length of network determines the economic efficiency for the operating company. Therefore, areas with high population density and high demand rates (i.e. mostly in colder climates, especially Scandinavia) show best economic performances.

Economics
Installation costs for a network connection and transfer apparatus are offered for EUR 4,760 in Duisburg. This amount may increase with a longer connection length[77]. Operators and local authorities offer subsidies to enhance use and acceptance of heat networks.

Compared to heat generation at local level, heat is provided by the network and hence has to be bought instead of fuel. Heat prices in terms of EUR per GJ of energy are usually higher than for wood, coal and oil, but as 'local' system efficiency (between transfer station and room heating) is nearly 100%, energy losses do not occur. For illustration, we cite prices of exemplary district heating operators for private consumers in EUR per kWh heat: Duisburg EUR 0.0479 per kWh (EUR 12.29 per GJ), Mannheim EUR 0.0417 per kWh[78], Karlsruhe EUR 0.0508 per kWh[79] and Växjö (Sweden) EUR 0.053 per kWh[80].

Driving force for implementation
Overall non-renewable resources efficiency increase and waste heat reuse lead to the development of local and district heat networks. As European governments aim at increasing the incentives for CHP plant use, these heat networks have to be built to distribute the heat of CHP plants to the consumer. Reasons for these incentives are specific emission reduction and increasing energy efficiency due to the use of available industrial waste heat.

Reference organisations
As district and local heating systems are often built and operated by public utility companies, these firms should be contacted for more information.

References
http://www.swdu.dvv.de/privatkunden/partnerfernwaerme.html
www.agfw.de

2.4.1.1 Technique: Adjustable high-efficency circulation pumps

Description

[77] See price information of Stadtwerke Duisburg at www.swdu.dvv.de.

[78] See price information of MVV Energie at www.mvv-fernwaerme.de.

[79] See price information of Stadtwerke Karlsruhe at www.stadtwerke-karlsruhe.de.

[80] See presentation "Fossil Fuel Free Växjö" at www.energy-cities.eu.

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 one single point of operation. This principle is especially important for times of low operation (which is most of the time).

Achieved environmental and health benefits

Reducing electricity demand will help to lower overall CO_2 and pollutant emissions of 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.

Environmental indicators

Reduced amount of electricity consumption on a specific or absolute basis may serve as an environmental indicator.

Cross-media effects

Lower electricity consumption leads to long-term emission reduction.

Operational data

Simple circulation pumps usually are standard products without adjustable output and hence operate all the way through 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 pump operation.

Applicability

These pumps can be installed and retrofitted to every system. The economic advantage for these pumps is especially large for oversized systems, as adjustable pumps can downsize the power input. Therefore in new and freshly renovated buildings advantages are highest.

Economics

The German online-service www.energiesparen-im-haushalt.de conducted a test of several circulation pumps, where the best adjustable high-efficiency pumps had 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

As adjustable pumps can lower operating costs by more than 50%, governmental schemes have been developed to increase investment incentives. The driving force behind these incentives is to reduce unnecessary electricity consumption and hence to lower CO_2 emissions.

Reference organisation

Adjustable pumps are standard products of most heating system suppliers, such as Viessmann, Buderus, Grundfos and Wilo. Contacting persons for installation are usually local plumbers.

References

www.energiesparen-im-haushalt.de
www.hocheffizienzpumpe.de

2.4.2 Ventilation

2.4.2.1 Air collectors

Description

An air collector is a feeding apparatus for ventilation systems. Air collectors are upgrades of classical mechanical ventilation systems, as they can be added onto the existing system. Air collectors are installed 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.

Achieved environmental and health benefits

Air can be preheated even in times of cloudy skies and sunny, but cold weather. Hence, further air heating energy needs are expected to decrease. The inherent humidity control reduces the risk of fouling due to indoor moisture problems. Preheating air reduces energy consumption, thereby reducing overall CO_2 emissions as the process itself does not emit any pollutants.

Environmental indicators

General figures concerning CO_2 reduction potential and a quantification of environmental impact are suitable as indicators. Deriving suitable holistic benchmarks is hardly possible, as reduction figures are strongly dependent on site and operational issues as well as the referencing case, therefore, indicators have to be compared on a case-by-case basis.

Cross-media effects

Lower electricity consumption leads to long-term emission reduction.

Operational data

None.

Applicability

Retrofitting is easily possible, as long as a ventilation system exists. If not, installation costs for the in-house air ducts are expected to rise to unattractive levels.

It is an attractive solution for summer residences and other houses only used for parts of the year due to its characteristics with very low energy needs during “base-line” ventilation.

Economics

Air collector equipment cost is regarded to start at around EUR 1,000[81]. The main factor of equipment cost is the type of collector used. Herein, simple and cheap systems may only use cheap material, whereas highly efficient and expensive systems can raise costs with a factor of 3-5[82].

Installation costs and retrofit difficulties are expected to have no relevant impact on overall costs, as long as a ventilation system already exists.

Driving force for installation

Reducing fossil energy consumption and promoting the use of renewable energy.

Reference organisations

[81] Hess offers an air collector „Solar Venti Maxi SV14“ for EUR 940, www.hess-shops.de.

[82] www.solarserver.de

Pfendler: www.solar-pfendler.de

References
www.energiesparen-im-haushalt.de
www.solarserver.de
www.solarwall.de

2.4.2.2 Earth-to-air heat exchanger

Description

This type of system is used for ventilation and has a baseline temperature control mechanism included. 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, we focus on open systems, 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 with approximately 3 meters of filtration length, filter the air mechanically with additional particle filters and supply it 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 to provide the air at soil temperature and 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 one point and away from the drainage system.

Attention has to be paid to the following aspects:

- Air inlet should not be next to large roads and other locations of especially polluted air
- The soil has to be checked for radon concentration. Radon is a harmful gas allocated 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.

Additional installations to this system might be heat recovery exchanger, heat pumps and air-conditioning systems. In passive and other low-energy houses, a combination of this technique with other techniques of heating and cooling can replace the need of classical heating systems, thereby reducing overall HVAC-installation and operational costs.

Achieved environmental and health benefits

Natural filtration of air will be especially helpful for allergic persons, as the soil filters dust, bacteria and pollen. In general, this type of ventilation system uses natural resources for air pre-cooling or pre-heating. Hence, overall energy demands to provide air at the requested temperature levels are expected to decrease.

This system needs energy for fan operation and temperature control. As overall demand for modern low energy houses is expected to be at low levels, it might be covered by renewable energy generation, e.g. photovoltaic. Accordingly, associated CO2 emissions vary according to system configuration.

Environmental indicators

Electricity consumption per time and area may serve as an environmental indicator, as this indicator clearly shows the amount of energy saved due to installing this system.

Cross-media effects

Electricity demand for ventilation increases and energy demand for temperature control decreases.

Operational data
Power needs are highly site specific; however, efficient and modern systems should not have large needs, so that overall consumption rates are expected to be low. Consumption depends on fan efficiency, air change requirements, pressure drop in the ventilation duct system and pressure drop in the air sourcing system (drainage plus filter). One supplier states a fan consumption of 80 W[83].

Applicability
Retrofitting is easily possible, as long as a ventilation system exists. If not, installation costs for the in-house air ducts are expected to rise to unattractive levels.

Technically, installation is possible, where soil is available for system installations (in general, this is the garden). Attention should be paid for radon and general outdoor air quality, which might limit the practical applicability.

Economics
Installation costs vary according to the system size and duct length. Equipment costs for an application to a regular 4-persons house are cited to be around EUR 3,000[84].

Driving force for implementation

Reference organisations
Elka AG: http://www.elka-ag.com.

References
www.elka-ag.com
www.energiesparen-im-haushalt.de

2.4.3 Air conditioning

2.4.3.1 Desiccant and evaporative cooling

Description
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 achieve humidity control as well, thereby making separate dehumidifier obsolete, as it needs dehumidification of air 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 being dehumidified by an adsorption process, where special materials like 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 being 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 being 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

[83] ELKA Luftbrunnen brochure on www.elka-ag.com.

[84] ELKA Luftbrunnen brochure on www.elka-ag.com.

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 like central heating systems. New developments integrated solar thermal heat generation into DEC systems, as it does not produce any emissions and may use excess collector heat.

DEC systems are available in sizes between 20 and 350 kW.

Achieved environmental and health benefits
DEC systems do not use any gaseous or liquid harmful substances, which is why break-down and malfunctioning is not dangerous for users. Attention should be paid to a well operating humidifier, as bacteria and other unwanted substances in water can be spread around the whole ventilation system.

Electricity consumption is reduced strongly in comparison to other systems, as the only consumers are fans. In cases, where heat can be provided from renewable sources, e.g. solar thermal collectors, overall direct and indirect emissions are only occurring from fan needs.

Environmental indicators
Electricity consumption per time and area may serve as an environmental indicator, as this indicator clearly shows the amount of energy saved due to installing this system.

Cross-media effects
Lower electricity consumption leads to long-term emission reduction.

Operational data
Coefficients of performance (COPs)[85] can vary between 0.5 and 1, depending on inlet and desired air temperature, humidity and overall system effectiveness.

Economics
Experts cite installation numbers to be around 30 in Germany, mostly pilot or former demonstration projects. This technology is already in place for approximately 20 years, but still has to be assembled by craftsmen, since system pieces (adsorptive dehumidification, heat exchanger, humidifier and recovery) have to be bought individually from special companies. Hence, prices are hardly predictable, but should be in line with comparable investments into closed cycle adsorption techniques.

Applicability
In general, no special limits of application should exist. In practice, economic constraints might limit this product to larger buildings and to buildings with an existent (or easy to retrofit) central ventilation system.

Reference organizations
Working Group on Desiccant Technology, Fachinstitut Gebaeude – Klima e.V.
Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

References
[24] BINE (2004): Klimatisieren mit Sonne und Wärme, BINE Themeninfo I/04, FIZ Karlsruhe, Germany, available under http://www.bine.info.
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2.4.3.2 Absorption Chiller

Description

Absorption chillers are closed systems and use the principle of thermal compression to provide cooling. Herein, a refrigerating medium is being absorbed and evaporated off another, usually liquid, medium, thereby drawing heat off the surrounding and passing heat onto the surrounding, respectively. 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 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 chapter 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) as well.

Installation sizes vary from 10 kW onwards up to around 4,000 kW and are usually installed as centralised cooling system.

Health and environmental benefits

Using H_2O-LiBr instead of NH_3-H_2O and water being the refrigerating medium instead of ammonia, this process lowers the risk of poisonous gas leakages. In addition, as the H_2O-LiBr process works below and the NH_3-H_2O process works above atmospheric pressure, choosing the H_2O-LiBr process minimises the risk of material failure due to pressure levels.

As long as the required heat is not directly provided by thermal combustion (usually by firing gas), absorption chillers do not directly emit any pollutants but only use heat or electricity and produce noise.

Old air conditioning systems often use CFCs, replacing these systems with adsorption chillers using LiBr decreases environmental risks due to malfunctioning and disposal.

Environmental Indicators

The indirect rate of emission will vary largely according to the systems COP and the heat source, starting from zero by using solar thermal heat and ending at heat produced of fossil fuel combustion.

Cross Media Effects

Lower electricity consumption leads to long-term emission reduction.

Operational Data
The main performance measure of an absorption chiller is the coefficient of performance (COP). One step systems usually have COPs between 0.7 and 0.8, whereas two step systems can have COPs of up to 1.2, which means that it provides more energy than it consumes electricity.

Economics
Investment cost for an absorption chiller is expected to be very high in comparison to electricity-driven air conditioners. Advantages are low operating costs, especially with regard to old electricity-driven systems. An example installation in a German hotel with 127 kW cooling capacity cites equipment costs of EUR 67.000.

Applicability
In general, no limits of application are known, as machines in the range of 10 kW to 4,000 kW do exist. Economic aspects may limit the range of theoretical application in certain cases. Retrofitting this technique can be very expensive, as centralised systems require an air distribution network. Consequently, applicability may be limited to new buildings and buildings with an existing but inefficient air conditioning system.

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2.5 Available Techniques for lighting

2.5.1 Selection of most suited lamp type for interior lighting

Description

Using efficient lighting technology (when artificial lighting is needed) can lead to significant reductions of electricity consumption. In the following, the main types of light bulbs are described with a focus on interior lighting (mainly residential buildings, offices, etc.).
In European legislation on efficiency requirements and on bans on 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. Regarding the whole lifecycle 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% is released as heat. The lifetime is low (often as low as 1000 hours), in most cases, other types of illumination are clearly to be preferred. A step-wise ban of incandescent bulbs for general use is decided 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; both types achieve 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 all gas-discharge lamps, fluorescent lamps require a ballast to control their amount of current. Electronic ballasts should be preferred to (old) magnetic ballasts, which led to energy losses of about 10% of power input and flickering.
Their lifetime is also a multiple of light bulbs, however shortened by frequent switching. This type of lamp is widely used in offices and other large rooms, but 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 toxic waste, as they contain a small amount of mercury. As 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. Their lifetime is 8000 to 10,000 hours. The required ballast (newer electronically ballasted CFLs don't flicker or hum) is either integrated in the socket or separate as for standard fluorescent lamps. Traditional weaknesses of this type of lamp (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 (however 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 longest life time 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. Negative is their expensiveness and requirement of precise current and heat management. LED lamps can be used for a lot of 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) lamps that produce high light output for their size, making them a compact, powerful, and efficient light source. They need an electrical ballast and are mainly used for high light demand applications like flood lighting outdoors, or lighting for warehouses or industrial buildings. Concerns about possible eye damages due to UV light emissions exist.
- Sodium vapour lamps: These are gas discharge lamps 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 the relatively high energy efficiency.

Achieved environmental and health benefits

The main environmental benefit is the reduction of electricity consumption. By a reduction of thermal load a smaller heat emission is realized which relieves other facilities concerning ventilation and air conditioning.
Additionally, possible negative effects (comfort, health) can be avoided if well suited and high quality lamps are selected (broad spectrum, no flickering).

Environmental indicators

Main indicators for light bulbs:

luminous efficancy [lm/W] (alternatively energy efficiency class)
minimum lifetime
lumen maintenance [% over certain number of hours]
switch on-off cycles [number]

Additional indicators:

use of harmful substances, e.g. mercury
colour rendering index (CRI)

Cross-media effects

Lamps have the most environmental impact during their use phase. This can reach amounts up to 90% depending on the lamp type.[86] 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 colors. However, for modern high quality lighting (especially those lamps having an EU-ecolabel), these issues have been resolved.

Operational data

Table 2-37: Comparison of wattages and features for different types of light bulbs[87]

	Incan-descents	Halo-gen	Compact fluorescent lamps	Fluo-rescent lamp	LEDs	Other gas discharge lamps

[86] http://www.elcfed.org/1_health.html

[87] Sources: http://www.eartheasy.com/live_led_bulbs_comparison.html, http://www.energie-bewusstsein.de

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 (poten-tially in electronic s)	some: mercury
Replacement frequency (50k hours)	40+		5		1	

In the following, criteria for choosing a household-type light bulb are summarized:

- **EU energy label**: For common household light bulbs, the EU energy label shows the energy efficiency category from A to G (A being the most energy efficient), as well as some additional information (the luminous flux of the bulb in lumens, the electricity consumption of the lamp in watts, the average life length in hours)
- **Lumen output**: To maximize 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-efficient 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, too. However it is usually preferable to use dedicated fluorescent fixtures as they allow higher energy savings, and a 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 2-38. This table by a German industry association shows a clear increase of importance for LED lighting.

Table 2-38: Current and projected application areas for different lamp types [87, FGL, 2010]

	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	X X	xxxx	xxx	
In 3 years			x	xx	xx	
In 10 years				x	x	

Economics

In general, investment in efficient artificial light sources are more than compensated by the lifetime savings, however exact numbers depend on individual products and conditions of application. A guide for calculating lighting retrofit economics can be found at http://www.lightsearch.com/resources/lightguides/retrofitecon.html

Compact fluorescent lamps have higher acquisition cost, but including energy savings over their whole lifetime, total cost are lower than for incandescent light bulbs (which additionally have much lower lifespans).

LED as a source for interior lighting is currently characterized by high initial cost, but these are in general more than compensated by whole lifetime cost. Their price is expected to decrease, as their diffusion in the market is just beginning. The following two tables show exemplary calculations for comparing economics of fluorescent lamps and LEDs for workplace and corridor lighting.

Table 2-39: Cost comparison of halogen lamps and LED for a typical workplace lighting in industry [87, FGL, 2010]

	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 € = 1125 €
Energy costs (50,000h, 0.18 €/kWh)	81 €	180 €
Total costs	381 €	1505 €
Savings Break even point	1124 € About 4500 hours of operation	

Table 2-40: Cost comparison of halogen lamps and LED for a typical corridor lighting [87, FGL, 2010]

	LED	Fluorescent lamp
No. 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	
Corridor length 20 m; 4 down-lights with fluorescent lamps (2*26W each) or LEDs (26 W each); ten years of operation with 12 hours daily on 250 days per year		

Driving force for implementation

In general, efficient electrical lighting significantly reduces electricity consumption and thus 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 at further accelerating the change to more efficient lighting, with the main aim of reducing energy consumption and thus CO_2 emissions. In European legislation efficiency requirements and bans on inefficient lamps were decided. 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 organizations

Not applicable

References

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2.5.2 Integrated daylight optimization and artificial lighting concept

Description

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 optimized concerning planning of building design and use of appropriate technical solutions. A proper integration of daylight and artificial lighting is important, as well as detailed analysis of user demands, as savings of energy depend very much on their behaviour.

Daylighting is the practice of 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 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, however only 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 to let light into a building without letting heat in or out, which was a typical concern with skylights and large windows of the past. The optimum number of skylights is usually 4-8% of floor area, however often skylights aren't needed to achieve good daylighting results until you get beyond 8 m of the perimeter windows.
- **Sunlight-Transport-Device:** 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, like for example prismatic panels and laser-cut panels that both are 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[88].
- **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 like linoleum or polished wood can reflect a lot of 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 and health benefits

The need for artificial lighting of buildings is reduced, as well as space cooling, both leading to large energy savings and reductions of CO_2 emissions.[89]

Table 2-41 shows exemplary lighting energy consumption of two newly built office buildings as a reference.

Table 2-41: Two examples of newly built office buildings that use daylighting concepts [25, BINE, 2005], [28, BINE, 2009a]

	Office building in Düsseldorf, Germany [25, BINE, 2005]	Building in administrative centre in Eberswalde, Germany [28, BINE, 2009a]
Year of construction	2000-2003	2007
Rentable area	27500 m²	4878 m² (total centre 17131)

88 http://www.brita-in-pubs.eu/

89 Information on lighting and HVAC interactions: http://www.lightsearch.com/resources/lightguides/hvac.html

Gross room volume	84435 m³	20127 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

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*a)]. [66, EN15193, 2008]). Table 2-42 gives reference values for different building categories and light qualities. [66, EN15193, 2008]

Table 2-42: Reference values for LENI indicator for several building types [66, EN15193, 2008]

Building type	Quality class of lighting	P_N (W/m²)	LENI reference value (constant illuminance control) [kWh/(m*a)]		LENI reference value (no constant illuminance control) [kWh/(m*a)]	
			manually switched	automatic	manually switched	Auto-matic
Offices	*	15	42.1	35.3	38.3	32.2
	**	20	54.6	45.5	49.6	41.4
	***	25	67.1	55.8	60.8	50.6
Education	*	15	34.9	27	31.9	24.8
	**	20	44.9	34.4	40.9	31.4
	***	25	54.9	41.8	49.9	38.1
Hospitals	*	15	70.6	55.9	63.9	50.7
	**	25	115.6	91.1	104.4	82.3
	***	35	160.6	126.3	144.9	114
Hotels	*	10	38.1	38.1	34.6	34.6
	**	20	72.1	72.1	65.1	65.1
	***	30	108.1	108.1	97.6	97.6
Restaurants	*	10	29.6	-	27.1	-
	**	25	67.1	-	60.8	-
	***	35	92.1	-	83.3	-
Sport locations	*	10	43.7	47.7	39.7	37.9
	**	20	83.7	79.7	75.7	72.1
	***	30	123.7	117.7	111.7	106.3
Retail	*	15	78.1	-	70.6	-
	**	25	128.1	-	115.6	-
	***	35	178.1	-	160.6	-
Production	*	10	43.7	41.2	39.7	37.5
	**	20	83.7	78.7	75.7	71.2
	***	30	123.7	116.2	111.7	105.0
Quality class: higher classes fulfill more esthetic and health criteria P_N: Used total luminaire power per area for this building type and quality class						

Beside energy efficiency and ergonomics health aspects were discussed lately. They do well for the circadian rhythm and light demand of humans.

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*a)]. It is calculated based on the wattage of installed lamps, their daylight and non-daylight time usage, an occupancy factor and other factors (for details on calculation like formula and factors [66, EN15193, 2008]).

Several qualitative indicators have to be considered too, as a successfully daylit 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. Main design issues are illuminance levels, contrast ratios, window to wall ratios, ceiling to skylight area percentages, and reduction in unwanted glare.

Cross-media effects

With the increasing proportion of glass surfaces in building facades, the heat input 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 mechanical cooling. Schading is an option to avoid heat input in summer. Possibilities of "redirecting light" should be fully applied.

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 maximize the daylight income winter, but guarantee an effective sun protection in summer. Furthermore, especially in winter, there is dull sky and the daylight concept must be adjusted to this fact. Systems, which deflect direct sunlight, can be only an additional solution. Innovative daylight and control systems make sure that even 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 can not change generally this geometrical rule. But they can partially compensate issues, like the influence of surrounding buildings. Rooms, which need for functional reasons great depth, and which shall be 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 seasonal or conditioned 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 2-8). Automatic lighting regulation adapts the shading to desired temperature and illumination (the interior glare protection can be positioned individually). It considers aspects like 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 for reducing energy consumption of air conditioning. Another benefit is increased security, as in case of fire the shading appliance return to their initial state to allow evacuation of the building.

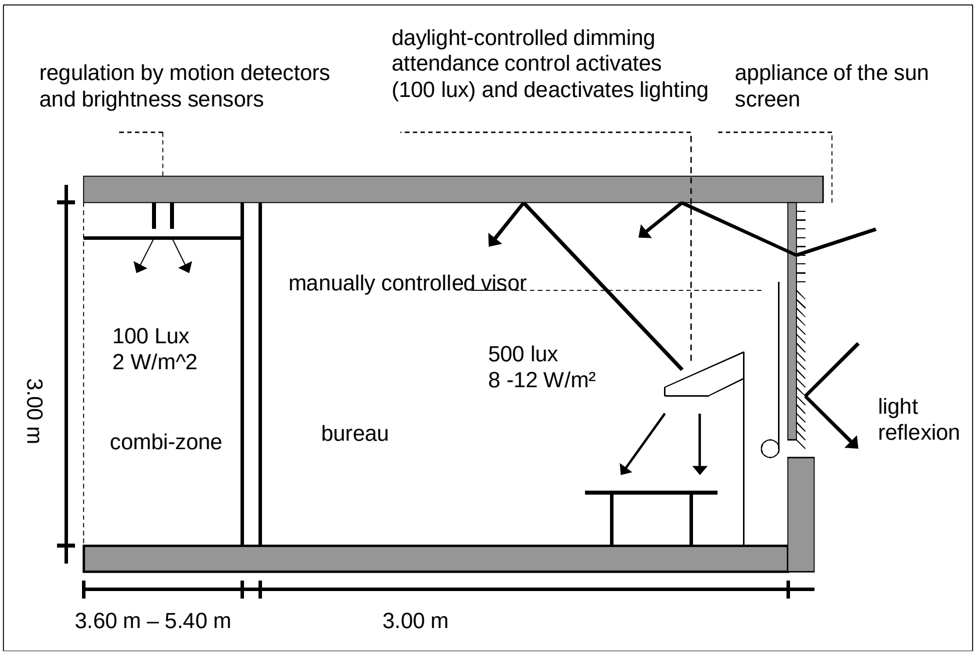

Figure 2-8: Office combining daylight and artificial lighting concept [28, BINE, 2009a]

Control requirements for different scenarios: Various types of 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 (only sunlight is measured, rather inexpensive) or closed loop systems (sunlight and artificial light is measured) depend on the building equipment (part of 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 2-43 gives an overview of different daylight responsive lighting control strategies depending on room use characteristics. Comfort needs of occupants also have to be considered. For more information see [111, IEA, 2001].

Table 2-43: Overview of suited scenarios for different daylight responsive lighting control strategies shortened from [111, IEA, 2001]

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[90], room based,		x	x	x	x							
Closed loop, luminaire based		x	x	x	x		x	x	x			

[90] Open loop: Sensor only for daylight (outside); closed loop: Sensor inside building measuring also total light (feedback)

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	

Applicability

User acceptance has been a problem of some daylighting concepts in the past. It is important to include a zoning in the planning that is adapted to the users' needs and allows them to individually control the illumination of zones according to their needs. The sunlight characzteristics of the geographic region in question (frequency of weather changes, prevalence of blue sky or clouds, etc.) also plays a major role concerning the selection of a suited control system (selection criteria for control systems see Table 2-43).

Economics

No detailed data is available on integrated concepts; for some exemplary cost (investment for total technical equipment and annual lighting cost per m²) of two office buildings with integrated lighting concepts see Table 2-41 in section "Environmental benefits".

There is quite a variety of technical solutions for daylighting and of daylight responsive control systems on the market. According to [111, 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 1 percent productivity increase equalling the total energy cost in offices. [91]

Concerning individual techniques, investment for some of the innovative reflection devices is given table Table 2-44.

Table 2-44: Investment for selected innovative reflective techniques [39, BRITA, 2008]

System	€/m²
Prismatic panels	200 – 400
Prismatic films	40 - 80
Laser-cut panels	100 – 130
Sun directing glass	200

Driving force for implementation

Reduction of energy consumption and comfort/productivity issues. 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.[92]

[91] L. Edwards, P. Torcellini, (2002), A Literature Review of the effects of Natural Lighting on Building Occupants, US National Renewable Energy Laboratory NREL/TP-550-30769.

[92] http://www.brita-in-pubs.eu/

Reference organizations
International Energy Agency - The Solar Heating and Cooling Programme: Daylight in Buildings4 : Design Tools and Performance Analysis, http://www.iea-shc.org/task21/

EU research project "bringing retrofit innovation to application in public buildings", http://www.brita-in-pubs.eu/

References

[28] BINE (2009a): BINE Informationsdienst: Administrative buildings as energy-efficient complex, Projektinfo 16/2009, http://www.bine.info/en/hauptnavigation/publications/publikation/verwaltungsgebaeude-als-energieeffizientes-ensemble/, accessed: 01.06.2010.

[39] BRITA (2008): EU research project "bringing retrofit innovation to application in public buildings": Retrofit design guideline: Daylighting Improvement; http://www.brita-in-pubs.eu/

[63] DGUV (2009): Deutsche Gesetzliche Unfallversicherung : Tageslicht am Arbeitsplatz – leistungsfördernd und gesund, Die Handlungshilfe für die betriebliche Praxis; http://regelwerk.unfallkassen.de/regelwerk/data/regelwerk/inform/I_7007.pdf, accessed: 15.15.2010

[111] IEA (2001): International Energy Agency: Application Guide for Daylight Responsive Lighting Control, http://www.iea-shc.org/outputs/task21/8-8-1%20Application%20Guide.pdf, accessed: 07.06.2010

http://www.licht.de/en/info-and-service/publications-and-downloads/lichtwissen-series-of-publications/
http://www.sunlight-direct.com/sample-installations.php
http://gaia.lbl.gov/hpbf/techno_a.htm
http://www.glassmanual.com/Spectrally_Selective_Glazing/
http://hubpages.com/hub/low_solar_gain_windows
http://iopscience.iop.org/1402-4896/32/4/026

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[25] BINE (2005): BINE Informationsdienst: Tageslichtnutzung in Gebäuden, Projektinfo 1/2005, http://www.bine.info/hauptnavigation/publikationen/publikation/tageslichtnutzung-in-gebaeuden/, accessed 01.06.2010.

http://www.umweltbundesamt.de/energie/licht/
http://www.licht.de/de/licht-know-how/lichtmanagement/
http://www.haus.de/PH2D/ph2d.htm?snr=13&snr2=13
http://www.baunetzwissen.de/standardartikel/Tageslicht-Tageslichtleitung-durch-Lichtkamine_806541.html
http://www.baunetzwissen.de/standardartikel/Tageslicht-Lichtmanagement_896503.html
http://www.baunetzwissen.de/standardartikel/Tageslicht_Beleuchtungsstaerkeempfehlungen_167320.html

2.5.3 Fibre optic skylight system

Description
The fibre optic skylight is an innovative way to bring natural light deep into an interior space. The fibre optic skylight system consists of solar panels that collect sunlight which is focused onto optical cables. These cables are connected to lamps in the chosen room where the sunlight is directed. The commercially available product described in the following (company "Parans2

fibre optic skylight system “SP2.1”) consists of one or more exterior modules, connecting fibre optics and interior lights.
The fibre optics that leads the light in the optical cable has high light transmission and flexibility. As the fibre optic cables can be up to 20 m long, this system can transport daylight to rooms not traditionally suited for skylights (for example several floors away from the roof or far away from exterior walls).

Achieved environmental benefit
The electricity consumption needed for illumination is reduced, as electrical lamps can be substituted by this type of skylight.
The manufacturer claims 10-15 percent lower emission of greenhouse gases by exchanging half of a building’s electrical lighting for Parans fibre optic solar lighting.

Environmental indicators
Reduction of artificial lighting demand during daytime (cf. operational data).

Cross-media effects
The solar panels consume on average less than 2 W for control of the lenses. The light has a continuous spectrum (but no IR and UV radiation) and does not flicker, leading to increased occupant comfort (aesthetics, potential health benefits).

Operational data
The sunlight output from depends on the sunlight conditions and the length of the fibre optic cables. For light to be able to flow through an optical fibre, it must enter from an angle which lies within the fibre’s acceptance angle. In practise, this means that only the parallel light rays of direct sunlight can be efficiently collected. The light output on cloudy days is therefore little or none depending on the thickness of the clouds.
The luminous flux of one module with a cable length of 10 m (about 1900 lm) for example corresponds to an incandescent light bulb of 100 Watt or a compact fluorescent lamp of 23-30 Watt.

Table 2-45: Luminous flux chart of the fibre optical skylight system (Source: www.huvco.com)

Cable length (m)	Total Luminous Flux (lm)
0	3000
5	2383
10	1893
15	1504
20	1195
All values based on solar illuminance of 100 000 lux; With “Parans L1, large lamp”	

Exterior module: The exterior daylight collecting panel has fresnel lenses on the inside. These lenses rotate to track the sun automatically, controlled by an internal computer. Each lens acts like a magnifying lens to focus the sunlight. This focused sunlight is directed into a fibre optic strand. Except for the need of electrical supply for tracking the sun according to the solar path in its internal memory, it is an autonomous unit.

Table 2-46: Summary of specifications for exterior module of PARANS system

Dimensions	980 x 980 x 180 mm
Weight solar panel	30 kg
Weight optical cable	273 g / m

Power Supply	AC 100 - 250 V
Power Consumption	0 - 6 W
Operating Temperature	-20°C – 40°C
Luminous Output	3 000 +/- 300 lm*

Cable: Optical cables (6 mm in diameter) with a minimum bending radius 50 mm are used. Within the cable, the light is transported in 16 of the 0.75 mm plastic optical fibres. The light transmission is 95.6 percent per meter. The optical cables can be no longer than 20 meters. A shorter distance if possible is preferred due to attenuation in the optical fibres (see Table 2-45).

Interior module: Different types of lamps/fixtures are available for spot illumination and more diffuse room illumination, that use one or more optical fibre cables as a light source. These can be at the same time equipped with standard fluorescent lamps for hybrid operation. The hybrid fixture can be combined with a sensor that will automatically turn the electric lights off when the natural light is sufficient.

Applicability
If buildings are retrofitted, improving daylighting by standard measures may be difficult and costly. In contrast, the fibre optic skylight system can be installed to buildings with rather little changes to their structure.
As overcast skies a re common in many central and northern European countries during large parts of the year, this technique can rather be used as a supplementary technique.

Rooms that have their main lighting requirements during daytime (e.g. offices, schools, retail industry, etc.) are preferred locations for fixtures using this technique. The exterior module requires direct sunlight, so it should be mounted where it receives a maximum amount of sunlight during the functioning hours of the panel and that the resulting length of the optical cables is as short as possible. It can be installed on both roofs and facades which generates a wide range of installation possibilities.

Economics
No data available.

Driving force for implementation

Reduction of energy consumption for interior illumination.
Comfort issues (aesthetics, potential health benefits).

Reference organizations
http://www.parans.com/ (manufacturer, Sweden)
www.huvco.com (large distributor, USA)

References
http://www.buildinggreen.com/live/index.cfm/2010/3/3/Alexs-Cool-Product-of-the-Week-FiberOptic-Daylighting-from-Parans
http://www.inhabitat.com/2006/08/16/green-building-101-environmentally-friendly-lighting/

2.5.4 Energy-efficient lighting control systems

Description
Energy-efficient lighting control systems enable the automatic regulation of the lighting system via timers or sensors. The main types of energy efficient techniques currently used for lighting control are time scheduling control, occupancy sensors and daylight sensors.
Achieved environmental benefit

Lighting control systems reduce energy demand for lighting significantly (up to 60% in non-domestic buildings) and minimize the related environmental impacts due to the combustion of fossil fuel resources.

Environmental indicators

- Reduction of energy consumption: KwH/m² per year

Cross-media effects

-

Operational data

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 to leave lights on all night. Timers can be connected to light switches, wall plugs or light sockets.

Lighting controls mainly base 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. If you only wanted a light to stay on from dusk until, say, 10 p.m., however, a timer would be a better choice.

Applicability

Electric lighting controls are applicable in any type of building and in a wide variety of spaces (restrooms, open offices, conference rooms etc.). Lighting controls are most commonly used in office buildings, where they prove particularly effective due to the number of occupants and the high energy demand for lighting (lighting typically accounts for up to 40% of commercial buildings' energy demand). They are also increasingly being used in residential applications, where they also offer great saving potentials. The different techniques can be applied in a same 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

Appropriate lighting controls can help achieving significant cost-effective lighting energy savings, reducing the electricity consumption for lighting in non-domestic buildings up to 60% (savings typically range by 30-35%)93. 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 to 45%.

Driving force for implementation

Reduction of energy demand for lighting
Convenience through automation

Reference organisations

Lighting control systems manufacturers and suppliers:
Legrand Group (http://www.legrandgroup.com)
Lutron (http://europe.lutron.com)
Tridonic (http://www.tridonic.com)

[93] Agence internationale de l'énergie (http://www.iea.org).

GE Energy Industrial Solutions (http://www.geindustrial.com)

References

Daintree Networks (2009): Wireless lighting control saves money and makes sense. http://www.daintree.net/downloads/whitepapers/smart-lighting.pdf

2.6 Available Techniques for water system

2.6.1 Water monitoring

Description

Water meters collect and save data on water consumption, which can be communicated to the users and building managers.

Water metering systems are installed in the building to measure the total potable water use, either for the entire building and associated grounds, or for some water subsystems (e.g. indoor plumbing fixtures and fittings, irrigation, cooling towers, domestic hot water). If a water recycling system is in place, non-potable water supply can also be measured.

Achieved environmental and health benefits

Monitoring water consumption contributes reducing water demand in two different ways. One the one hand, by encouraging demand management: building users tend to reduce their water consumption, when provided with a detailed account of how much water they use for their different purposes. On the second hand, water meters allow to quickly identify and deal with water wastage due to leaky pipes, dripping taps or running toilets.

Environmental Indicators

- Water consumption: m^3 per person per year
- Water consumption in offices: m^3per m^2 per year

Cross-media effects

By reducing water consumption, water monitoring can contribute reducing energy consumption for water heating. Another aspect is reduction of wastewater.

Operational data

The main technology for metering is AMR (Automatic meter reading), which allow the remote collection of data from utility meters back to the local utilities for analysing and billing, using telephone line, radio frequency, power-line, or satellite communications technologies

Applicability

Water metering systems can be installed in all types of buildings.

Economics

Water consumption monitoring can helping reducing water demand considerably (by 20 to 30% and up to 40% when associated with basic retrofitting actions (DG ENV, 2009)), which contributes to consequent cost reduction.

Driving force for implementation

For planners, metering allows to analyse water demand thoroughly and estimate future demand. Monitoring is closely linked to user behaviour, which plays a key role in water consumption. Behavioural changes alone are believed to be able reducing water consumption by 20 to 30% and up to 40% when associated with basic retrofitting actions (DG ENV, 2009).

References

[62] DG ENV (2009): European Commission; Study on water performance of buildings, 2009.

2.6.2 Water leak detection system

Description
Leaky piping systems are a frequent problem which accounts for a great part of buildings' water consumption and can be responsible for considerable damage in a building. For example, a dripping tap wastes approximately 90 litres of water per week or 4,680 litres every year.

Maintenance should help identify toilet leaks due to e.g. deteriorated flapper valves and valve seals, worn or broken ball cocks, refill valves, lift chains, and handle rods. Some retrofitting measures on existing devices can help reduce the risk of leakage. For water inlet control in toilets, the best method to avoid leakage is the use of a siphon instead of a valve.

Dripping water taps can be easily identified. In other plumbing fixtures, identifying leaks can be more complicated. Simple tests can be made in toilets to check for leaks, such as using food ink in the tank.

Achieved environmental and health benefits
Preventing leaks contributes to the reduction of water wastage and water damage.

Environmental Indicators
- Reduction of water consumption: m^3per m^2 per year

Cross-media effects
The current leak detection sensors systems on the market are not only adapted to the detection of water leaks but also several other types of leak, such as chemical, oil and refrigerant gas leaks.Most of them can be integrated to an existing BMS.

Operational data
The location of the leaking source can be achieved through the implementation of sensor cables and monitoring systems. This consists in a water leak detector cable and a monitoring interface which monitors each section of sensor cable. The whole cable is sensitive to water and when it comes in contact with even a few millilitres of water, the system is able to detect the leak as well as report the location. In office buildings, it enables the monitoring of HVAC systems such as fan-coil units around the edge of the building office floors, detectors surrounding the central utility core on each floor of the building and dedicated monitoring of leaks in electrical switch gear rooms, server rooms, network communications, etc. Other technologies involve the use of high absorbent sensing tape to detect small amounts of water leakage from washing machines, hot water tanks, sinks, etc. All systems include a monitoring interface and a remote alarm system.

Applicability
Water leak detection systems are adapted to new buildings as well as to older buildings during retrofitting. Regarding sensor cables, section of sensor cable of any length can be applied throughout the building. This technology is particularly adapted to the monitoring of a particular rooms or system. Monitoring systems can easily be connected to a central alarm panel or an internet interface as a simple water leak detection system for one or two rooms. Sensor systems using sensitive tape are particularly helpful in basements, when placed around washing machines, hot water tanks, sinks, etc.

Economics
Water detection systems using sensitive tape

Driving force for implementation

Reduction of water consumption

Reference organisations
Aquilar leak detection system (http://www.aquilar.co.uk)
Wayscale (http://www.wayscale.com)

References
-

2.6.3 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.

Low flow toilets: Toilet flushing usually accounts for 25 to 30 % of domestic water demand (European Environment Agency). 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.
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 in retrofitting standard toilets with devices to reduce flush volume (typically use 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 period 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 pressure at different points of the building. The minimum pressure required usually lies by 175-275 kPa. Moreover, flush-valve operated toilets can be used to retrofit existing WCs. Regarding the flush type, double flush toilets, which allow users to adapt water pressure to the quantity of waste to remove, appear the most ecological option.

Instead of completely replacing existing toilets, retrofitting with new water-efficient devices is also possible. Inexpensive retrofitting measures can help saving around 1 litre per flush. The simplest of these measures consists in 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.

Waterless urinals: Standard urinals commonly consume 3 to 4 litres per flush. However, low-flow urinals use 1.5 litres per flush or less. Like for toilets, there are several possible flush mechanisms for urinals. However for hygienic reasons, urinals flush traditionally operate automatically rather than 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 more 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 last 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 to be released into the air. These models require some more maintenance, since the cartridge and sealant need periodical replacing. However, these systems are the most water efficient since they allow water savings by 100%. Water consumption of urinals is estimated by 50-100m³ per urinal per year but can even exceed 500m³ for some cyclic models.

Water efficient water taps: Retrofitting water taps presents a high 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.

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.
- Spray taps

Achieved environmental and health benefits

Through the implementation of water efficient plumbing fixtures, a massive reduction in water demand can be expected.
According to the requirements set by the German Federal Minister for Transport, Building and Housing for sustainable buildings, water-saving sanitary fittings should be implemented in all buildings in order to reduce flow-volumes to a maximum, for example of 6 l/min for hand-basins, or ensured with the use of flow restrictors.

Environmental Indicators

- Water consumption: m³per person per year
- Water consumption in offices : m³per m² per year
  - Toilets in offices: flush volume of 4.5 litres per flush or less[94].
  - Urinals in offices: flush volume of up to 1.5 litres per flush[10].
  - Water taps in offices: maximum flow rate of less than 6 l/min for a water pressure of 0.3 MP for all taps except kitchen taps, cleaners' sinks and external taps[10].

Cross-media effects

- Reduction of waste water
- Reduction of energy consumption for water provision

Applicability

Water saving plumbing fixtures can be implemented either during the design stage of the building or in the context of retrofitting.

Economics

- Toilets: the replacement of an older cistern can lead to highest savings, but are 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.
- Water taps: in commercial or public buildings, retrofitting water taps usually brings a reduction by 20 to 30 % in water consumption, within a payback period of less than 2 years.

[94] BREEAM sustainable building standards for offices requirement. Toilets with flush volumes up to 3 l/flush are granted additional credits.

According to estimations of the EC (DG ENV), for an average household of 2.7 inhabitants applying different levels of retrofitting measures, :

- First level/low-costs retrofitting can help save 20-25% of water demand. The measures applied being the installation of 1. 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 can 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 2-47: Potential water savings within buildings [62, DG ENV, 2009]

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	€
No fixture 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%	1 200 – 2 000

<u>Driving force for implementation</u>
Reduction of water consumption

<u>Reference organisation</u>

<u>References</u>

[62] DG ENV (2009): European Commission; Study on water performance of buildings, 2009.

2.6.4 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. For these applications, it is possible to recycle water by installing rainwater or grey water collection systems.

Rainwater collection systems: Rainwater collection systems consist in diverting rainfall water into storage tanks. Runoff systems can be installed on roofs and other impervious surfaces (car park, pathways, etc.). The harvesting water can be used for non-potable demand such as toilet flushing, washing machines, irrigation applications or general cleaning purposes. In Germany, a study into rainwater harvesting showed that 35 percent of new buildings built in 2005 were equipped with rainwater harvesting systems.

Grey water collection systems: Grey water is wastewater from domestic activities such as bathing, showering, laundry, dishwashers. It is less contaminated than black water (from toilets), even though both types of wastewater are usually evacuated through the same sewage system. Instead of being directly evacuated, grey water is being collected and reused for non-potable water demand such as toilet flushing, washing machines or irrigation applications.

Achieved environmental and health benefits

Water recycling systems help reducing buildings ‘water consumption and minimising their production of wastewater.

Environmental Indicators

- Water consumption: m^3per person per year
- Percentage of recycled wastewater

Cross-media effects

-

Applicability

Water quality legislation is still an obstacle to rainwater and grey water recycling in member States such as the UK and France (Umwelt, 2006), raising health issues since they may contain bacteria and other potentially dangerous pollutants.

Economics

The costs of equipment of water recycling facilities are high and the payback period is much longer than for other water efficient measures presented before. Therefore, this option should only be applied when other more cost-efficient measures have been taken, especially regarding retrofitting water efficient plumbing fixtures. According to a study lead by the EC (DG ENV), once retrofitting actions have been taken in an household and have allowed consequential water savings (estimated by 40% for a 2.7 household), water recycling equipment can be installed and help saving another 10% in water consumption.

Driving force for implementation

- Reduction of water consumption
- Reduction of wastewater

Applicability

Examples

Table 2-48: Case studies of rainwater harvesting in the UK [62, DG ENV, 2009]

Name	Size of Development	RWH/ Annum	Pay-back period (yrs)	Usage
Great BowYard	12 houses	28m3	24	WC; GT
Millennium Green[10]	24 houses, 1 office building	84m3	unknown	WC; WM; GT
Barn Park	37 houses, 11 systems	194m3	4.6	WC; WM;GT

WC = toilet flushing; WM = Washing Machine; GT = Garden Taps

Reference organisations
Aquavalor (France): http://www.aquavalor.fr/
UK Rainwater harvesting association: http://www.ukrha.org/
Rainwater harvesting and Grey water recycling: Free Water (UK) http://www.freewateruk.co.uk/
Grey water recycling: Aquacycle 900: http://www.freewateruk.co.uk/domestic-greywater-IV.htm

References
[62] DG ENV (2009): European Commission; Study on water performance of buildings, 2009.

2.6.5 Hot water heat recycling

Description
Water heating is usually the second largest source of energy demand in households. Water heat recycling consists in recovering energy of heat from drain water from various household activities (showers, bath-tubs, dish-washing, clothes washing) and through the use of a drain-water heat exchanger.

Achieved environmental benefit
This technology allows reducing primary energy consumption for water heating. Standard units save up to 60% of the heat energy that is otherwise lost down the drain.

Environmental indicators
Primary energy consumption

Cross-media effects
Hot water heat recycling systems can extend the life of water heaters.

Operational data
Drain water heat recovery systems capture heat energy and use it to preheat the incoming cold water going to water heaters. On its way to the hot water heater, the incoming cold water line passes through a pipe which is tightly coiled around the hot drain water pipe, absorbing heat from the hot water going down the drain.

Applicability
Water recycling is adapted to the use in households and residential buildings.
Drain-water heat exchangers work with all types of water heaters, especially with demand and solar water heaters. Heat exchangers are particularly useful for water heating of showers, which require the simultaneous flow of cold water and hot water. Usually, the recovered heat can also be stored for later use. For the use with dishwashers or clothes washer, an additional storing unit capacity will be needed to store the heat recovered.

Economics
Hot water heat recycling enables to save up to 60% of the energy consumed for water heating in households. The installation of water heat recycling system is expensive and cost savings can be realised within a payback period of 2 to 10 years.

Driving force for implementation
Reduction of energy consumption for heating

Reference organisations

References

2.7 Available Techniques for finishings, interior fitting

2.7.1 Use of products bearing an Ecolabel for interior finishing (and all other construction activities)

Description

For many consumer products, so-called ecolabels are awarded by different organizations. 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 if available to all other sectors of the construction industry).

It is good practice to prefer construction products all having a generally recognized international or national ecolabel to those without one. An ecolabel is a voluntary labelling system for consumer products that are made in a certain fashion to avoid negative effects on the environment. 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.

Many (but not all) ecolabels are not directly connected to the firms that manufacture or sell the ecolabelled products. Due to the differences in existing ecolabels, it is important to know their criteria for assessing products and if they are independent of the products manufacturer.

Achieved environmental and health benefits

Ecolabels include many different aspects, which make them a helpful alternative to comparing numerous individual ecological, life-cycle-related and other criteria. The individual focus of these criteria depends on the regarded sectors (e.g. pollutants and harmful emissions for glues, sustainable management of forests for wood products…).

Environmental indicators

Cf. achieved environmental and health benefits.

Cross-media effects

No data available.

Operational data

Examples of ecolabels relevant for the Construction sector (list not exhaustive):

EU Ecolabel (http://ec.europa.eu/environment/ecolabel/index_en.htm)

The EU Ecolabel aims at helping 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 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
- (wooden, textile, hard) floor coverings
- Light bulbs
- Heat pumps
- Under development: lighting, refrigeration, buildings

Natureplus (http://www.natureplus.org/)

The natureplus label is an international label of quality for sustainable building and interior finishing products, tested for health, environmental-friendliness and functionality. The label's 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% of renewable raw materials or mineral based materials which are almost unlimited in their availability will be 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 the one hand harmful emissions can be avoided and on the other, the use of fossil fuels and consumption of limited natural resources can be minimized. 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 (http://www.fsc.org/)

FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests.

FSC provides internationally recognized 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 (http://www.pefc.org/)

The Programme for the Endorsement of Forest Certification is an international non-profit, non-governmental organization 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 criticized by some parties[95].

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 (Germany, http://www.blauer-engel.de)
The Blue Angel 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 (in total 10 000 products in 80 categories):
- Paints and varnishes
- Wallpapers
- Floor covering
- Furniture
- Flushing tanks
- Building insulation materials
- Solar collectors
- Wood pellet heaters

The Nordic Swan (http://www.ecolabel.no/)
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 at 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 product's impact on the environment throughout its lifecycle 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 regard to quality and performance. The product must possess features, which are at least as good as those of other respective products.

RAL Institut certification mark (RAL Deutsches Institut für Gütesicherung und Kennzeichnung, Germany, http://www.ral.de/)
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 associations different labels (certification mark / quality seal), according to its own criteria or in cooperation with government agencies. RAL labels are mainly of interests in those fields of application, where no standards or official guidelines but interest in quality assessment exists. For the construction sector, its quality seals assess processes (e.g. demolishing), building components and complete constructions (e.g. low-energy houses).

Umweltzeichen (Austria, http://www.umweltzeichen.at)

[95] http://www.oroverde.de/regenwald-wissen/tropenholz/zertifizierung-von-tropenholz.html

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 (Germany, http://www.emicode.de/)

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 don't 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 percent 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 organizations 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 regard 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).

Applicability

Ecolabels exist for construction materials, as well as for many other products. As they are mainly directed directly at consumers, it is mainly consumer products (paints, carpets, wood products, light bulbs) that these labels are relevant for.

Table 2-49: Examples of areas in construction covered by different ecolabels

	Wood	Floor covering	Adhesives	Wood preservation	Paints Varnishes	Insulation	Light bulbs
EU-Ecolabel		x			x		x
Natureplus	x	x		x	x	x	
FSC	x						
PEFC	x						
Blauer Engel		x	x	x	x	x	
Umweltzeichen	x	x				x	
GEV-Emicode			x				

Economics

No detailed data available.

As products with ecolabels tend to be those of higher quality, higher initial cost are possible for some products, however regarding the total product lifecycle, reduced total cost can be assumed for many products with proven durability, energy saving properties (e.g. light bulbs) etc.

Driving force for implementation

Consumer awareness for ecological and general product quality issues.

Reference organizations

http://ecolabelling.org/
www.ecolabel.eu
http://ec.europa.eu/environment/ecolabel/index_en.htm
http://www.natureplus.org/)
http://www.fsc.org/)
http://www.pefc.org
http://www.ecolabel.no/
http://www.blauer-engel.de
http://www.ral.de/)
http://www.umweltzeichen.at
http://www.emicode.de/
http://www.zukunft-haus.info
http://www.passiv.de/
http://www.tuev.com/
http://www.sentinel-haus.eu/en/

References

[20] BBSR (2009a): German Federal Office for Building and Regional Planning (Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)): Guideline for Sustainable Building, 2001, http://www.bbsr.bund.de/nn_463880/BBSR/DE/Bauwesen/NachhaltigesBauen/Geschaeftsstelle/Leitfaden/leitfaden.html

2.7.2 Guidance on 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 reasons. After the solvent has dried, a solid film remains on the surfaces.

Many different kinds of paints exist; Table 2-50 gives an overview of 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 with rather high environmental and health impacts.

Some conventional paints have negative environmental and health impacts, mainly due to the content of volatile organic compounds (VOC) 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.

Volatile organic compounds (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:

- *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 VOC 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 like turpenes or citrus oil (often seen as a rather pleasant fragrance). Water-based natural paints normally give off almost no smell.[96]

<u>Achieved environmental and health benefits</u>
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 environmental aspects, VOC have negative consequences for plant growth and contribute to photochemical pollution. This means they contribute to the formation of ground level ozone; in sunlight, some organic solvents used in paint can react with nitrous oxides in the atmosphere to form smog.

Concerning 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

[96] Cf. www.buildgreennow.org

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 offgassing 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.

Environmental indicators

Compliance with product related indoor air quality standards and certification schemes (ecolabels cf. 2.7.1, additionally www.greenguard.org) provide indication concerning major health and environmental concerns.

The main environmental indicators for paints in construction indicators are (see also Table 2-50 several environmental aspects of paints):

- VOC concentration: For maximum VOC contents allowed by European legislation see Table 2-52.
- 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 2-50):

- 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 be adverse to health) or not at all present, e.g. for indoor use in non-critical applications. For low- or no-VOC paints, cleanup does not require toxic solvents that release additional VOC pollutants.

Cross-media effects

No data available

Operational data

- *Use low-VOC or zero-VOC paints*: Low and zero-VOC paints reduce emissions of VOC, 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 were 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.

Complete declaration of all used ingredients is important for selecting natural paints and available from many producers[97].

In Table 2-50, a summary of characteristics of main types of paints is given. However sometimes different fields of application are suited for different paints.

[97] 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 2-50: Characteristics of selected paints [48, CRTE, 2009]

Part 1

	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 – 5000	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

	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
Median expected useful life	15 (interior painting)	15 (interior painting) 20 (exterior painting)	15 (interior painting)	No data available	No data available	18 (interior painting) 8 (exterior painting)	18 (interior painting) 8 (exterior painting)	18 (interior painting) 8 (exterior painting)	18 (interior painting) 8 (exterior 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								

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

	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
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-forming colour)	brushing, washing and new over coating, (but not with film-forming colour)	brushing, washing and new over coating, (but not with film-forming colour)	cleaning by high pressure and coating with silicon resin, complete removal only with high efforts	refurbishing limited, complete removal only with high efforts	can be washed, sanded and over coated, complete removal only with high efforts	can be sanded and over coated (with synthetic or natural resins), complete removal only with high efforts	Can be over coated
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

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					

<u>Applicability</u>

- *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 offgas 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, the 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 specilized 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.

<u>Economics</u>

- *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.[98]
- *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 last for a larger surface (sometimes twice or three times the surface of conventional coatings). The useful life time 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 2-51.

Table 2-51: Comparison of costs [€/m²] of different conventional and natural coatings (complete build-up including primer or pretreatment) [90, FNR, 2010]

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	

[98] http://www.toolbase.org/Technology-Inventory/Interior-Partitions-Ceilings/low-voc-paints

Product	Floor	Wood interior	Wood exterior	Walls interior (2 coatings)
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

Driving force for implementation
Increased end-user awareness of environmental and health issues have created demand and wide availability of low-VOC and natural resource paints.

Besides, the European "Decopaint" Directive (2004/42/EC) is limiting 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 2-52. 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 2-52: 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

Reference organizations
Not applicable

References
www.thegreenguide.com
www.buildgrenenow.org
http://www.toolbase.org/Technology-Inventory/Interior-Partitions-Ceilings/low-voc-paints
http://www.metaefficient.com/paint/agalia-plant-based-paints.html.
http://www.toolbase.org/Technology-Inventory/Interior-Partitions-Ceilings/low-voc-paints
http://eartheasy.com/live_nontoxic_paints.htm

References (in German)
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.
[62] FNR (2010): Fachagentur Nachwachsende Rohstoffe e.V. (FNR): Naturfarben Oberflächenbeschichtung aus nachwachsenden Rohstoffen; http://www.fnr-server.de/ftp/pdf/literatur/pdf_414-brosch_oberflaechenbeschichtungen_2010.pdf, accessed 10.06.2010

2.7.3 Guidance on choosing certified wood and substituting tropical wood

Description

Certification of wood: Without the FSC label (or other independent wood certification labels), timber may stem from illegal or controversial sources. The Forest Stewardship Council (FSC) is an independent, not for profit, non-governmental organization that provides standard setting, trademark assurance and accreditation services for companies and organizations interested in responsible forestry. It is recognised worldwide and only awarded, if wood is produced without clear cutting, soil degradation and 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. Summarizing, the sustainable use of forests ensuring its survival for future generations is assured for wood having the FSC label.

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 at promoting sustainability throughout the wood supply chain. However, it is not as strict concerning sustainability criteria as the FSC label and criticized by some parties for allowing use of natural woods in Scandinavia.[99]

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 (cf. section Achieved environmental and health benefits), those woods should be avoided; options for substituting different tropical woods by local woods are given in Table 2-53.

Use reclaimed/recycled wood: Reclaimed/recycled wood often has special esthetical features making it suited 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** negative environmental impacts from its production like the following examples:

Deforestation of rainforests: Tropical and temperate rainforests have been subjected to heavy logging and agricultural clearance throughout the 20th century and the area covered by rainforests around the world is shrinking. Globally, around 40% of rainforests have been destroyed in the last 30 years.[100] 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 in 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[101] thirty-five percent 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

[99] http://www.oroverde.de/regenwald-wissen/tropenholz/zertifizierung-von-tropenholz.html
[100] http://wecobis.iai.fzk.de/cms/content/site/wecobis/Home/Bauproduktgruppen/Holz-Holzwerkstoffe/Tropenholz

[101] http://wwf.panda.org/how_you_can_help/greenliving/out_shopping/fsc/facts/

WWF, 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.

Environmental indicators
See “Achieved environmental and health benefits” for qualitative description of avoided negative environmental issues.

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 2-53 gives an overview of traditional application areas for tropical woods and possible local substitution woods with similar properties.

Table 2-53: Tropical woods by application area and possible local substitutes[102]

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,	Teak, Framiré	Alder, Larch, Walnut

[102] http://www.oroverde.de/regenwald-wissen/tropenholz.html

brushes)		
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

Applicability
Selection of sustainable wood products (FSC certified, no tropical woods) is recommendable for all interior and exterior application in construction. Concerning options for substituting tropical woods see Table 2-53.

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 organizations
www.certifiedwood.org
www.espen.de
www.preciouswoods.com
www.ecotimber.co.uk

References
[86] FAO (2001): Forestry Department, Food and Agriculture Organization of the United Nations, 2001: Promotion of valuable hardwood plantations in the tropics. A global overview; www.fao.org/forestry/plantedforests/10368/en/, accessed 20.05.2010

- Guide (pictured) for identifying tropical woods and checking sustainability: http://wwf.panda.org/how_you_can_help/greenliving/out_shopping/fsc/list_of_wood/
- Uses of tropical wood: http://www.unctad.org/infocomm/anglais/timbertrop/uses.htm
- Use of tropical wood in construction (German): http://wecobis.iai.fzk.de/cms/content/site/wecobis/Home/Bauproduktgruppen/Holz-Holzwerkstoffe/Tropenholz

2.7.4 Guidance on choosing environmentally friendly materials for floor covering

Description
Concerning available materials for floor covering, general data is presented in Table 2-54. In the following some examples for floor covering materials with good environmental performances are shortly presented (more details on techniques in section "operational data") [6, ALAMEDA, 2005]:

- Select certified (FSC or PEFC) or reclaimed flooring wood
- Use rapidly renewable flooring materials
- Use ceramic tiles with recycled-content

- Use exposed concrete as finished floor
- Use recycled-content carpets
- Use thermally massive floors

Achieved environmental and health benefits

- **Select certified (FSC or PEFC) or reclaimed flooring wood**: FSC certification assures that forests are managed in a way that protects the long-term availability of wood resources, the health of old growth forests, and the economic sustainability of forestry operations and workers (cf. section 2.7.1). 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.
- **Use rapidly renewable flooring materials**: 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.
- **Use ceramic tiles with recycled-content**: 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.
- **Use exposed concrete as finished floor:** 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.
- **Use recycled-content carpets**: 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.
- **Use thermally massive floors**: 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.

Environmental indicators

- Percentage of recycled materials content in floor coverings: Floor coverings ideally should exist at least to 95 percent of renewable raw materials; the glue portion should be reduced as much as possible. Table 2-54 shows the typical composition of different floor covering products.

Table 2-54: Composition of floor covering materials [48, CRTE, 2009]

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

- Alternatively: Percentage of (fast growing) renewable materials (from certified sources especially for non-European woods) in floor coverings.
- Other performance indicators include
  - Absence of emissions or pollutants as in some floor coverings
  - Life-cycle related issues like primary energy consumption and recyclability
  - Comfort issues and reduced heating (for warm flooring materials like 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" (http://ec.europa.eu/environment/ecolabel/ecolabelled_products/categories/pdf/wooden_coverings/User_manual.pdf) gives comprehensive information on additional aspects.

Producing floor coverings mainly leads to environmental impacts through the use of more or less environmentally friendly raw materials (see Table 2-54 and Table 2-55). Further environmental impacts arise through the installation of floor coverings (cf. section adhesives) and through their cleaning and maintenance. Table 2-55 shows the main types of floor coverings with their application areas, environmental and practical performance indicators.

Table 2-55: Operational and environmental parameters of different floor coverings [48, CRTE, 2009]
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 &	Decomposition products of the styrol-butadiene-structure can emit (nitrosamines - vulcanization accelerator, VOC, vinylcyclohexane - synthetic rubber, 4-phenyl-cyclohexane), consider type of	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
	aldehydes), chloranisole	glue			
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

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)

	Laminate	Natural fibre carpet	Synthetic fibre carpet	Natural stone floor covering	Ceramic tiles and plates
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)
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

	Laminate	Natural fibre carpet	Synthetic fibre carpet	Natural stone floor covering	Ceramic tiles and plates
Recyclability	Energy recovery	Energy recovery	Energy recovery	Reuse possible theoretically, further utilization 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

- **Select certified (FSC or PEFC) or reclaimed flooring wood (cf. section 2.7.1):** FSC-certified wood flooring comes from forests managed in accordance with stringent sustainable forestry practices. FSC-certified products are available in a wide variety of domestic and exotic species. Reclaimed wood is wood from another building or other use that is salvaged for use in a new application.
- **Use rapidly renewable flooring materials:** 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 is indoor air quality concern related to the urea-formaldehyde binders used in some products. While conscientious manufacturers wouldn't 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. 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.
- **Use ceramic tiles with recycled-content**: Recycled-content ceramic tiles can contain up to 70% recycled glass or other materials. Ceramic tile is 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.
- **Use exposed concrete as finished floor**: 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 (like 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).
- **Use recycled-content carpets:** 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.
- **Use thermally massive floors:** Use flooring materials that improve thermal mass. Some types of floors (concrete, cement or brick tile and other hard floors...) provide 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

- **Select certified (FSC or PEFC) or reclaimed flooring wood:** FSC-certified or reclaimed wood can be used without special limitations in place of conventional hardwood flooring.
- **Use rapidly renewable flooring materials:** Use these rapidly renewable flooring materials in place of conventional hardwood, carpet or vinyl 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 underlayment 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.
- **Use ceramic tiles with recycled-content:** Install recycled-content tiles wherever conventional tiles are specified. They 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.
- **Use exposed concrete as finished floor:** Use this approach for slab-on-grade construction. The finish must be designed and constructed when slab is being poured. This approach is especially appropriate for in-floor radiant heating systems and passive solar design.
- **Use recycled-content carpets:** 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.
- **Use thermally massive floors:** 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
End-user awareness for environmentally-friendly living.

Reference organizations
Not applicable.

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3 BUILDING CONSTRUCTION PROCESSES

3.1 Introduction: Building construction processes

3.1.1 Production of construction materials

Techniques, measures and processes of builing product producers are not part of this document. To some extent the production of materials is approached, as a part of construction on site. Furthermore it is important that the construction company considers environmentally-friendly production of materials as well as environmentally-friendly products itself as one central point of their purchasing activities. The production of certain building materials is covered in Best Available Technique Reference Documents (BREFs), e.g. for cement and lime, glass, included glass fibres.

3.1.2 Site preparation and groundwater management/treatment

3.1.2.1 General

Before the construction company starts with the earth works and the construction itself, they have to prepare the construction site and determine areas for construction equipment and certain construction processes. Firstly the ground and groundwater conditions have to be determined and recorded. Therefore test pits and test drillings are performed. It is essential to analyse the construction area to know about barriers and difficulties, such as old cables, pipes and foundations. Those residuals are removed, protected, or allocated. Often existing infrastructure has to be redirected, this procedure requires planning of detours, protections and safety signals around the site as well as their changes during construction. With regards to minimising negative impacts on the pre-existing environmental conditions on the selected site a plan and inventor of vegetation on this site have to be prepared, showing all trees and bushes to be retained [46, COLE, 2000].

3.1.2.2 Space requirement and arrangement

In the beginning of all construction works the area is marked and cleared by for instance cutting of trees. Hence to reduce the impact on the environment minimal land use for construction plants, equipments and infrastructure should be considered.

3.1.2.3 Main supply and utility services

To ensure a good functioning construction site and to minimize impacts on 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 applied already before construction starts.

3.1.2.4 Circulation areas and transport ways

Within the construction phase a vast amount of logistic processes are performed which ask for sufficient transport ways and circulation areas. Those areas are prepared in advance while existing environmental and infrastructural conditions are affected. Little land consumption and minimised changes over the whole construction phase should be considered during site planning to reduce and minimize negative impacts on the environment and inhabitants. 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 minimize 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.

3.1.2.5 Installations for safety and protection

Certain arrangements have to be installed and a safety management plan has to be established to protect workers, society and the surrounding. Besides fences, platforms, scaffoldings, safety cloths and various other safety equipment, the construction company need to perform safety trainings for all personnel on site.

3.1.2.6 Water management

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 fluids and materials resulting from construction and transportation activities has to be avoided. Therefore solvent-based substances should be used as little as possible and have to be stored safely. Processes with a possible hazardous impact on groundwater should be performed within certain areas, where the ground is protected by respective pavements or waste water treatment systems. If processes have to be carried out on site, locally depended, the site management has to apply flexible ground protection facilities, such as impermeable tarpaulins or mobile waste water treatment systems. Furthermore water consumption on site has to be reduced. This fact touches specific water reduced construction procedures, techniques, equipments, materials as well as a sufficient water management for sanitations, for instance the installation of waterless restrooms. 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. Especially submersible motor-driven pumps are used for construction operations, as these water pumps are able to pump sewage and slurry, besides pure water. Furthermore those pumps can be fully submerged, as their motor is totally water resistant. Lowering of the groundwater becomes necessary, when the foundation of the building is lower than the groundwater table or ground upraise by groundwater is expected. There are different procedures depending on ground conditions [119, KÖNIG, 2005].

3.1.2.7 Accommodations and storerooms

Different containers are necessary on site during the construction process. First of all there have to be accommodations for the workers, where they can stay during the day during breaks and during bad weather and depending on the project living accommodations. Sanitary faculties, office trailers and storerooms for tools, equipment and construction materials have to be placed on site. The arrangement of containers should require as little space as possible to reduce the impact on the environment around the construction site, while guaranteeing safety. Moreover, they should be located to protect existing vegetation from being trampled and to reduce soil compaction by workers [67, DRESS, 2002; 46, COLE, 2000].

3.1.3 Earth works

3.1.3.1 General

The spectrum of earth or soil in construction 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. Based on these characteristics soil is classified to get an overview of the load bearing behaviour and possible treatments.
Earth works is the change of soil in terms of form, location and density. Earth works includes especially soil removal, such as building of cuttings, pits and ditches as well as soil application, for instance land fills. Hence earth works encompass loosing, loading, transportation, unloading as well as application and densification of soil. Transportation is the most expensive activity of earth works. Hence transportation ways have to be minimized, which is also very important under environmental viewpoints. 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 [17, BAUER, 1994].

3.1.3.2 Soil movement

On construction sites soil is removed by diverse 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 tooth 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 efforts swimming excavators, so called dredgers, sometimes it is possible to use normal excavators and place them on a pontoon.

A selection of earth works equipment is listed in the following:

- hydraulic excavators
- hydraulic crawler excavator
- wheel loader
- backhoe-loader
- dump truck/dumper
- caterpillar
- scraper
- motor grader.

Noise of these equipment, which can be up to 100 db, can be reduced in general up by to 15 db through shielding of the engine and installation of sound absorbers on intake and exhaust systems [23, BGBAU, 2010].

3.1.3.3 Soil compaction

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 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 [119, KÖNIG, 2005].

3.1.3.4 Removal of matrix/top soil

Matrix soil is called the notorious soil up to 30 centimetres on top. This soil has to be removed and stored separately to be able to apply it in the end after all construction work is finished. Other notorious soil has to be protected as well for later re-cultivation.

3.1.4 General issues on construction sites

3.1.4.1 Emissions and pollutions

Activities of the construction process have always an impact on the surrounding environment as well as on neighbours. Emissions and pollutions in form of dust, noise, exhausted gases and hazardous fluids and substances may affect flora and fauna, watercourses and nuisance. Nevertheless, the construction company can reduce these impacts by good environmental practice.

Dust emissions can be reduced by sprinkling heavily dusking equipment on dry days. For sprinkling or cleaning purposes process, water out of the settling basin or collected rain water should be used.

As the process water of construction sites contains a lot of mineral fines, this water has to be collected in a settling basin. Water from concrete production has to be neutralised as it is basic/alkaline. For process water which had been in contact with oil or fuel an oil extractor becomes necessary.

Construction noise needs to be reduced as far as possible. In general this is an important issue in connection to the selection of construction equipment, such as compressors machines, those should be low-noise. Furthermore the construction company has to inform beforehand the surrounding residents about the type, the degree and the duration of the construction process, before the construction process starts. Critical noise and dust generating activities should be scheduled to minimise disturbances. Necessary noisy construction equipment should be placed as far as possible away from residents by taking into account natural and artificial noise barriers. Windless areas should be chosen for stockpiles of sand, soil and aggregates [46, COLE, 2000; 47, CONRADY, 2007; 45, CIRIA, 2010; 23, BGBAU, 2010].

3.1.4.2 Erosions

Erosions through wind and rain on unstable soil are a major risk for people and the environment on construction sites, as they can result in water pollution 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 [139; MIDWESTIND, 2010].

3.1.4.3 Transportation and logistics

Besides the goal of little land consumption in connection to logistical activities on site, transport ways outside the construction area should be in general as short as possible. Therefore a sufficient analysis of available materials and suppliers in the surrounding of the construction site is necessary in advance. Conditions, advantages and disadvantages by using prefabricated products, which have a great impact on logistics, are mentioned later in this document.

3.1.4.4 Supply management, resource use and building site waste management

The construction sector consumes about 50 wt. % of all extracted materials in the EU and generates 22 wt. % of waste and especially the construction phase holds here the greatest portion. Therefore, reduced resource consumption and construction waste generation is a major environmental issue on construction sites. Before construction starts the construction company should pay attention that waste management and recycling issues are included in the construction contract specifications and develop a waste management plan, including recycling options, as 80% of waste generated during construction is reusable and recyclable.
Primarily waste generation is to prevent. As listed in Table 3-1, this touches all areas of the construction process, from design considerations to implemented construction methods on site.

Table 3-1: Waste prevention activities [93, GA, 2010]

Waste prevention	
Waste plan	
	• focus on specific waste producing practices for waste prevention • develop a waste management plan, described later in this document • communicate the waste management plan in meetings and promote the results
Construction and job-side 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
Purchasing	

	• salvaged, recycled or recycled-content materials and equipment • check correct amount of material delivered to site • up-to-date material ordering and delivery schedule: minimize 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

Besides waste prevention several methods exist to reduce construction waste and at the same time to increase profits through reuse, recycling and salvage. Within this context reuse describes materials used as they are or being converted on side, whereas for salvage the materials are removed from the side. Recycling is then the next level, when there is no possibility of reuse or salvage. The implementation of reuse and salvage methods on site implicates several benefits, as the need for new materials is reduced, waste ending in the landfill is minimised, a cleaner and safer project site is derived. Especially on-site reuse reduces emissions, such as greenhouse gas as well as energy and water consumption related to production of construction elements from virgin materials and decreases emissions through transportation of these materials. Moreover, through recycling and reuse waste disposal costs are reduced and revenues can be derived from recycle, reuse and salvage materials. Efforts to prevent waste and recycle can reduce in the long run, dependence on natural resources, such as trees, oil and minerals. The following procedure, shown in Table 3-2 can be used for the development of a waste management plan.

Table 3-2: Development of a waste management plan [93, GA, 2010]

Plan design	
Establish the waste management plan	
	• identify materials to be salvaged, reused, recycled and disposed and appoint subcontractors being responsible for • outline procedures, expectations, 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, salvaged, recycled, 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	
	• contact recyclers and haulers using the Yellow Pages or recycling directories. • 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 • look for training for the crew • receipts for tracking types and quantities for the use of recycled materials
Identify recycling materials	
	• determine potentially recyclable materials and the recycling method. • select recyclable materials.

	• identiy costs and revenues for recycling different construction wastes, mixed and separated • identfy 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 formalized plan and control procedures with everyone involved in project administration • discuss waste handling requirements with crew 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 minimize 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 to all involved regarding placement and pickup of waste
Promotion and training	
	• include waste management into the safety education, or design a separate recycling education program • choose a name or slogan for the recycling program • 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

Additionally, in the site office it is also commendable to focus on recycled-content products, such as copy paper and desk supplies [46, COLE, 2000].

The following selection of recyclable material of a building (Table 3-3) should be checked by the construction and deconstruction company [93, GA, 2010].

Table 3-3: Selection of recyclable material of a building [93, GA, 2010]

- asphalt
- bricks
- carpets
- concrete
- drywalls
- insulation materials
- landscaping materials
- marble
- metals
- paints
- paperboard
- plastic films from packaging, sheeting
- shingles
- tiles
- window glass
- wood.

Waste management and recycling is also an issue for demolition companies, approached in chapter 5.

3.1.5 Standardisation and pre-fabrication

Standardisation describes the classification of the building in certain uniform elements. This implies repetition and continuity and supports the optimisation of materials and construction elements. Standardisation is therefore good to optimise the building economically and ecologically at the same time. 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 [164, PHD, 2010].

3.1.6 Selection of construction materials

The choice of construction material types is usually already performed by the designer and the structural engineer in the design phase before the construction process starts. However, as environmental impacts differ also largely within the material type, besides eco-friendly construction techniques, the construction company can reduce the environmental implications by focusing on environmental-friendly options. 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 the material selection process, carried out by the construction company, it would be desireable to consider the environmental impacts over the whole life-cycle of a material. Therefore, Environmental Product Declarations (EPD) according to ISO 14025 offer basic information for a life-cycle analysis (LCA) with respect to the application of the material [65, DIMOUDI, 2008; 161, PE-INT, 2010].

In General the construction company should use as much as possible recycled-content materials. Those materials are 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 3-4) includes common recycled-content materials and products [93, GA, 2010].

Table 3-4: Common recycled-content materials and products [93, GA, 2010]

- 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
- fiberglas insulation
- fill materials
- floor joist
- floor mats
- flooring
- lumber
- paint
- pilings
- plastic lumber
- recycling containers
- roofing
- structural steel
- underlayment
- wallboard.

3.1.7 Concrete and reinforced concrete work

3.1.7.1 General

Concrete is the most popular and most commonly applied material in construction. Difficult formats can be made out of concrete, as it is fluid in the preparation phase and becomes firm 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 coarse aggregates such as gravel, limestone and granite and finer aggregates such as sand and fly ash [67, DRESS, 2002; 182, SB, 2010].

3.1.7.2 Environmental performance

Conventional concrete is not environmentally-friendly, either in production, in use or in dispose. A lot of energy and water is necessary to gain and treat raw material. The production of raw material also results in environmental degradation and pollution. Furthermore concrete has a large impact on global warming, as cement plants emit more than one milliard 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 cement, which is burnt at very high temperatures. Hence the more cement is included the more energy is necessary for one cubic meter concrete. Research is done to minimise the cement content in concrete as far as possible. Further research activities are performed with regard to the reduction of energy and resource consumption through a decrease in concrete dead load as well as through reuse of construction elements and formwork [225, WECOBIS, 2010; 182, SB, 2010; 113, INNO, 2010].

Nevertheless, concrete has less environmental impacts and implicates less energy consumption than construction materials such as aluminium and ceramic [65, DIMOUDI, 2008].

3.1.7.3 Concrete mixing facilities and their environmental issues

Usually concrete is premixed in stationary plants and then transported by trucks on site. 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. Manly there are two mix systems, free fall and positive mixers. Today free fall 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 positive mixer is used generally today [119, KÖNIG, 2005; 67, DRESS, 2002].

The first environmental aspects regarding concrete mixing facilities is recycling of remaining concrete. Remaining concrete comes from the construction site as well as from cleaning of facilities. Concrete is rinsed within the recycling facility and at the same time water loaded by cement and aggregates are separated, so that the aggregates and about 50% of the cement water can be reused within the concrete production. Secondly noise is 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 aspects are dust emissions. Dust is generated especially by transportation and metering of cement. Here special filters and security valves on the cement scale and the mixer reduce dust emissions [119, KÖNIG, 2005].

3.1.7.4 Concrete transportation

Concrete is mainly transported by driving mixers of different sizes onto the construction site. Sole exception is in road construction. Here articulated lorries with a steel basin are used regarding the enormous concrete amounts.

3.1.7.5 Placing of concrete

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 a regularly used equipment to move the concrete from the mixer into the formwork. There exist mobile and stationary concrete pumps; stationary ones are applied on major construction sites, as they are more efficient then. If the structure is too high, the the concrete is placed via crane and concrete bucket, as the placing by pump becomes too expensive and energy consuming [119, KÖNIG, 2005; 67, DRESS, 2002].

3.1.7.6 Concrete compaction

Concrete is compacted through vibration. Vibration reduces the friction within the grain structure; the grains store denser and the air void content decreases, so that a high concrete quality and strength is reached 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 tent for noise protection around the vibrator and by the installation of sound absorbers on intake and exhaust openings of the vibrator [119, KÖNIG, 2005; 67, DRESS, 2002; 22, BGBAU, 2010].

3.1.7.7 Finishing works and facilities

After concrete pouring and until hardening, concrete has to be protected against damages and need to be kept moist 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 includes 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, stabilizers, thickeners and driers. VOCs contribute to ground-level ozone formation and to global warming [17, BAUER, 1994; 196, SERVICEMAGIC, 2010; 182, SB, 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 minimize hazardous emissions [17, BAUER, 1994; 196, SERVICEMAGIC, 2010; 182, SB, 2010]. Therefore various ecological labels have been developed by different countries to indicate that the paint has fulfilled certain environmental requirements, in accordance with respective government regulations. The construction company should especially focus on the European Eco-label, carrying the flower label. 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 3-5[76, EC, 2010; 72, EC, 2008].

Table 3-5: VOC content limits for outdoor paints and vanishes regarding 2009/543/EC [72, EC, 2008]

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

3.1.7.8 Sprayed concrete

Sprayed concrete is a technique, where concrete is sprayed with 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 a sufficient coverage of loose rocks and soils. With the inclusion of steel fibre the concrete is strengthened and its water resistance is increased. Two major methods of sprayed concrete are available. In the dry technique, 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. But as it is connected to certain drawbacks, such as great dust generation and difficulties to control qualities, the wet-mix technique was implemented especially for tunnelling and will soon represent more than 80 to 90% of all sprayed concrete works worldwide. Here 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 done 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, alkali-related respiratory health problems can be avoided [67, DRESS, 2002; 179, ROSS, 2006].

3.1.7.9 Form and false work

Form and false work has to secure the load transformation under construction, has to fit exactly and should be as economically as possible in use. Form work 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. False work is usually a steel frame, either used as a temporary support of form work and other construction elements, or as working platform and safety scaffold. As form and false work is quite expensive, their flexibility and longevity is highly important, so that they can be reused several times, which is also beneficial from an ecological view point. 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 [67, DRESS, 2002; 17, BAUER, 1994; 185, 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 efforts of disassembling and no storage area is needed, when the material remains as a structural element [113, INNO, 2010].

3.1.7.10 Reinforcement

Reinforcement facilitates concrete 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. For preparation of the steel in general cutting and bending machines are applied [67, DRESS, 2002].

3.1.8 Selection of equipment

3.1.8.1 General

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 [17, BAUER, 1994].

The major environmental impact of construction equipment results from energy consumption in the form of electric power and fuel. A certain CO_2-emission is connected to each energy source. Some energy sources and related direct CO_2-emissions and fuel values are listed in**Table 3-6**. With this information CO_2-emissions can be calculated from the average fuel consumption of equipment.

Table 3-6: Direct CO-emissions from fossile fuel combustion process of certain energy sources [127, 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 directly CO_2-emissions, but through the energy mix it results in 0.62 kg CO_2/kWh.[103]

3.1.8.2 Piling machines

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. As general impact equipment generates noise up to 120 db, which meets the pain threshold of human beings, the construction company should focus on other techniques rather than impact piling, such as vibration piling. 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 as well. For instance, the anchoring depth can be decreased [119, KÖNIG, 2005; 23, BGBAU, 2010; 167, PROTHERM, 2010; 215, TRANSZVUK, 2010].

[103] BLU (2010): Bayrisches Landesamt für Umwelt: Infozentrum UmweltWirtschaft: Excel-Tabelle zur Berechnung der CO_2-Emissionen; http://www.izu.bayern.de/praxis/detail_praxis.php?pid=0203010101217, accessed 22.06.2010.

3.1.8.3 Drilling machines

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. Besides all these aspects the construction company should always consider reducing as far as possible noise, vibrations, air-emissions and required space [119, KÖNIG, 2005].

3.1.8.4 Transport equipment

The construction process is very transportation intensive. Materials, components and elements are transported by trucks, rails and sometimes by ships over far 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 [46, 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 3-7 lists emission standards for HD diesel engines.

Table 3-7: EURO emission limits for trucks with HD diesel engines [82, EG, 2009; 64, DIESEL, 2010]

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

The construction company should focus on EURO V standards, when renting or purchasing trucks for any kind of construction works Trucks regarding emission standards of EURO V operate with reduced gasoil consumption. Respective fuel consumption and CO_2-emissions of different trucks are shown in Table 3-8 below.

Table 3-8: Gasoil consumption and CO2-emissions of trucks with control gear EURO V [based on 221, VOLKSWAGEN, 2010]

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

Table 3-9 shows other measures, influencing fuel consumption of transport equipment and which should be considered by the construction company in purchasing and during operation [54, DAIMLER, 2010].

Table 3-9: Measure for reduced fuel consumption [54, DAIMLER, 2010]

Measures to reduce fuel consumption of transport equipment
• aerodynamic auxiliary equipment reduces fuel consumption by up to 10% • fuel consumption can be reduced when all tarpaulins are fixed • sufficient air pressure in truck tires 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 [219, VIENNA, 2004].

3.1.8.5 Lifting and loading equipment

Lifting equipment encompass different crane types, such as tower, mobile and truck-mounted cranes, forklifts, construction elevators as well as jacks and winches. Loading equipments have been mentioned with regards to earth works in chapter 3.1.3 those are excavators, loaders and scrapers. 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, maximal necessary bearing load, necessary lifting height, lifting pace and available space. Economic aspects are costs for transport, assembling and disassembling, use and rent. 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 [130, LIEBHERR, 2002].

Table 3-10 gives average gasoil consumptions and CO_2-emissions of diverse state of the art wheel loaders.

Table 3-10: Gasoil consumption and CO2-emissions of diverse state of the art wheel loaders [based on 130, LIEBHERR, 2002]

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

3.1.9 Worker protection/safety issues

On construction sites workers handle with many toxic substances, including solvents, paints, pesticides, adhesives, wood preservatives and sealants. Connectedhealth risks can be minimised through the selection of materials, being safe to handle, by avoiding hazardous solvents and fibres, heavy metals and caustics. Essential hazardous substances should be labelled clearly, should be stored and disposed securely and waterproofed. In general the construction company has to establish an occupational savety and health administration being responsibele for savety and heatlth of the workers over the whole construction phase. This organisation outfits the workers withsafety helmets, shoes and glasses, as well as protective clothing, absorbent materials and dusk masks. Moreover, safety trainings for general and specific construction activities and trainings in clean-up procedures have to take place for all workers.

Additionally, the construction company should decrease the health risks to people, being 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 within the context of finishing works, construction companies have to select construction products and methods with low- or no-VOC reduce health impacts for later tenants [46, COLE, 2000].

3.2 Available Techniques concerning building construction processes

3.2.1 Site preparation

3.2.1.1 Sustainable drainage system

Description
Construction sites need to be drained to remove surface water. Conventionally this is done by an underground pipe system, alternating natural flow and transferring the water as fast as possible to prevent local flooding. Those drainage systems do not consider the natural surrounding conditions and only little control runoff qualities, which may result in groundwater pollution. Therefore, sustainable drainage systems are drainage concepts including long term environmental and social issues by focusing on flood control, quality management and amenity. These systems are more sustainable than conventional drainage systems by dealing with the runoff close to where the rainwater falls. They manage the potential pollution at its source by protecting the water resources from point pollution, such as accidental spills, as well as from diffuse sources. Construction related groundwater lowering is minimised and groundwater levels are remained as far as possible, so that impacts on the environment and risks for the surrounding are reduced.

Achieved environmental and health benefits
Sustainable drainage systems reduce the impact of urbanisation on flooding by managing the quantity and the flow rate of runoffs. These systems protect and enhance the groundwater quality, prevent groundwater pollution and encourage where appropriate natural groundwater recharge. They reduce risks in connection to changes in the groundwater level. Sustainable drainage systems integrate into the environmental setting and consider the needs of local communities.

Environmental indicators
None available.

Cross-media effects
Not applicable.

Operational data
Sustainable drainage systems include one or more structures to manage surface water runoff. They are used in conjunction with good management of the site, to prevent flooding and pollution. The system provides varying levels of treatment for surface water by using the natural processes of sedimentation, filtration, adsorption and biological degradation. The four general methods of control and preventions within these systems are filter strips and swales, permeable surfaces and filter drains, infiltration devices and basins and ponds. The complete construction site is divided into a net of various measuring points, where different groundwater parameters, such as the level, quality and duration and time of variations from the target value are monitored and controlled automatically every hour.
A useful concept for the development of these systems is the ‘surface water management train’, which is geared to the method of natural catchments. The flow and quality characteristics of the runoff are changed over stages. Therefore, the ‘surface water management train’ starts with pollution prevention, then the water flows over local source controls downstream to regional controls. The management train concept divides the drainage area into sub-catchments with individual drainage strategies, different drainage characteristics and land uses.

Applicability
SUDS should be located as close as possible to where the rainwater falls to attenuate the runoff. The design of those systems is very flexible so that they function in most urban settings, from

areas with hard undergrounds to soft landscaped features. Due to the flexible design, designers and planners can go beyond simple drainage and flood control planning and can consider local land use, land consumption and future management aspects.
A sustainable groundwater management strategy was successfully applied for construction procedures around the 'Potsdamer Platz' in Berlin, here the compliance of existing groundwater levels were focused.

Economics
Not mentioned.

Driving force for implementation
The driving forces are the different conditions on site and diverse environmental and social needs of stakeholders, which can be met by the flexible design of the system.

Reference organisations
CIRIA: construction industry research and information association: http://www.ciria.org.

References
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3.2.1.2 Concrete block system based on sustainability - Ecological paving stones for infiltration systems

Description
Green gutter stone or ecological paving stones are rainwater sewage plants with economic and ecologic benefits. Those stones facilitate the return of surface water into deeper ground levels by cleaning the water by dust and other particles. The method includes a chamber system of cruciform arranged concrete footbridges and the chambers are filled with ground material, which is vegetated. Here a biologically active zone arises, which is about 30 cm deep and a living space for micro-organisms and other microscopic organisms.

Achieved environmental and health benefits
The system cleans surface water and therefore prevents groundwater pollution.

Environmental indicators
None available.

Cross-media effects
As the technique reduces general run-off by cleaning the water by dust and other particles, less capaceties are needed to collect wasted water. Adverse for the system is ,that liquid poillutions such as oil, which is usually collected in sewage plants, might flow directly into the groundwater.

Operational data
Not available.

Applicability
Ecological paving stones are mainly used in parking bays or in street edges.

Economics

By the complete integration of the GMS arrangement in the whole usable area on site, space savings from up to 25% are possible on account of the combination of the functions for seeping, for cleaning and parking.

Driving force for implementation
Groundwater protection on biological basis.

Reference organisations
Steinsysteme GmbH: www.steinsysteme.at

References
[206] STEINSYSTEME (2010): Steinsysteme GmbH: http://www.steinsysteme.at/, accessed 31.03.2010.
[226] WEGENER (2009): Wegener, Wolfgang: Hochwertiges Produkt mit qualifizierter Ingenieursleistung. Steinsystem erweitert Angebot für Schwerlastpflaster, in Straßen- und Tiefbau, 63, No. 11, pp. 5-6.
[227] WEGENER (2010): Wegener, Wolfgang: Steinsystem setzt auf Nachhaltigkeit – Baustoffe für eine gesunde Umwelt, Pflasterverlegetechnik, Fachbeitrag: http://www.steinsystem.de/web/cms/upload/pdf_dokumente/strassentiefbau.pdf, accessed 30.03.2010.

3.2.2 Methods for general issues on construction sites

3.2.2.1 Emulsion for dust, erosion control and soil stabilisation

Description
Dust emissions, erosions and soil instability are huge problems on construction sites. All three problems can be solved by stabilizing the soil by applying an emulsion. Commonly used emulsions include chlorides, chemical polymers, various oils and other toxic chemicals. By applying these emulsions, included chemicals enter the ground and can have long-term harmful effects on the environment. In the following a technique is described, which solves the problems of dust emissions, erosions and soil instability on construction sites and at the same time does not harm the environment. This technique is an environmentally safe polymer emulsion with a pH-value between 4.0 and 9.5, soluble in water and comprised of 100% natural materials, such as natural grains and minerals. The emulsion provides very good bonding, cohesion and is versatile.

Achieved environmental and health benefits
The polymer emulsion protects the environmental conditions around the construction site, as it stabilizes soil and makes it possible to control dust and damages through erosions. The emulsion includes no polycyclic organic matter, is non-corrosive, non-toxic, non-flammable and does not contaminate groundwater.

Environmental indicators
None concrete indicators available.

Cross-media effects
As the emulsion has to be packed and transported, additional waste as well as transport costs and emissions might evoke.

Operational data
The polymer emulsion has such a great strength and resilience due to its long and strong polymer molecules being able to bond with the materials of the surface and which are able to form grids of up to 1,000,000 molecules long. To have a comparison, the structure of oil or asphalt emulsions consist of 100 to 10,000 molecules.

Applicability
The polymer emulsion to control dust and erosion and to stabilize soil is applicable to any unpaved grounds, such as construction sites, roads and parking areas as well as to sealed surfaces for instance, to make it resistance against water, to protect it against wind erosions or to avoid wind-blown dust.

Economics
The use of polymer emulsion to stabilize for instance a construction road is cheaper than the sealing of a surface. Additionally, maintenance and rehabilitation costs for roads are reduced.

Driving force for implementation

Reference organisations
Pryor Group: www.pryor.co.uk/

References
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3.2.3 Earth works activities

3.2.3.1 Excavator with an energy storing cylinder

Description
On construction sites a lot of energy is needed for transportation and lifting activities. Transport/lifting equipment used for this purpose usually includes hydraulic cylinders. These hydraulic techniques generate power by a piston connected to a piston rod moving back and forth inside a cylinder barrel, compressing 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. In construction this technique is for instance implemented for lifting purposes in hydraulic excavators.
To make these hydraulic excavators more environmental-friendly and economically by increasing their energy efficiency, a new technique is developed to decrease the energy demand for the hydraulic system. This new invention is a self-sufficient energy memory cylinder, additionally installed in the excavator and forming together with the two heave cylinders an energy recovery system.

Achieved environmental and health benefits

Through the installation of a separate energy storing cylinder less power is demanded, this facilitates the need of smaller diesel engines and hydraulic cylinders, which results in reduced fuel consumption and decrease of pollutant and noise emissions.

Environmental indicators
Fuel/energy consumption

Cross-media effects
Not mentioned.

Operational data
A lot of energy is required by hydraulic cylinders, when the excavator lifts and moves material. The new invention facilitates storing 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 that less force and energy need to be exerted.

Applicability
The installation of an energy storing cylinder is theoretically possible in any hydraulic excavator.

Economics
The technique decreases the costs in connection to fuel consumption.
No data is available about the investments for the energy storing cylinder and its installation.

Driving force for implementation
A driving force is the increasing fuel price.

Reference organisations
Firmangruppe Liebherr: www.liebherr.com/de-DE/default_lh.wfw

References
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[131] LIEBHERR (2010): Liebherr Innovationspreis: http://www.liebherr.com/de-DE/123146.wfw, accessed 31.05.2010.

3.2.4 Concrete and reinforced concrete work methods

3.2.4.1 Energy efficient concrete pump with continuous flow

Description
Concrete is one of the most important construction material especially in civil construction and most of it is placed by concrete pumps. The existing technology has not been changed since decades. This technology is extremely energy-intensive, usually driven by diesel engines, with a requested power up to 500 kW.
To improve the existing system a concrete pump type has been developed, which needs less power and a much lower energy input. The main reason for this is a lower speed of flow inside the pipes and a steady concrete volume stream with steady pressure in the conveyor medium. The characteristics of the pumped concrete stay remain.

Achieved environmental and health benefits

The new pump system has a reduced energy input of up to 50% compared to common pumping systems. As energy is usually delivered from fuel, CO_2 emissions are reduced accordingly.
There are approximately 400 Mio m³ of concrete pumped per year in Europe. For this operation approximately 2.5 kWh per m³ are needed. If the entire quantity of concrete placed by concrete pumps in Europe would be handled with constant flow pumps, 120,000,000 l of fuel (400,000,000 m³/year * 0.3 l/m³ fuel = 120,000,000 l) would be saved and theoretically the total energy savings would amount to 3,160,000 tons of CO_2-emissions.

Environmental indicators
0.3 liters per m^3 less fuel is consumed and CO_2-emissions are reduced by 7.9 kg/m^3.

Cross-media effects
Not mentioned.

Operational data
Table 3-11 shows the difference in energy demand between common concrete pump systems and systems with constant flow.

Table 3-11: Comparison of the energy consumption of concrete pumps

	Common System	**Constant Flow**	**Difference**
Energy			
Demand per m³	2.5 kWh/h	1.5 kWh/h	1 kWh/h
Gas-oil consumption l per m³	0.75 l/m3	0.45 l/m³	0.3 l/m³
Emission			
CO_2 kgper m³	19.75 kg/m³	11.8 kg/m³	7.9 kg/m³

Applicability
The new pump system has no limit of application.

Economics
The reduced energy consumption decreases the cost per m³ of pumped concrete considerably. Due to reduced friction within the pumping lines, considerable savings of wear and tear is reached.
The entire investment of a truck-mounted pump is paid by the savings of energy and wear and tear within approximately 6 to 10 years of operation.

Driving force for implementation
The pressure of competition, especially from far-east will speed up the implementation.

Reference organisations
Reich Baumaschinen GmbH: www.reichag.com

It is cooperated with Prof. Geimer of Lehrstuhl für Mobile Arbeitsmaschinen (MOBIMA) at the Karlsruhe Institute of Technology (KIT).
The system is also supported by Deutsche Bundesstiftung Umwelt (DBU), one of the largest foundations in Europe, promoting innovative and environmentally-friendly projects.

References
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[220] VÖLKER (2009): Völker, Lars; Hudelmaier, Gerhard: Optimierung einer Betonpumpe. In: Fachtagung Baumaschinentechnik 2009 - Energie, Ressourcen, Umwelt, 14.-15.05. 2009, pp. 191-202.

3.2.4.2 Environmental-friendly concrete

Description
Concrete is the major construction material, as it is very flexible in use, assuming diverse shapes, it can bear high compressive forces and in combination with steel high tensions as well. Concrete is a mixture of cement, aggregates, such as sand, gravel and crushed stones, and water. The features of concrete can be variegated depending on the composition and treatment. The construction company can contribute to sustainable construction by using environmental-friendly materials in concrete production, such as recycled materials and supplementary cementitous materials (SCM), which are usually co-products of other processes and natural materials.

Achieved environmental and health benefits
The use of 35-50% slag cement in concrete instead of Portland cement concrete reduces greenhouse gas emissions by 30-45%.
By using SCM, energy consumption is reduced, as cement is the most energy-intensive product within the concrete production process.

Environmental indicators
Reduced greenhouse gas emissions per m^3 concrete.

Cross-media effects
Not mentioned.

Operational data
45-80% of the old concrete can be recycled and reused as a base material within the mixture of new concrete. Furthermore many other materials can be used as SCM, which would be deposited in landfills otherwise. Within this context, almost all concrete includes slag cement and fly ash, which is a by-product of coal-burning. Furthermore, old rebar and recycled steel can be used for new reinforced steel.

Applicability
Concrete out of recycled materials can be implemented in all constructions, if the used recycled material has a good quality.
In Germany construction projects with recycled concrete are performed in Heilbronn, Reutlingen and Stuttgart. With the project in Stuttgart, for the first time recycled concrete is implemented in a high demanded structure, a de-icing salt demanded retaining wall.

Economics
Not available.

Driving force for implementation
Not mentioned.

Reference organisations
Institut für Energie- und Umweltforschung Heidelberg GmbH (IFEU): http://www.ifeu.de/, on behalf of the federal state ministry of Baden-Württemberg for the environment, conservation and transport.

References
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3.2.5 Piling methods

3.2.5.1 Vibrator for piling with a variable static moment

Description
Piling is a main activity in civil and underground engineering. Within this context the use of vibrators, applied on a cable or hydraulic excavator, employed to pile sheet piles, casings and beams already reduce noise by 15 db in contrast to impact piling. Usually the static moment of these vibrators, which is the dimension of the unbalance, the product of the mass of the unbalance and its distance from the axis, is fixed. The invention 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 frequency can be driven. Hence the vibrator becomes applicable for diverse site conditions and a wide range of diverse piling activities.

Achieved environmental and health benefits
The vibrator works with higher piling and gear efficiency; hence the average energy consumption of a vibrator is reduced.

Environmental indicators
Not defined.

Cross-media effects
By counter rotating eccentric weights the vibrator generates vibrations higher than the eigenfrequency of the surrounding ground, by this the risks of damages on the surrounding environment and buildings with regards to vibrations are reduced.

Operational data
The vibrator can be used as other vibrators and additionally the static moment can be adapted with respect to individual conditions. The static moment of the vibrator can be changed between 0 and 100% by turning the eccentric weights. The output of the vibrators is increased up to a maximum of 2600 revolutions per minute, whereas fuel consumption and emissions remain as for conventional vibrators, which generate outputs around 2000 revolutions per minute.

Applicability
The vibrator can be adapted to the individual conditions on site. Hence the vibrator with a variable static moment is suitable for piling and extracting of diverse methods to secure foundation trenches and pit walls, such as steel sheet piles, casings, beams and other carrier sections.

Economics
Not available.

Driving force for implementation

Not mentioned.

Reference organisations
ABI GmbH: www.abi-gmbh.com

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3.2.6 Transportation system

3.2.6.1 Fuel-efficient truck

Description
For the transport of construction materials and elements to and on construction sites trucks are usually used. The major environmental impacts of these trucks, generally equipped with diesel engines, are air pollution emission, such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) and particles, caused by the combustion of the fuel-hot-air-mixture within the combustion chamber of the diesel engine. Hence the amount of gasoil consumption and the amount of ejected emissions have to be reduced for environmental purposes. Therefore a fuel-efficient truck is been invented, which consumes 2-5% less energy (less gasoil) than standard trucks with the help of an enhanced drive system. Additionally non-poisonous and odourless urea solution is injected into the hot exhaust line. This technology reduces emission of noxious NO_x.

Achieved environmental and health benefits
The fuel-efficient 40-ton truck consumes less than 20 liters fuel per 100 km, which corresponds to less than 0.8 liters per 100-ton-kilometers (tkm) and result in relatively little CO_2-emissions between 20 and 35 g/tkm depending on the driving conditions. In connection to standard trucks the fuel-efficient truck consumes 1500 to 2000 litres less gasoil per year or depending on the number of operations and can save therefore up to 5280 kg CO_2-emissions per year. Due to the innovative technology, where non-poisonous and odourless urea solution is used, NO_x-emissions are highly reduced.
Environmental indicators

- CO_2-emissions: 20 and 35 g/tkm
- Fuel-efficiency: 0.8 l/100tkm
- NO_x-emissions: reduction up to 80%

Cross-media effects
Not mentioned.

Operational data
The basis of this innovative truck is a new diesel technology, called BlueTec, including two nitrogen reducing systems. Other innovations in the engine, such as a new automated gear drive, computer-regulated air control and a regulated water pump, do increase the energy efficiency and reduce emissions as well. An active brake assistant helps to reduce unnecessary fuel consumption and emissions.

Applicability
There are no differences to other trucks regarding the applicability of the energy efficient truck.

Economics

Fuel consumption accounts for about 30% of the total costs of a truck. Energy reductions of 2-5% correspond to 1500-2000 litres less gasoil consumption of a truck per year depending on the number of operations. With an average gasoil price of €1.16 in Europe, up to €2320 can be saved per truck per year.

Driving force for implementation
The driving forces are reduced total costs for the truck.

Reference organisations
Daimler AG

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3.2.7 Lifting system

Description
Forklifts are common lifting equipment on construction sites to lift and transport 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 pollution emission, such as carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (HC) and particles. To reduce the impact on environment, the amount of gasoil consumption and the amount of ejected emissions should be limited. Hybrid forklifts have been recently developed, including diesel engine coupled with a nickel-metal hydride cell (NiMH) battery and an electric motor, which reduce fuel consumption as well as emissions of 50% in comparison to conventional forklifts with normal diesel engines.

Achieved environmental and health benefits
Emissions are significantly reduced by the hybrid forklift compared to conventional non-hybrid forklifts:

- CO_2 up to 57%
- NO_x by 99%
- HC by 99%

Especially the application of an electronically controlled throttle makes it possible to reduce the consumption of gasoil and therefore CO_2-emissions up to 15%. Besides minimised emissions, the operating noise of the forklift can be reduced with the help of sound insulation and absorption instruments.

Environmental indicators
Reduced fuel consumption [l/h] and emissions [kg/h], depending on the loading sequence, compared to current state of the art forklifts.

Cross-media effects
Not mentioned.

Operational Data

The new hybrid forklift possesses a 2.5-liter diesel engine coupled with a nickel-metal hydride cell (NiMH) battery and an electric motor. It is highly energy efficient, as it combines a series hybrid system for driving running on electric energy by the engine-powered generator and battery and a parallel hybrid system to handle load running with mechanical energy from the diesel engine and generator as well as with electric energy from the battery. Additionally, the forklift uses regenerated energy from the accelerator release and from switch back operation and the battery is recharged through the operation of the engine and not by plugging-in. The maximum load capacity of the forklift is 3,500kg.[104]

Applicability

The hybrid forklift is applicable as conventional diesel-powered forklifts.
At the moment the main market is Japan, but might be soon very popular on the European market, as the new European emissions standards ask for high reduction in emissions.

Driving force for implementation

Driving forces are the new European emission standards.

Reference organisations

Toyota Motor Europe

References

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4 OPERATION, MAINTENANCE AND REFURBISHMENT

4.1 Introduction: Operation, maintenance and refurbishment

This section concerns the operational and utilisation phase of a building, the use and the management of its facilities, as well as their maintenance and refurbishment. In a perspective of sustainable construction, attention is usually focused on new buildings. Nevertheless, existing buildings account for the greatest share of total buildings energy consumption. However, this section does not only concern existing building, but also buildings under planning, which can be designed in order to optimise their operation phase.

4.1.1 Definitions

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 lifecycle (50-100 years).

Building maintenance is the combination of all technical and associated administrative actions during the service life to retain a structure in a state in which it can perform its required lifetime quality. In the specific context of sustainable building, maintenance has for objective the duration of the building's environmental performance. The long-lasting effectiveness of the techniques implemented in the building during the design stage depend on maintenance and care activities such as cleaning, control, troubleshooting, repair, or the replacement of components.

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[13].

Refurbishment (also called **renovation or refitting**), refers to the modification and improvement of an existing facility or part of it to bring it up to an acceptable condition and quality level.

4.1.2 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"[105]. Maintenance management aims at verifying that all technical equipments are functioning efficiently, and restoring to good condition any part of a building that is in any way defective.
Maintenance includes technical actions as well as administrative, managerial and supervision actions.

In the European Construction sector, maintenance and repair activities account for 40 to 60% of buildings construction costs. This reveals the need for improvements in the durability and efficiency of building design; see section 2 on building design for more information on this topic.

The costs for inspection, maintenance and operation involve significant expenditures. Several examples from 1998 are given by the Guideline for Sustainable Building released by the German Ministry of Transport, Building and Housing:

- Electricity/cooling: (15 - 40 €/m2 per year) [106]

[105] Definition by the European Federation of National Maintenance Societies.

[106] These results were calculated for the main utilization area (including habitable and living rooms, offices, technical rooms, storage rooms, etc.).

- Cleaning: (15 - 35 €/m2 ·year)
- Inspection and maintenance: (5 - 35 €/m2 ·year)
- Value-conserving building maintenance: (5 - 15 €/m2 ·year)
- Heating: (5 - 15 €/m2 ·year)

The building technical equipment and systems covered by building maintenance are mainly:
- 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

4.1.3 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 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, the purchase of land. Those services generally not belong to the core activity of the building's owners, who chose to outsource them to an external organisation specialised in Facilities Management.

Facilities Management covers three main areas of activity [102]:
- 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, reproduction, sweeping, snow and ice control, relocation management, operating washroom and shower facilities, etc.
- Commercial facilities management embraces the commercial services related to 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 for sustainable building by reducing the environmental impacts of buildings and extending their lifecycle.
Facilities Management covers the whole lifetime of a building (design, planning, construction, operation, refurbishment, and deconstruction). The focus lies however on the operation phase, which lasts the longest (usually several decades) and the most important in terms of costs.

Facilities Management is a continuous process, seeking continuous improvement, which bases on monitoring, evaluation, and anticipation (forecasting the buildings' future requirements). Facilities management allows the availability and the supply of all information and data on a building management.

<u>Further issues that are not regarded here:</u>
- winter services

- green area management
- street -cleaning

Computer aided facilities 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 intelligent building.

CAFM allows the automation of all functional processes of a building according to pre-adjusted values or parameters. This implies the integration in a network of all sensors, control elements, user parameters and other technical devices.

CAFM tools concern all aspects of facilities management. In the context of intelligent building, the advantages of CAFM are:

- A better monitoring, controlling of electrical and mechanical equipment
- A better data collection on performance and energy use
- "real time" data synchronisation
- Accurate report for data managers
- Provide access to corporate applications, e-mail and intranet
- 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

Nowadays, facilities management increasingly uses wireless technologies, which have many advantages:

- Cost reduction through automation of all the building's systems
- Central monitoring and control, which allow a better overview of all data
- Wireless technologies do not require cable-laying and therefore no complex installation : they are able to connect all parts of the building rapidly and economically.

References

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4.2 Key environmental issues

The utilisation phase of the building is the longest of its lifecycle, generally lasting many decades, and has many environmental impacts, accounting for the greatest part of a building' energy consumption. The main environmental impacts occurring during the operation phase result from the operation of building facilities, which requires the consumption of electricity or water resources. Besides, a great number of pollutants are emitted and a large volume of natural resources are consumed.

4.2.1 Energy efficient use of facilities

Environmental impacts of energy consumption
The main environmental impact of building operation is the consumption of energy from fossil sources for electricity, which are non-renewable and are becoming scarce and increasingly expensive. Moreover, the combustion of fossil sources contributes to the emission of greenhouse gases which deplete the ozone layer and cause climate change, and the release of air pollutants sulphur dioxide and nitrogen oxide which are responsible for acid rains. Through the consumption of electricity from the network, buildings also contribute to the production of nuclear energy and consequently to the production of radioactive waste.

Main parameters
The main components of energy demands are heating, heating of drinking water, electricity for lighting, ventilating cooling, as well as conditioning systems.

Legislation
The European directive 2002/91/EG foresees the introduction of user-oriented Energy certificates.

General recommendations
The Guideline for Sustainable Building released by the German Ministry of Transport, Building and Housing formulate many requirements for Energy Conserving Characteristics of Buildings.
First, the energy requirement of a building should be reduced from the design stage**.** The architectural design (mainly the building insulation) has an effect on the energy consumption during the utilisation phase for heating, cooling and for the electricity needed for lighting and mechanical ventilation. Other recommendations are formulated in this guideline regarding buildings' requirements for heating, water heating, electricity, cooling.

For more information on building design, refer to:
- section 2.1.6 on heating, ventilation and air conditioning
- section 2.1.7 on lighting
- section 2.1.9 on water systems

The energy requirements of a building can also be minimised with an efficient energy management, which is an integral part of the goal of facility management.

The main technique used for energy management are building automation through energy or building management systems, which enable the integrated control and monitoring of all automated components (e.g. boilers, cooling plants, ventilators, pumps, single-room control systems, lighting control systems, etc). For more information on building management systems and energy management systems, see section 4.4.3.1.

References
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4.2.2 Use of renewable energy

The production of energy from fossil fuels is responsible for the vast majority of carbon dioxide emissions worldwide. Beside this, fossil energy sources are becoming scarce and less affordable throughout the world. To face the scarcity of energy resources and reduce environmental impacts of energy consumption, it is nowadays possible to use energy from renewable resources such as solar energy, wind energy, hydroelectric energy, geothermal energy, biomass or end-use waste heat.

Main parameters
The most frequent renewable energy sources for building operation are solar energy for heating, and wind or water energy for energy accumulation. Environmental techniques for the production of renewable energy can be implemented during building design. For more information, refer to section 2 on building design. In the context of procurement, it is also possible for facilities manager to purchase green electricity from the market. For more information on this topic, see section 4.4.2.3.

4.2.3 Indoor environmental quality

Indoor environmental conditions are determinant to users ‘comfort. They also influence their living quality or productivity at work. Finally, they raise many health issues.

Acoustics
In buildings with poor acoustic isolation, 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 proper design features (e.g. sound insulated windows), whilst allowing users to keep hearing the interior environment and outside by perceiving the signals which are useful for them or which they consider interesting. Acoustic comfort also depends on the local conditions, of the adjustment of the rooms and the characteristics of the building itself.

Some buildings and construction are hosting activities which are source of noise, and a poor noise insulation conditions or a bad location can induce neighbouring conflicts due to noise emissions.

Odour emissions
During the operation 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 construction are hosting activities which are source of smell, and a poor isolation or a bad location can induce neighbouring conflicts due to these emissions.

Indoor air quality
Air quality on the premises is a determinant of user’s health. Through the use of cleaning products or paint, containing hazardous or toxic chemicals, building operation causes can potentially be harmful to the users’ health. Poor air ventilation can induce health risks such as respiratory systems diseases and allergies. Besides users’ health, the emission of chemical compounds can negatively impact the environment.

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 the acclimatization: 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 involves values between:

- Temperature: between 19 and 24°C.
- Air humidity rate : between 30-70 % RH (relative humidity)
- Air velocity: 0.2 m/s.

These values can be measured with appropriate devices (respectively thermometer, hygrometer, and anemometer). These comfort parameters can be regulated through the use of a building management system. Please refer to section 4.4.3.1 for more information.

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 offers great potential in terms of energy efficiency (see section 4.2.1)

4.2.4 Water use

Regarding water use, please refer to section 2.1.9.

4.2.5 Waste production

Large quantities of waste are produced during the operation phase of a building, resulting 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.), the maintenance or activities of refurbishment of the building.

Waste trashing contributes to the pollution of air, water and soils. Waste disposal also has indirect aspects such as energy consumption and emission of pollutants in transportation and manufacturing processes. To reduce these impacts, the objectives of waste management are, one 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).

4.2.6 Cleaning activities

Cleaning activities are particularly relevant in terms of environmental impacts. Regarding building operational costs, cleaning activities are the second most important expenditure after electricity (consumption of water and electricity not included) [20, BBSR, 2009a]. Their environmental are also significant. 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, which are responsible for air pollution, ozone formation, bioaccumulation or even hazardous effects on aquatic organisms.
Besides, cleaning activities are 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 the users' health. Cleaning services also raise the issue of waste, especially regarding packaging of used cleaning products. Finally, cleaning activities can lead to noise and dust generation. Cleaning activities impact cleaning staff's performance and ergonomics.

To reduce the environmental impacts of cleaning activities, it is possible to design the building as to facilitate cleaning activities (see section 4.3.1.2) or to purchase green cleaning services (see section 4.4.5).

References

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4.3 Relevant activities for sustainable building operation and maintenance

It is possible to minimise the environmental impacts resulting in the operation phase during the building design phase, e.g. by implementing energy efficient facilities (please refer to section 2.1.3 on Ecodesign). But even the sustainable design and construction of buildings is no guarantee for a later sustainable operation of the building. Approximately 20% of the green buildings fail to meet their planned target values and partly even the minimum requirement[107]. Once an environmental building is constructed and the operation 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 play a key role in sustainable building, guaranteeing the long-lasting environmental performance of buildings and the effectiveness of the environmental techniques implemented in the building during the design stage.

For a building to be environmentally efficient, it has to be operated and maintained properly by the users. Studies have shown that in many buildings, the introduction of environmental and saving measures in their operation management can reduce the building's electricity and heat consumption by 10 to 20%.

4.3.1 Building design

In order to optimise building operation, facilities management takes into account the whole design of the building, and starts with the design stage.

4.3.1.1 Design for maintenance

Maintenance activities can be facilitated when considered during the design stage of the building, e.g. by designing the building as to guarantee a good accessibility for cleaning, inspection, maintenance, and repair activities. On the 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 of technical rooms accesses
- The accessibility to 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 reducing users' 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. Finally, building design can enable a certain anticipation of maintenance activities by involving the building's owner and take their experience and expectations into account in the design process.

4.3.1.2 Design for cleaning

In the context of design for maintenance, cleaning can be taken into account as early as in the design stage of buildings in order to facilitate the cleaning work during building operation.

[107] According to an evaluation of buildings certified after green building standard LEED.

Cleaning requirements can be considered as criteria during the design stage so as 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, hardly accessible areas or edges, as well as interior installations (e.g. toilet bowls) which can hinder cleaning when not placed properly. As an example, stairways should be designed with lateral 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 material 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 optimization of cleaning process. Cleaning rooms should provide sufficient space for the storage of cleaning products, devices and machines. 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 or floor mats in the entrance area to reduce and wetness entering into the building; the roofing of the entrance area,
- Self cleaning facades, roofs or windows, made of self-cleaning glass (this technique is described in the following section 4.4.5.1).

4.3.1.3 Design for energy efficient operations

In order to optimise the environmental performance of a building during the operation 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, from example through building simulation. Facilities management consists in managing all buildings' facilities as a whole under consideration of sustainability aspects. Each investment is considered taking into account the functionality of a building instead of its construction. Building operation costs depends on most design choices, such as the type of building envelope, the lighting systems, windows, doors, bathrooms, HVAC systems etc. For more information on building design, please refer to section 2. Through an integrated planning and design approach, it is possible to plan and optimised all tasks of a building's operation as a whole. For example, a high insulation façade with integrated sun protection can be installed in order to reduce the number of interior heating and cooling systems. The main instrument for integral planning is building simulation: see section 4.4.1.1 on simulation based building design.

4.3.2 Maintenance management

In the context of sustainable buildings, the role of maintenance is to ensure that all environmental performances planned during the design are lasting through the operation phase. In this perspective, the activities of building maintenance include:

- The cleaning, control, troubleshooting, repair, or the replacement of components of the buildings' equipments and systems
- The control and monitoring of the building's consumptions
- The control and monitoring of the building's environmental performance

From an ecological perspective, an effective maintenance is one that fulfils the following criteria [48]:

- Optimised maintenance needs
- Low environmental and health impacts of the products used and processes implemented
- Execution guaranteed in all situations
- Monitoring to maintain performances
- Access to equipments and systems

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 (see section 4.3.1)
- To enable control and monitoring of the building consumption and environmental performances during the operation phase (see section 4.3.3).

4.3.2.1 Definition of a maintenance strategy

There are generally 3 possible types of maintenance strategies: corrective maintenance, preventive maintenance and predictive maintenance [106].

Corrective maintenance covers the actions taken to restore a failed system to operational status. This usually involves the repair or replacement of the component(s) responsible for the failure of the overall system. Since component's 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's users in their activities.

Preventive maintenance consists in 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 risks of breakdowns, increase reliability and equipment life. The schedule for preventive maintenance is based on the knowledge acquired through monitoring of the system, for example regarding component wear-out mechanisms. Since preventive maintenance is performed before a failure occurs, consequential damages are minimized as well as risks to users' health. Preventive maintenance is performed at regular intervals, and can be scheduled at a time which is convenient to buildings' 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 also very demanding in terms of labour and spare parts.
Predictive maintenance (or condition-based maintenance) consists in 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 a detailed monitoring of the building's envelope (walls, roofs, floors) and the buildings 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 (see section 4.3.3).

Preventive and predictive maintenance are proactive strategies, which offer many environmental benefits such as:

- The extension of the building's equipment and materials lifecycle
- The reduction of solid and hazardous waste production
- The continuous energy efficient operation of the systems
- The avoidance of negative effects on occupant's health by preventing disruptive failures (e.g. of HVAC systems since they are determinant of air quality).

Preventive and predictive maintenance are therefore the privileged maintenance strategies for sustainable building, the challenge for facilities 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 operation and maintenance plan.

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4.3.2.2 Maintenance planning

To allow optimal efficiency and continuous improvement, maintenance and repair activities must be planned, documented and monitored. This requires the implementation of an appropriate operation and maintenance plan (O&M plan).

For an efficient building operation and maintenance, the planning and monitoring of maintenance activities play a central role. As soon as a building enters its utilisation phase, a planning is established regarding small, medium or large maintenance interventions in the future. This planning is based on the experience and knowledge on facilities lifetime and maintenance requirements.

The O&M Plan should contain a schedule of all preventive and predictive maintenance activities for all Buildings 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 preventive maintenance and care plan during the design stage of Energy efficient buildings [48], which addresses to building owners or facility's managers to help them maintaining the building operation and detect predictable equipment wear and degradation. This plan includes a list all interventions to perform and their frequency, and must underline particular maintenance requirements for specific components or equipment regarding fire security.

O&M planning is based on the continuous monitoring of the building's equipment performance. In association with alarm signals, monitoring enables the early detection of defects or failures and helps planning predictive or preventive maintenance activities in order to repair defect components before the system fails.

Checking a building's operation efficiency also implies redefining maintenance to include operation activities. To this purpose, additional controlling procedures are undertaken to check the operation efficiency of the facility's operation instead of only focusing on its maintenance. In order to check the building's 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:

- Reviews of HVAC and lighting schedules, temperature set points,
- Diagnoses of the users'/tenants' requirements to perform demand-oriented management and ensure that equipment runs only when needed.

The O&M plan must be adjustable to changing users' needs and allow the modification the HVAC, lighting, electrical, telecommunications, safety, housekeeping, and building automation control systems. Like maintenance tasks, controlling strategies should be reviewed and adjusted seasonally, depending if it is 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 identifying successful intervention and judge the quality of different actions undertaken. Maintenance monitoring is the main condition of an effective preventive maintenance. Maintenance actions and information on 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 a building maintenance, which can be useful for future interventions. Maintenance planning also requires the regular training of the maintenance and facilities management staff in order to perform and document maintenance activities.

Besides maintenance and repair activities, O&M planning should also include procedures and recommendations regarding:

- Waste management: see section 4.4.4
- Cleaning activities: see section 4.4.5

4.3.3 Operations monitoring

4.3.3.1 Monitoring of the building's consumption

The monitoring of the building's consumptions (water, energy) helps to avoid uncontrolled consumption of resources and contributes restraining resource exhaustion.

Different metering systems are implemented to monitor the building's consumption of water, energy. Traditionally, each different energy types are measured by a specific meter, differentiating: electricity; energy for heating such as gas, fuel, district heating; energy for cooling such as district cooling. More sophisticated metering systems allow sub-metering by substantial uses (cooling, lighting, water heating, 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 consumptions 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.).

4.3.3.2 Monitoring of the building environmental performance

Monitoring has a central role in sustainable building. During the operation phase, it is particularly important to monitor the consumption of resources (energy, water) and operation costs, in order to allow the ecological assessment of the building.

Monitoring and control of the comfort parameters: The objective is to guarantee the duration of comfort parameters and optimise equipment operation. All production systems of the building must comply with regulations regarding the programming of comfort parameters (temperatures, flow rate, etc.) and the operation time of the equipment. More advanced systems allow to monitor and control of the comfort parameters for each sector (or even for each room) of the building by optimising the operation of the building's systems according to the occupation of each area. This optimisation can be implemented for the following systems:

- Heating / cooling (via temperature monitoring and control)
- Ventilation (via flow rates monitoring and control and optimisation of the ventilators operation time)
- Lighting (via lighting systems monitoring and control).

Monitoring and control of the building systems: The objective is to enable the optimisation of systems during building operation phase and the detection of failures. 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 2.6.1). Advanced systems also allow the adjustment of HVAC systems, the monitoring of the equipment operation (visualisation, overview), or the management/optimisation of the energy supply contracts.

- Heating and cooling systems, for example:
    - Controlling for several parameters (occupancy and other parameters such as room).
    - Filter pressure drop indicators (prevention of plugging in case of air filtration).
    - Monitor and control hygrometry
    - Possibility for the user to adjust the room ambience (thermostats, timing systems, etc.).
- Ventilation systems, for example:
    - Filter pressure drop indicators (prevention of plugging in case of air filtration).
    - Measuring systems for air velocity, ventilation operating mode, air quality (CO_2 sensors, etc.).
    - Installation of a flow manager (to adjust the volume to extract to the reel needs depending on humidity and temperature) to adjust ventilation.
    - Controlling for several parameters (occupancy and hygrometry, ventilator controlled by heating systems, etc.).
- Lighting systems, for example:
    - Management of light grade depending on desired ambiance
    - Optional measurement of lighting
    - Management of solar protections according to interior lighting
    - Controlling for several parameters (brightness, occupation, etc.)
    - Lighting control from any location
    - Automatic grading systems controlled by brightness
- Water management systems, for example:
    - For temperature control of the whole hot water circulation network: installation of a system for surveillance and automatic management of cold water network coupled with a system for repatriation and treatment of data.

Reference literature
[50] CSTB (2009) : Guide Pratique du Référentiel pour la Qualité Environnementale des Bâtiments – « Salle multisports », CSTB, © Certivéa – December 2009.
[48] CRTE (2009): Centre de Ressources des Technologies pour l'Environnement (2009): Leitfaden für nachhaltiges Bauen und Renovieren Version 2.01, www.crtib.lu/leitfaden, accessed: 14.06.2010.
CSTB (2004) : Référentiel technique de certification "Bâtiments Tertiaires – Démarche HQE®"Bureau et Enseignement, CSTB, 2004.

4.3.4 Refurbishment

The management of the existing building stock offers a great potential for sustainable building in Europe. With a annual increase between 0.8 and 2 percent annually, the European residential building stock is renewing rather slowly. Moreover, 70 percent of the existing buildings are older constructions, built before the first energy crisis, while one-third of the dwellings are over 50 years old. Old buildings often raise the issue of occupants' comfort and health, when equipped with obsolete lighting systems, inefficient ventilation, heating and cooling systems, or a bad insulation. They often do not meet the actual standards in energy efficiency.

In terms of costs, the most effective solution often appears to be the demolition and reconstruction of these buildings. But this option leads to massive waste of materials and resources, longer construction works and stronger neighbourhood disruption, as well as cultural and architectural loss. The refurbishment alternative mostly proves to be the most sustainable solution. Actually and in the decades to come, the refurbishment of the existing building stock to respond to the actual requirements in terms of sustainability is a central issue for the European construction sector.

In the context of sustainable building, the role of refurbishment is not only to contribute making existing buildings more energy efficient, it can also minimise all environmental impacts of a building, increase users' comfort, increase the building's indoor environmental quality and prolong its lifecycle (see green retrofitting).

4.4 Available Techniques and processes concerning operation, maintenance and refurbishment

4.4.1 Building design

4.4.1.1 Simulation based building design

Description
Building design increasingly builds on dynamic simulations of buildings and their facilities. Under consideration of dynamic conditions such as wind, temperature, radiation, operating and use conditions, it is possible to represent in models, to study and to optimise different construction measures regarding energy demand and users comfort. Energy simulation systems usually consist in software systems with modular structure to 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 projects, 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.

Achieved environmental benefit
Through the analysis of different building configurations, different occupation scenarios and the thermal behaviour under dynamic conditions, energy simulation systems can help taking into

account energy efficiency during building operation at an early design stage and help reducing considerably the energy needs of the planned building. Simulation based design is a great support to the integrated design of buildings, which takes into account the complete life-cycle analysis of the building.

Environmental indicators

-

Cross-media effects

-

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 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 most impacting cold bridges, different ventilation and heating strategies, etc.

Applicability

Energy simulation systems can be used for the design of new buildings as for refurbishment projects. The new generation of advanced energy simulation systems (see BENOSim) also support simulation at district and neighbourhoods level. Energy simulation systems are an efficient decision system, allowing the design team to provide their clients with relevant energy consumption data at the initial concepts stage. This brings a valuable support for decision making regarding building form and building materials considering both economic and environmental: building owners can make an economic decision regarding design choices, while optimising energy efficiency and occupants comfort.

Economics

Significant energy savings can be achieved through optimal energy consumption, simulation, optimisation and configuration of new buildings and refurbished old buildings. Simulation based design helps architects and building owners calculate exactly how much savings can be realised by implementing a considered energy efficiency solution and compare different design choices in terms of energy efficiency and costs.

Driving force for implementation

Legal requirements concerning the energy efficiency of buildings.

Developing techniques: holistic energy simulation system

The energy simulation software actually on the market simulate only isolated parts, e.g. design (space), heating, lighting, ventilation, moisture, etc. However, the new generation of energy simulation software will be interoperable between different tools and offer different simulation levels as for energy management between buildings and district. This is the case of BENOSim, a holistic energy simulation system that covers all relevant discipline areas throughout the lifecycle of a building, and which is presented in the REEB Best Practice Report (European strategic research roadmap to ICT-enabled energy efficiency in buildings and construction).

BENOSim (Built Environment energy Simulator) is an advanced energy simulation system for integrated building design. It has a modular structure with different levels (buildings, district and urban environments) and different user interfaces. Its main advantage is the support of hybrid modelling environments making optimal use of available data and supporting the interface between buildings, district and urban environments.

BENOSim can be used as a decision support for the design and operational phases of districts and buildings. The system takes into account not only technical data but also occupancy behaviour and human interaction with buildings. The analysis and optimisation of real-data enable the creation of a performance database and energy usage patterns, allowing lifecycle support through real-time information.

Reference organisations

Several case studies on energy simulation systems can be found in the download webpage of REEB (European strategic research roadmap to ICT-enabled energy efficiency in buildings and construction).

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 of heat pump and gas boiler, or blinds. This method enabled a reduction of the annual consumption of the building from about 250 kWh/m²/y to 60 kWh/m²/y.

Detailed information can be found in the download webpage of REEB on the following case studies:

- Cenifer Centre. ICT-s and architectonical solutions applied to renovation
- TRNSYS-powered positive energy building design
- EnergyPlus energy simulation software

References

Simulation of the impact of sound on building:
http://international.cstb.fr/frame.asp?URL=software/acoustics.asp

Simulation based design - simulation of lighting systems: In association with digital display technologies, the PHANIE® photosimulation software includes many modules to calculate and display the lighting of a room or building based on its architecture, natural or artificial light sources, furnishings, component materials and the influence of the climate.
http://international.cstb.fr/frame.asp?URL=software/lighting.asp

Holistic energy simulation systems:

REEB (European strategic research roadmap to ICT-enabled energy efficiency in buildings and construction):

[172] REEB (2009): ICT-based Energy efficiency in Construction- Identification of criteria and selection of Best practices. http://www.ict-reeb.eu/objects2/REEB_D21_IdentificationCriteriaBestPractices_updated_m20_CEApm_case%20studies.pdf

[173] REEB (2010): ICT-based Energy efficiency in Construction- Best Practices Guide, 2010. http://www.ict-reeb.eu/objects2/REEB%20D22_BestPracticesGuide_m23.pdf

4.4.2 Energy management

4.4.2.1 Decentralised ventilation and climate control of office buildings

Description
The decentralisation of ventilation and climate control mostly concerns office buildings. Traditionally, office buildings are equipped with heating and air-conditioning services, the air being channeled and conditioned centrally. With this technique however, buildings are equipped with decentralised ventilation systems integrated into the exterior wall. Separate devices are installed in each room to channel and condition the air decentrally, supplying each workroom with conditioned outdoor air.
The new ventilation systems are integrated into the exterior walls or floors. The main advantage is that these new ventilation systems can be controlled individually and be adjusted precisely to the operational requirements and to the user's demand. Each occupant can control the ventilation and temperature of their own office individually.
A heat pump can be integrated to these systems in order to recover heat and use it for concrete core temperature control or domestic hot water heating.

Achieved environmental and health benefits
Buildings with decentralised ventilation and climate control consume less energy than comparable, centrally climate controlled buildings. No more energy is used than necessary: the ventilation and air conditioning parameters are adjusted to user demand in each workroom and can even be shut down when a room is not being used. Office indoor air quality and comfort are maximised since the ventilation systems are adjusted to users' heat and comfort requirements.

Environmental Indicators
- Reduction of energy consumption: KwH/m² per year

Cross-media effects
The advantages of the systems are energy savings, increased air-quality and user comfort. Most surveyed operators were satisfied with the devices, but analyses108 also revealed occasional imperfections, such as excessive noise emitted by the devices or excessive dryness of air.

Operational data
The new ventilation systems consist in separate devices installed in each room and integrated either to exterior walls or floors.

Applicability
Decentralised ventilation systems can be integrated to all currently prevalent façade structures, under floors or in the parapet areas.The systems can achieve best results when integrated from the design stage of the building and coordinated with building design. Finally, these systems should be combined with user presence detectors to provide optimum efficiency.

Economics
Regarding equipment costs, decentralised ventilation systems are not more expensive than centralised ones. They do require a large number of individual devices, but then no such components as the HVAC equipment of centralised systems. During operation, decentralised

[108] The Steinbeis Center for Energy, Building and solar technology investigated 16 building equipped with decentralised ventilation systems in order to evaluate the performance of the systems in terms of comfort and energy consumption, through on-site audit and occupant survey.

systems allow significant energy and costs savings due to shorter running times. The investment per device lies between 1140 and 2400 Euros (according to the 2006 building cost index, for three building. Source: BINE Projektinfo 13/09).
It is recommended to replace filters every year, otherwise the amount of electricity consumed can rise drastically: filters in end of life can increase the electricity consumption by up to one third. Due to the large number of separate devices, actual models require about twice more time for maintenance and replacement of filters. However, this difference is decreasing with newer devices.

Driving force for implementation
- Augmentation of occupant's comfort and productivity
- Reduction of heating and cooling energy demand

Reference organisations
Honeywell Control Systems: www.honeywelluk.com
Siedlungswerk office building in Stuttgart, Germany

References
[29] BINE (2009b): BINE Projektinfo 13/09: Decentralised Ventilation and climatisation of offfice buildings, Gerhard Hirn, FIZ Karlsruhe, 2009. http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2009/Projektinfo_13-2009/projekt_1309_engl_internetx.pdf

4.4.2.2 Energy-efficient lighting control systems

For more information on lighting control systems, please refer to section 2.5.4.

4.4.2.3 Purchase of electricity from renewable resources

Description
As a result of the liberalisation of electricity markets in the EU (directive 2003/54/EC now 2009/72/EC), consumers can choose their electricity supplier and have the possibility to switch for a supplier offering electricity from renewable energy sources.

Achieved environmental benefits
The consumption of electricity from renewable energy resources helps facing the scarcity of energy resources and reducing environmental impacts of energy consumption: climatic change, acid rains, to the production of radioactive waste and to depletion of the ozone layer

Environmental indicators
Percent of electricity bought from renewable energy sources (in the context of green public procurement, the European Commission recommends public authorities a minimal percentage of 50% electricity from renewable energy sources)

Cross-media effects
-

Operational data
Green electricity providers guarantee that at least 50% of the electricity provided comes from renewable energy resources (according to EU directive 2001/77/EC).

Applicability
Any electricity consumer can switch to green electricity supplier, although public and commercial buildings make a bigger difference when procuring green electricity since their demand is higher. To switch to green electricity provider, public organisations have to insert

green criteria in their public tender. Guidance for public procurers is provided on the European Commission's website on Green Public Procurement.

Economics

Green electricity is usually more expensive than conventional electricity, although the price difference is narrowing substantially, and in some cases it may even be available at a cheaper rate. Price differences vary from country to country, depending on the status of liberalisation and the availability of green electricity plants.

In the next years, electricity from renewable energy sources should become more and more competitive along with the increasing market liberalisation, the maturing of renewable energy sources generation technologies, and increasing fossil fuel prices.

Another possibility which is increasingly offered by electricity supplier, is to combine the procurement of green electricity with the introduction of energy efficiency measures in order to reduce electricity consumption needs.

Driving force for implementation

Reduction of the environmental impacts through the consumption of energy from fossil fuel resources

Reference organisations

European Commission: Green Public Procurement (http://ec.europa.eu/environment/gpp)

References

[110] ICLEI (2008b): European Commission Green Public Procurement (GPP) Training Toolkit - Electricity, 2008. http://ec.europa.eu/environment/gpp/pdf/toolkit/electricity_GPP_background_report.pdf .

4.4.3 Intelligent Building systems

The 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 include end user devices such as computers & peripherals, digital data recorder-storage-player devices, modems, phones and multimedia mobiles, fax machines, settop boxes and TV & peripherals. ICT infrastructure covers hardware equipment and software elements such as server and data centers, wired core telecom networks, cellular phone networks, Wireless Local Area Networks, Radio/TV broadcast equipment and micro systems.

ICT are closely linked to the concept of Intelligent Building, which is “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”[109].

4.4.3.1 Building management systems

Description

Building management systems (BMS), also called “building automation systems” (BAS) or energy management system (EMS) are the central tools of an intelligent building. BMS are central computerised systems for managing and operating various equipments within a building. They aim at optimising the operation phase of a building, through the monitoring and control of a building’s mechanical and electrical systems. Energy optimisation is one of the main functions of BMS, with the objective to achieve an optimal level of control of occupant comfort while minimising energy and resources consumption.

In an “intelligent building”, the BMS can be compared to the nervous system of the building since it registers all information and reacts to it. The main functions of BMS are computer-based monitoring and controlling, as well as building automation.

The monitoring function of a BMS allows to collect, handle and analyses users’ 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 verifying if building users are using the facilities in an efficient way. The energy monitoring function of BMS has many advantageous functions for the building tenants/facilities managers:

- A rapid overview of the consumption of water, electricity, heat and gas
- The identification of problem areas and sources of error
- Supply of comparative data for specific energy consultancy from the energy manager
- Optimisation proposals for the operation and the use of the building
- Representation of the cost-effectiveness of planned measures by simulating the targeted situation

BMS also usually include automation functionalities, such as controls for air conditioning, heating, cooling, ventilation, lighting, energy production and storage, maintenance management, security, access and fire systems. A basic example of energy efficiency solution based on building automation is lighting based on occupancy.

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.).

Fundamental control systems include technical functions such as:

[109] European Intelligent Building Group.

- 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, outdoor lighting) 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 CO2 levels in the rooms or humidity
- Optimum start/stop: definition of the optimal time to gradually start 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 towers 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 the building's 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 system, 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 shutdown 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 4-1). 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 manager to monitor and control the whole building from a single interface, either on-site or remotely over the Internet.

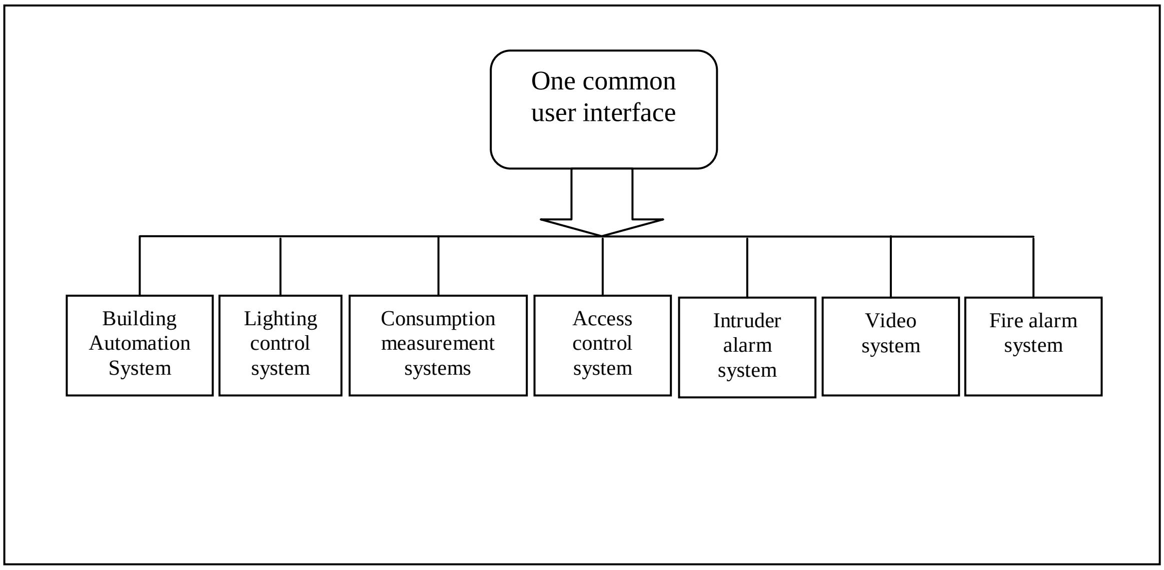

Figure 4-1: Integrated building management system

Home automation systems

Home automation system also called "domotics" or „smart homes" is a type of building automation system designed for the use in residential dwellings and households. Like BMS, they are centralised computerised systems enabling the management of building equipments, 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 the lighting and heating/cooling control systems. However home automation systems generally integrate all electrical devices in 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 and health 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 saving as well as comfort increase within the living environment. By optimising comfort for users, BMS have positive effects on user's comfort and health. In office buildings, improving workers health can contribute to raising productivity in office building.

Environmental indicators
-kWh/m² saved per year

Cross-media effects
BMS are the most advanced solutions in terms of energy management. When a BMS is installed in the building, the following techniques are integrated in the BMS (via smart circuit breakers) and do not need to be implemented separately:

- lighting system control (see 4.4.2.2)
- decentralised ventilation and climate systems (see 4.4.2.1)

Operational data

In practice, the BMS can be connected to the buildings mechanical and electrical systems such as fans, pumps, mixing boxes, thermostats. The integrated systems of a BMS are for example:

- HVAC systems
- Lighting systems
- Fire protection systems
- Elevators
- Security systems
- Communication systems

The architecture of the BMS is made of the following major components: A data collection system for data gathering and dissemination. This consists in a great variety of sensors, which are implemented 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. A direct digital control systems 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 controlling action to undertake and sent the controlled device a signal for action.
- 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.

A user interface for the data analysis, which can contain different software modules energy management, maintenance, planning software to simulate, calculate and optimise the energy consumption of planned construction measures. A basic example of user interface can be the illustration of the different energy efficiency classes in form of traffic lights on the user's or facility manager's screen. The analysis directly shows where for ex. too much heat is flowing and the management can take action for regulation. Nowadays, BMS take residents and users more actively into account and their interfaces become increasingly user friendly.

Home automation systems have a similar architecture, with as main elements hardware controllers or software controllers, sensors and actuators. The system can either be centralized with one centralized 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 decentralized 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.
Wether in homes or larger buildings, the implementation of a BAS requires the installation of external sensors systems. They are mostly integrated during the design process, but it is also possible to integrate BMS to existing building, 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 can't begin during the planning phase, but during the inventory and audit phase. Integrated BMS solutions are designed for larger office buildings in the frame of total facilities management. Some advanced controlled applications can be added to the BMS through software change or update, without the need of additional sensor installation. BMS require the implementation of appropriate technical provisions in order to ensure the communication between different

technical components and functions on the one hand, and products from different manufacturing companies on the other hand.

Economics

For a BMS with fundamental control, the data collection devices are usually inexpensive, and despite an ineligible installation cost, 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 help achieving energy savings from 10% to 40% as well as reduce maintenance costs by 10% to 30%. The most challenging task for maintenance is the calibration of sensors, which requires a concrete maintenance program. Even though they are hard to detect through a simple maintenance inspection, calibration errors can induce massive energy waste, since all parameters are based on the data measures by the sensors. All EMS rely on sensors for proper feedback to adjust to efficient conditions. Therefore calibration activities play a key role in EMS. 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 being used for all systems (BMS, security and fire alarms systems) the installation costs are reduced. Integrated BMS have a lifecycle of over 30 years and allow a reduction of operational costs up to 35% annually. Additional cost-savings can be realised through the increase of employees' productivity.

Driving force for implementation

- Reduction of energy demand
- Reduction of building and infrastructural costs through the optimisation of all operational functions
- Comfort and time savings for the users: one contact person for all technical and facilities management issues.

Example

KENWO (kostengünstiges Energiemanagement-System für Wohn- und Bürogebäude) is an EMS designed for residential and office buildings, and based on a sustainable energy concept. KENWO focuses on energy monitoring (rather than automation): it collects, handles and analyses users' data, then alarms the building manager in case of failure or disturbance. One of the principal advantages of KENWO is that it allows energy controlling by new constructions as well as by existing buildings. The extern sensors systems used are cheap, which makes the implementation particularly cost-effective.

KENWO lays the focus on user friendliness, with simplified data collection, directly from the meters, simple software modules and a comprehensible analysis. In order to provide an overall assessment of results, a specific data handling software illustrates the different energy efficiency classes in form of traffic lights on the user's or extern manager's screen. The analysis directly shows where for ex. too much heat is flowing and the management can take action for regulation. Meanwhile, this system is being used in the housing industry, using inexpensive external sensors, since the system has a great number of interfaces and can be integrated into almost every existing system

Like all EMS, KENWO is equipped with a data collection system and a controlling system. Beyond this, KENWO offers original software components in the field of energy management, such as:

- A software module for the issuing of energy certificates
- A planning software to simulate, calculate and optimise the energy consumption of planned construction measures
- A multitenant consulting platform for the issuing of energy certificates as well as the energy assessment of buildings, enabling multiple clients/users to work on the same operating system, without having access to each other's data.

More information on the KENWO Project can be found in BINE Projektinfo 10/2008 (see literature references).

Reference organisations
Ennovatis GmbH (http://www.ennovatis.de)
Ecovert (http://www.ecovertfm.co.uk)
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4.4.4 Waste management

In order to reduce the burden of waste on the environment, the primary objective is to avoid excessive waste production. Beside this, suitable measures are reuse, recycling, valorisation, as well as environmentally harmless disposal of unavoidable waste. The design of buildings should include consideration of the environmentally harmless disposal of waste arising from the use of the buildings.

4.4.4.1 Waste management system

Description
Waste management systems aim at facilitating waste disposal and collection. They are based on an audit of the waste production which is used to optimise the collection process and to adapt the premises to separate collection of operational waste. Waste management bases on several sub-objectives:

- Waste avoidance as a procurement criteria
- Adaption of the premises to separate collection
- Monitoring of the waste production and collection
- Staff training for waste management

The primary objective is waste avoidance, which can be considered at an early stage, when fitting out the building. When procuring furnishings and technical installations, building users should consider the issue of waste as criteria and take into account the impacts on environment and health, the durability, and the possibilities of reuse and repair of the goods.

As for unavoidable waste, waste management aims at facilitating separate waste collection and disposal. At least the following waste materials should be collected separately: waste paper, glass (separated by colour), bio-degradable waste, light wrapping material ("Green Point"), residual waste,
waste which requires special supervision, and significant volumes of other use-specific waste.

To this purpose, the premises shall be adapted to separate collection. The premises must contain a waste storage room/area for separate collection, with different containers for each type of waste (glass, paper, metal, plastic, or reuseable/non-reusable). Adequate, large areas should be provided outside the building for standing of suitable waste containers. The design is to provide for extension areas for additional containers which may needed in the future. This storage room can be designed taking into account many parameters such as: amount of waste produced, types of waste, capacity, location, and maintenance of the storage room. These parameters can be estimated with the building users. In case the building contains several storage rooms, the waste is tracked to a central collection point on the premises before disposal.

The central point of the waste management process lies in the awareness raising and training of staff for waste separation, organisation of the storage process, monitoring of the waste production, etc.
Bio-degradable wastes (mainly from plants such as green waste, food waste, or paper waste when not suitable for paper recycling) should be composted on the premises. This requires regular maintenance and care, trained personnel and a sufficiently large storage area for the resulting compost.

Achieved environmental and health benefits

- Increased reuse and recycling rate through the facilitation of separate collection
- Reduced resources consumption
- Reduced air and soil pollution

Environmental Indicators

- Amount of waste produced per person per week
- Percentage of waste recycled

Cross-media effects

By encouraging higher reuse and recycling rate of operational waste, this process contributes reducing of air and soil pollution and the related negative impacts on human health. Moreover this process focuses on hygiene conditions in the storage process to avoid potential impacts on users comfort and health.

Applicability

Waste management is applicable to all types and sizes of building.

Economics

Waste management has no significant economic impact.

Driving force for implementation

Reduction of environmental impacts due to waste production and disposal

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4.4.5 Cleaning

4.4.5.1 Self-cleaning coating

Description
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 needs for cleaning and extends the lifetime of the facade 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 cleanings agents which might contain harmful chemicals for the environment.

Environmental indicators

- Percentage of water consumption reduction

Cross-media effects
-

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 coatings techniques do not demonstrate enough hydrophobicity to provide a total self cleaning effect[110]. 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 photocatalytic coatings, a type of hydrophilic coatings containing titanium dioxide (TiO2) 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 oxidized into carbon dioxide and water. Today's self-cleaning surfaces are made by applying a thin nanocoating film, 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.

Economics
By reducing water consumption for cleaning pruposes as weel as maintenance costs, self cleaning coating 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, has even tested TiO2 on road surfaces and found it reduced nitrogen oxide levels by up to 60 percent. At present, their self-cleaning facade system costs 30 to 40 percent more than regular concrete, but they believe that self-cleaning materials will save money in the long run[111].

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[110] Ivan P. Parkin and Robert G. Palgrave, Self-Cleaning Coatings, Journal of Materials Chemistry, 2005.

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Driving force for implementation

- Reduction of maintenance costs
- Reduction of water consumption (no water required)
- Reduction of water pollution since no cleaning agents are used

Reference organisations

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4.4.5.2 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, floors 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[112].

The different product categories must allow comply with the EU Legislation:

- 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 following aspects:

- **Use of the appropriate dosage of products**: Using cleaning agents in appropriate proportions can help saving considerable amounts of product and reduce the environmental impacts. Therefore, dosage instructions or suitable dosage

[112] http://ec.europa.eu/environment/ecolabel/index_en.htm

recommendations for every cleaning agent used should be defined in the 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 like microfibre cloths, synthetic fibre cloths or cellulose fibre technique cloths. These techniques facilitate the work of the cleaning staff, support ergonomic cleaning, increase productivity and may also contribute to reduce the use of cleaning agents and water.
- **Demand oriented cleaning**: Demand oriented cleaning aims at determining the best way to organise cleaning (frequencies and methods used) in order to respond to the user's demand for cleanliness while reducing environmental impacts. This implies redefining user's requirements for cleanliness: cleanliness standards for each room, the needs of the main users of the rooms, the frequency and type of cleaning wished.
- **Training of the cleaning staff**: The training of staff plays a central role in cleaning management. Cleaning staff are usually trained especially for security reasons, including an extensive introductory training for new cleaning staff and a regular training (e.g. once a year) for permanent staff. Information on green cleaning can be added to the topics raised during training, e.g. regarding new techniques and alternative cleaning methods, new and environmentally sound cleaning products, use of cleaning products in an ecologically sound manner, ecological and health risks associated with the active ingredients in the detergents used, dosage instructions and the use of dosage devices, awareness raising for the importance of use of protective equipment. Instructions and information should be translated also in appropriate foreign languages, when foreign personnel with a poor proficiency of the national tongue are employed.

For the healthcare of staff cleaning should be performed with the appropriate protective equipment like working clothes and gloves. Protective gloves and skin care products have to be made available for the staff and their use should be assured.

<u>Achieved environmental and health benefits</u>
Green cleaning can have positive effects on the health conditions of the cleaning staff and the building's occupants. Beside this, green cleaning can help saving water resources and reduce emissions of pollutants.

<u>Environmental Indicators</u>
- Water consumption
- Energy consumption
- Consumption of cleaning agents
- Biodegradability of detergents

<u>Cross-media effects</u>
Cleaning activities are a major factor of water consumption, as well as energy. Green cleaning can therefore help reduce energy and water consumption during building operation phase.

<u>Applicability</u>
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 antivirus is necessary. When cleaning services are done by an exterior company, any organisation can purchase these services from a company offering green cleaning services. Public organisations have to insert green criteria into their public tender; guidance on this topic is available by the European Commission's website on green public procurement.

<u>Economics</u>
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.

The use of cleaning agents takes on a special significance. Even if their environmental impact is consequent, the cost difference for the purchase of green cleaning products has a minimal impact on the budget. The price difference for purchasing green cleaning products is generally minimal and depends on the development of the market for green cleaning products
in the different countries. In the Nordic countries where the market is very developed, green cleaning products are cheaper than their non-green version113. On the other hand, behavioral changes of the cleaning staff may result in a reduced need for cleaning products and consequent cost savings.

Driving force for implementation

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5 BUILDING DECONSTRUCTION

5.1 Introduction: Building deconstruction/demolition

This section describes general issues about conventional demolition and selective deconstruction of buildings at the end of their life-cycle. Many issues are closely related to Design for Deconstruction and Reuse or Recycling (chapter 2.1.4), which aims at facilitating this concept already at the first stages of a building's life-cycle.

Deconstruction is the selective dismantlement of building components, aiming at their direct re-use, recycling, or more generally at mono-fractional separating of waste already at the source. Deconstruction focuses on giving the parts and materials within a building a new life by applying a "construction in reverse". Conventional demolition in contrast aims at the efficient removal of a building without special regard to recyclability of materials.

Direct (local) impacts of deconstruction/demolition [132, LIPPOK, 2004]

- **Dust:** During most deconstruction/demolition activities, the creation of dust as a local nuisance that can be harmful to health and can damage property is hard to avoid entirely. These dust emissions arise mainly from the breaking-up of mineral construction materials; they should be minimized 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 is less decisive than the creation of ultra-fine water droplets (high-pressure nozzles, air-assisted atomizing). Worker protection laws define maximum dust concentrations at national levels; example values for Germany are 3 mg/m^3 (exceptional level for certain construction and demolishing activities 6 mg/m^3).
- **Splinters and debris:** Splinters and debris are created when breaking materials and are only a problem for small areas around the demolition site. They can be a problem for high buildings and nearby roads; in these cases the enclosing of parts with demolition activities is recommendable.
- **Noise:** Most demolition activities create high levels of noise. Several (national) regulations concerning workplace safety and maximum noise immission have to be respected. Noise can be reduced by selection of demolition method, 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:** Vibrations are created by explosions, machinery, falling construction parts and transferred though the ground to surrounding structures. They can mainly be reduced by avoiding some demolition methods (explosives, jack hammers, demolition hammer)

<u>Selective deconstruction versus conventional demolition</u>

Selective deconstruction, the systematic disassembly of buildings in order to maximize reuse and recycling of recovered materials is emerging as an alternative to conventional demolition around the world. Whereas demolition of a building often leads to the mixing of various materials and contamination of non-hazardous components, deconstruction aims at separating materials at the source. The separation of building materials for recycling applications can alternatively be achieved by different 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 from the others, the achievable separation of the building materials is extremely high. But on the other hand an extensive dismantling leads to high personnel costs. Depending on the prices for disposal and recycling in the region the building is situated in, these personnel costs can more than offset savings caused by less expensive disposal. Selective deconstruction is described in more detail in 5.2.1. [192, SCHULTMANN, 2005]

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 an issue (construction near to traffic ways) or when requirements concerning quality of material streams are low. 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.

Recycling and reuse planning

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 a simple coordination. Several projects carried out in practice and analysed so far have shown a potential for further improvements concerning cost reduction as well as environmental benefits. Based on these results, computer simulations help to reveal improvement potentials for deconstruction[114].

In the UK, a so-called demolition protocol has been developed by the Institution of Civil Engineers 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 builds 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 re-use of elements can be a promising alternative if dismantling is well planned. [192, SCHULTMANN, 2005]

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 very structured approach using a demolition plan is essential for minimizing environmental impacts (i.e. mainly waste that is landfilled) when a building is demolished. Although developing such a plan costs time and money it will reduce the costs of landfill. The amount of a contract for a demolition project usually includes the cost of demolition (increased by planning) but also landfill cost (decreased by planning)

[114] A guideline and computer tool for deconstruction planning (in German only) is available 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 which procedure has to be carried out before the demolition of buildings containing the mentioned building elements. The guideline aims mainly to provide a decision support for the choice of the adequate demolition techniques. Therefore advantages and disadvantages of the different demolition techniques will be 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 contract letting of the deconstruction of a building, a calculation sheet for the determination of costs for demolition and recycling/disposal and a computer tool. The computer tool permits 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. 1. A rough estimation of costs and material composition of the building on the basis of the type and the volume of the building. 2. 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. [192, SCHULTMANN, 2005]

minus the revenues from salvaged parts and materials (increased by planning). Factors determining how a building will be deconstructed or demolished include location, type of building, construction method, materials used and the presence of any hazardous substances. [208, TE DORSTHORST, 2005]

Typical steps in a deconstruction or demolition project

As in practice a mixture of selective deconstruction and demolishing is often found and processes for both are similar, the general approach is described in the following (and in more detail in section 5.2.1). 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 hull is taken down floor by floor using suited deconstruction equipment (see 5.2.2 and 5.2.1). Finally foundations are broken up and removed by diggers or pulled out of the ground. [208, TE DORSTHORST, 2005]

Demolition techniques, methods and machinery

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. These techniques are described in more detail in section 5.2.2. Concerning differences between demolition and selective deconstruction, many processes are similar. There has always been some kind of 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 is still often performed manually or using light machinery that can operate on the building floors. For the final step of deconstruction, which is taking down the building's hull, similar methods are applied as in conventional demolition to the complete building. [208, TE DORSTHORST, 2005]

Deconstruction/demolition waste separation and recycling

The total amount of construction and demolition waste produced in the European Union in 1999 was about 450 million tonnes including earth and excavated road materials, and without these 180 million tonnes per year (480 kg per person each year) of 'core' construction and demolition waste. It is estimated, that this amount will have almost doubled in 2010. Recycling rates vary very much between different countries, but have generally increased in the last decade. Data from 2005 gave recycling rates between <20% (Spain) and 96% (UK), which has increased from <5% (Spain) and 45% (UK) in 1999. Construction and demolition waste has a very high recovery potential. However only a small proportion of these waste streams has been actually recovered in the EU as a whole in the past. In 1999, about 50 million tonnes of the 'core' CDW were re-used or recycled. The rest, 130 million tonnes, were incinerated or dumped on landfills.Table 5-1 shows some details for recycling rates in Member states. [79, ECTP, 2005], [207, SYMONDS, 1999]

Table 5-1: Member State core construction and demolition waste re-use or recycle million tonnes Percentage [207, SYMONDS, 1999]

Member State	„Core" construction and demolition waste [million tonnes]	Re-use or recycle [percentage]
Germany	59	17
UK	30	45
France	24	50
Italy	20	9
Spain	13	< 5

The Netherlands	11	90
Belgium	7	87
Austria	5	41
Portugal	3	< 5
Denmark	3	81
Greece	2	<5
Sweden	2	21
Finland	1	45
Ireland	1	< 5
Luxembourg	0	
EU 15	180	28

Reducing the amount of (construction and) deconstruction waste is not only an issue for deconstruction companies, but for the whole construction sector, as indicate these six core strategies [216, UBA-A, 2006]:

- avoid new construction
- use low-waste construction techniques
- use building efficiently
- use selective deconstruction
- collect mono-fractional waste streams
- recycle waste in high-grade applications

Demolition waste contains among other materials 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. A typical composition of demolition waste from a residential building is shown in Table 5-2. The composition of deconstruction waste strongly depends on factors like the kind 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 epoch has its typical building material, e.g. brickwork, steel skeleton or concrete, deconstruction waste will also change over time (tendency toward larger parts of concrete and plastics). More detailed information on deconstruction waste sorting and recycling is given in section 5.2.3.

[192, SCHULTMANN, 2005] [216, UBA-A, 2006]

Table 5-2: Exemplary composition of demolition waste from residential buildings [201, SPENGLER, 1995]

Material	Percentage in waste
Bricks and stones	50.2 %
Concrete	25.5
Wood	13.4 %
Gypsum and mortar	9.2 %
Steel	0.9 %
Plastics	0.6 %
Metals	0.2 %

<u>Pollutant sources</u>

Recycled construction materials from deconstructed buildings should be available in such quality, that they meet the required profile for natural construction materials. It should also be observed that both plain and mixed grades of building waste could contain pollutants, which could have negative environmental impacts during storage or re-use. These pollutants are contained in construction materials due to their natural material composition, or were artificially added during manufacture, for example in the form of additives. Nevertheless very few materials in demolition waste are invariably hazardous (as defined in European Council Directive 91/689/EEC). The major pollutant sources in buildings were identified mainly through studies and are to be seen in Table 5-3. A large share of pollutants is caused by surface area treatment such as paint. They are added partly for improvement and partly to protect the construction materials. [192, SCHULTMANN, 2005], [176, RENTZ, 1997], [189, SCHULTMANN, 1997]

Table 5-3: Potential pollutant sources in buildings adapted from [192, SCHULTMANN, 2005], [176, RENTZ, 1997], [189, SCHULTMANN, 1997]

Origin	Relevant Pollutants
Natural stone	Heavy metals
Gypsum	Sulphate, heavy metals
Easily-bond asbestos fibre 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

Key environmental aspects and performance indicators

- Reduction of waste by selective deconstruction and waste recycling efforts are the main subject of overall chapter and presented available techniques
- Noise and smell, air emissions (e.g. dust). These effects should be minimized by using suited machinery (see section 5.2.2). Concerning dust, special precautions should be taken like spraying water during demolition activities.
- Risks of accidents: Employing highly skilled workers, increasing mechanization using specially adapted tools and precautions in case of hazardous materials should contribute to minimize the risk of accidents.
- Reduction of transportation: The planning of deconstruction waste routes, its recycling and upgrading should consider environmental issues (CO_2, air pollutants, noise) of excessive transportation activities
- Energy efficient use of machines for deconstruction
- Soil pollution, contamination
- Deconstruction/Demolition Recovery Index DRI[115]: This index (percentage) represents the potential for recovering material from demolition for recycling or reuse, following the methodologies of the ICE Demolition Protocol. A collection of typical DRI values for standard practice, good practice and best practice is given in Table 5-4. [108, ICE, 2008]

Table 5-4: Potential demolition recovery indices/targets [108, ICE, 2008]

[115] www.ice.org.uk

Material	Standard DRI %	Good practice DRI %	Best practice DRI %
Concrete	75	95	100
Ceramics (eg. masonry such as bricks)	75	85	100
Metals	95	100	100
Timber	57	90	95
Inert (eg. subsoils)	75	95	100

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5.2 Available Techniques concerning deconstruction

5.2.1 Selective deconstruction of buildings

Description

The demolition of buildings, as it was done traditionally, 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 maximize 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 demolition of a building often leads to the mixing of various materials and contamination of non-hazardous components, deconstruction aims at separating materials at the 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.

Achieved environmental and health benefits

- Reduction of waste streams: Demolition debris is diverted from landfills, as mono-fraction waste from selective deconstruction can be recycled more easily
- 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.116
- 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) [198, SINDT, 1997]. Another issue are sulphates, which can be reduced by sorting out gypsum products.

Environmental indicators

Recycling rate (as a percentage): The main benefit and indicator of successful deconstruction is the percentage of recycled waste. Table Table 5-6 in section "economics" shows recycling rated

[116] www.buildgreennow.org

achieved during several case studies. The range of several national deconstruction waste recycling rates in Europe can be found in chapter 5.1 for comparison.
The quality of recycled waste and thus the increased number of potential uses is another important factor (several parameters relevant, depending on type of re-use).

Cross-media effects
No data available

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, a 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.
The challenges faced by deconstruction include the following issues, many of them are related to systematic planning for deconstruction and reuse already at the time of design of a building (see chapter 2.1.4). Existing buildings and building components have often not been designed for dismantling and special tools for deconstructing existing buildings are sometimes under development. A detailed planning of deconstruction including an evaluation of a suited scope of dismantling and checks of possible recycling options is recommendable and in general reduces overall economic efforts. This planning can improve economics, working conditions, worker safety and share and quality of recycled materials. Economically regarded, disposal costs for demolition waste are still frequently low but often government policy is beginning to enforce 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 can be an unknown cost factor (as is removing contamination from lead-based paint and asbestos containing materials).
[44, CHINI, 2005], [216, UBA-A, 2006]

In the following, aspects for choosing a demolition method are summarized:

- Economic aspects:
  - Demolition and dismantling costs: It must be distinguished 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 needs little dismantling, but leads to higher waste disposal costs, because the mixed demolition wastes must be separated in a more costly way and a higher share must be disposed (disposal costs are usually higher than the 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 a 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. They consist of costs for recycling and costs for disposal. Partly-selective and selective de-construction lead 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.
  - Costs for planning deconstruction/demolition activities: For selective or partly-selective deconstruction a detailed planning is advisable in most cases, because coordination is needed between the different steps. Often these higher planning costs do not 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.
- Environmental aspects

  - Recycling-quota: The recycling quote indicates the share of the whole waste of a building demolition being recycled. The quote of partly-selective and selective deconstruction is usually much higher than for conventional demolition.
  - Support of high-quality recycling: High-quality recycling is the second important factor besides the recycling quota, as it determines resource consumption. In most cases, high-quality recycling needs a mono-fraction material sorting.
  - Facilitated removal of impurities: Impurities can affect the quality of the recycling materials in a negative way. Typical impurities are gypsum, porous concrete, plastics and insulating material fibres. In selective and partly-selective de-construction these impurities are removed as far as possible.
- Other aspects:
  - Time frame for demolition measures: If only little time is available, conventional demolition can be chosen for this reason. However, adapted planning of the deconstruction works can also lead to reductions of deconstruction duration.
  - Regional recycling and disposal possibilities: A high-grade use of demolition wastes from selective deconstruction is only practicable economically if simultaneously high-quality recycling possibilities are available near the object at rational costs and the quantitatively important demolition wastes do not have to be transported over long distances.
  - Influence of building location and available space: Issues like space for containers or the use of heavy construction machines can lead to space problems. For example the machines for selective de-construction are often smaller and so this method is preferable if less space is available.

Demolition works create vibrations which are transmitted via the bottom to neighbouring buildings, pipes and wires. These can create earthquake-similar damages; most often this happens in conventional demolition. A summary of economic, environmental and other aspects for comparing different deconstruction/demolition strategies is given in Table 5-5. [126, LFU, 2001]

Table 5-5: Aspects for choosing demolition/deconstruction method [126, LFU, 2001]

	Conventional demolition	Partly-selective deconstruction	Selective deconstruction
Economic aspects			
◦ Demolition and dismantling costs	+	O	-
◦ Disposal costs	-	+	+
◦ Transport costs	O	O	O
◦ Planning costs for dismantling works	O	O	-
Environmental aspects			
◦ Recycling quota	-	+	+
◦ Support of high-quality recycling	-	O	+
◦ Facilitated removal of impurities	-	+	+
Other aspects			
◦ Monument conservation	O	O	O
◦ Time frame for demolition measures	+	O	-
◦ Availability of regional recycling and disposal possibilities	+	+	+
◦ Influence of building location and available space	O	O	O

Symbols:
"+" – positive influence of the demolishing method for the considered aspect
"O" – neutral or rather no conclusion possible
"+" – negative influence of the demolishing method for the considered aspect

The number ob dismantling steps necessary depends on the type of building; older buildings often consist of fewer materials than newer ones and require less dismantling steps. In general, selective deconstruction is done in the following steps:

- Check for hazardous substances: As a first step, the building has to be checked for any hazardous substances such as asbestos, which has to be removed by a specialist as 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 they are. 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 services installations and all other metal parts are removed (if accessible). Roof tiles or roofing gravel (reusable), roofing is removed and landfilled or recycled; if it is contaminated with PAH (polycyclic aromatic hydrocarbons, contained in tar) it has to be treated as chemical waste. In this step, all remainders are removed that could pollute the materials of the building hull.
- 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 as a 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.

[208, TE DORSTHORST, 2005] [216, UBA-A, 2006] [126, LFU, 2001]

Applicability

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 determining if a building is deconstructed are:

- 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

[197, SHELL, 2006]

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 lumber, 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 the plaster can be better sorted after the walls are taken down rather than being dismantled, at least from an economic point of view.

[192, SCHULTMANN, 2005]

Economics

Due to the high demand in manual labour or very specialized light machinery, a high degree of selective deconstruction is traditionally seen as a rather expensive solution. Table 5-6 shows data from several case studies.

Table 5-6: Overview of costs and recycling rates of several deconstruction projects ([189, SCHULTMANN, 1997] as cited in [192, SCHULTMANN, 2005])

No.	Country Year	Type of building	Construction	Volume	Dismantling Time, Projectdura tion [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%

Driving force for implementation

The increase of the construction materials recycling quota and thus the reduction of 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.

Reference organizations

No data available.

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5.2.2 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) is applied. In the following, different currently used deconstruction techniques are described with their field of application and specific (environmental) benefits and problems.

Achieved environmental and health benefits

See Table 5-7, Table 5-8 and Table 5-9.

Environmental indicators

An indicator for the environmental performance of a deconstruction/demolition technique is the percentage of total recycled demolition waste, or more specific the "Deconstruction/Demolition Recovery Index" DRI[117]: This index (percentage) represents the potential for recovering material from demolition for recycling or reuse, following the methodologies of the ICE Demolition Protocol. [108, ICE, 2008]

Further issues include:
- Noise and smell, air emissions (e.g. dust).
- Reduction of transportation
- Soil pollution, contamination

Cross-media effects
Some techniques use water (dust abatement, cooling, high pressure water cutting).

Operational data
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 in some extent before demolition. When a building is stripped and the structure should therefore remain intact, smaller equipment is used, which can move inside the buildings.

For the final step of deconstruction, which is taking down the building's hull, similar but often the rather selective methods (not explosives or balling) are applied as in conventional demolition to the complete building.
Recently, there has been a trend to replace labour with specialized 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 very expensive specialised equipment. Knocking down a building with a heavy steel ball (balling) is no longer widely used. 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 efforts.
Older buildings of non-complex construction are generally simpler to demolish, at least until toxic materials like asbestos is found. 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 hull) techniques. According to [Lippok], 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%).

[117] www.ice.org.uk

Table 5-7: Traditional methods of demolition [107, HURLEY, 2005], [132, LIPPOK, 2004]

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 ton suspended from a crawler crane	Fairly large, brick, masonry, (reinforced) concrete .	Remove floors as per hand Buildings > 30 m high should be reduced by hand before using ball. Detach from adjacent	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 / pulverizer	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 5-8: Demolition using explosives [107, HURLEY, 2005], [132, LIPPOK, 2004]

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 5-9: More recent methods of demolition [107, HURLEY, 2005], [132, LIPPOK, 2004]

	Tools/Equipment required	Application suitability	Preparation /procedure	Environmental and health criteria	Comments
Method Expansion/ bursting: Static	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.
	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
	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 r.c.	Uses large quantities of water	Expensive in comparison to other methods.
Heating	Thermic 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, omits 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
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	

Applicability

Some general judgements of preferred demolition techniques (list as in Table 5-10) based on demolition type, site, and object are given in the following (Table 5-11), as well as generally preferred techniques for demolishing or separating building parts (Table 5-12) and an evaluation of demolition techniques for constructions of mineral materials concerning economy and time effort (Table 5-13)

Table 5-10: List of techniques for demolition [132, LIPPOK, 2004]

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 5-11: Preferred demolition techniques for constructions of mineral materials according to building and site conditions [132, LIPPOK, 2004]

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 5-12: Preferred demolition generally preferred techniques for demolishing or separating building parts [132, LIPPOK, 2004]

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 5-13: Evaluation of demolition techniques for constructions of mineral materials concerning economy and time effort [132, LIPPOK, 2004]

Construction type	Cases (see below)	Demolition technique (see Table 5-10)												
		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	1	-	0	0	-	-	-	+	0	+	+	-	+	-
	2	-	0	0	-	-	-	+	0	+	+	-	+	-

Solid construction	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

Remark: For demolition of steel constructions, preferred techniques are deconstruction, steel shears, or pulling.

Economics
See Table 5-7, Table 5-8 and Table 5-9 for some indications; however no exact data is available.

Driving force for implementation
The selection of demolition techniques is traditionally based on economic and practical criteria, in future a growing demand for low environmental impact techniques suited for high recycling quotas is expected

Reference organizations

- 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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5.2.3 Deconstruction/Demolition waste sorting

Description

Deconstruction/demolition waste should ideally be separated during deconstruction, as mono-fractional waste streams are preferable for recycling and later improvements 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 whole waste, if separate collection is not an option at the deconstruction site). In general, large parts (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. At the end, the material is sieved in order to create the right fractions for the road building and concrete industry.
[208, TE DORSTHORST, 2005]

Achieved environmental and health benefits

- Reduction of waste that has to be landfilled
- Removal of the fraction being in general rich in pollutants
- Upgrading of waste to usable materials: Cleaned mineral fractions can be reused in construction projects (cf. recycling concrete, 5.2.5). Waste wood can also be recovered and recycled. However, the use of recycled materials is still mainly focused on low-grade applications.

Environmental indicators

Recycling quota of waste arriving at processing site (N.B.: ideally, selective construction leads to a separation of different usable material streams already at the deconstruction site that minimizes this remaining input stream).

Cross-media effects

- Crushing and sorting of materials consumes energy. Impacts of transportation activities have to be minimized too by adapted planning of sites and logistics and by selection of equipment (mobile or stationary). Concerning mobile sorting devices, they usually create materials of lower quality than stationary installations.

- Wet separation techniques are often more efficient in sorting and cleaning waste (also removal of pollutants), but create waste water that has to be cleaned.

Operational data

Manual sorting of mixed waste: As a first step, different building materials are separated by manual sorting after a demolition. 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 probably preferred. Some building elements such as water pipes and cables, located under the plaster or iron radiators can even be better sorted afterwards rather than being dismantled, at least from an economic point of view. [192, SCHULTMANN, 2005]

Separation devices in recycling plants: A further possibility to separate the foreign matter from the mineral building waste is the use of separating devices in recycling plants. Waste is crushed before the automatic sorting, in most stationary recycling plants a two stage process using first a jaw crusher and then an impact crusher is applied.
Experience from Germany shows, that most stationary recycling plants use either an air flow based or a water based separation device. Whereas the majority of recycling plants use air flow 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 the specific weight of the water and to change the point light materials flow up. Some water based separating devices use supplementary water jets or air to support the separation by density differences. [192, SCHULTMANN, 2005]

Figure 5-1 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 each vary in detail. [192, SCHULTMANN, 2005]

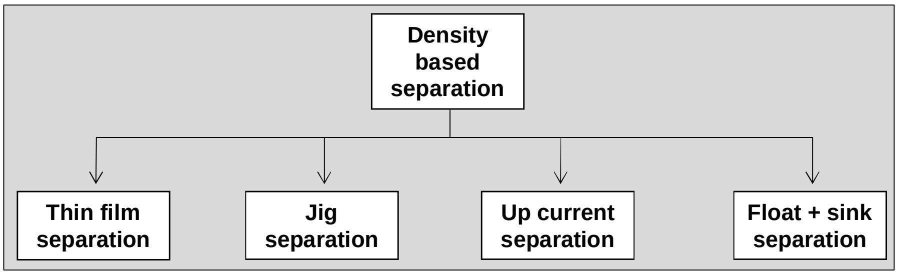

Figure 5-1: Water based separation techniques [2, SCHULTMANN, 2005]

Air flow 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 exact as with the wet techniques. However, mineral waste streams cleaned by each of both groups of techniques are basically free of non-mineral fractions and thus allow rather high recycling applications (for example as part of construction materials). Figure 5-2 shows the functionality of frequently applied airflow based separating devices. The "reverse air flow sorting technique" and the "cross air flow 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. Zigzag separation devices use the reverse air flow sorting technique, which is modified by the zig-zag form of the mechanism. Thus the effectiveness of sorting can be increased, because the zig-zag form has the same effect as a succession of several single cross air flow 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 already during deconstruction remains important.

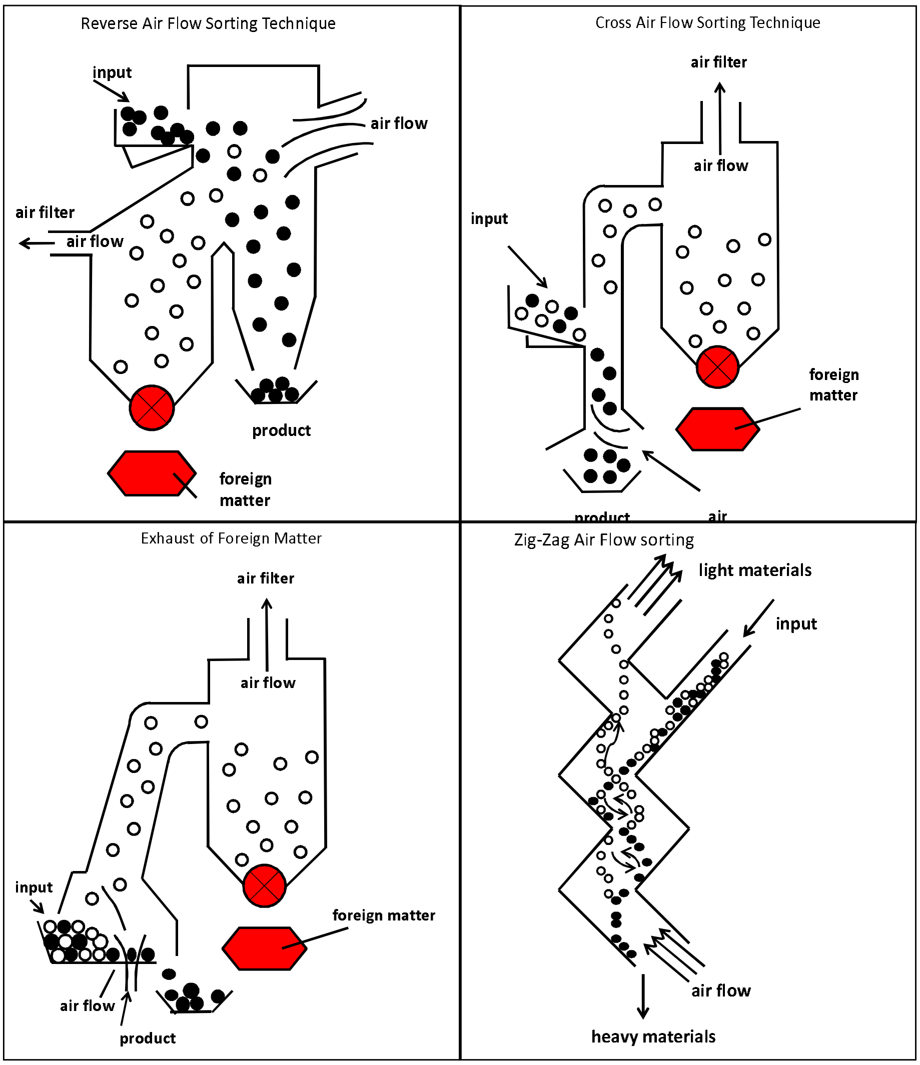

Figure 5-2: Main principles of flow based separating techniques [192, SCHULTMANN, 2005]

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 absence of pollutants. Preferred uses for this recycled material are road (or dam, canal, etc.) construction, use in new concrete (see 5.2.5) and other uses like foundations or greening of roofs.

Applicability

In general applicable to all construction wastes, the quality requirements of planned recycling uses determine the required degree of separation.

Economics

Little data is available concerning economics. In general, wet separation techniques produce purer fractions, but from an economic point of view, crushing, magnetic separation and air-flow based separation is the most preferred option. [216, UBA-A, 2006]

Table 5-14 shows a comparison made for Germany in 2001 of recycling costs (or revenues) versus deposit fees.

Table 5-14: Average deposit fees and recycling costs for various types of materials in Germany ([191, SCHULTMANN, 2001] as cited in [192, SCHULTMANN, 2005]

Category of Materials	Deposit Fees [EUR]	Recycling Costs [EUR]
Mineral materials		
Concrete Scrap	-	7 to 10 EUR/ton
Bricks	-	7 to 10 EUR/ton
Mixed mineral Materials	80 to 200 EUR/ton	9 to 13 EUR/ton
Metals		
Iron	-	-40 to 0 EUR/ton
Aluminium	-	-250 to -100 EUR/ton
Copper	-	-1000 to -250 EUR/ton
Wood		
Untreated Wood	-	35 to 65 EUR/ton
Lightly treated Wood	-	50 to 100 EUR/ton
Treated Wood (pressure impregnation)		50 to 250 EUR/ton
Other Building Materials		
Glass	-	30 to 65 EUR/ton
Plastics	-	50 to 200 EUR/ton
Mixed Building Materials *		
Mixed Materials (only recycling)		125 to 200 EUR/ton
Mixed Materials (recycling and disposal)	125 to 300 EUR/ton	
Mixed Materials (only disposal)	125 to 300 EUR/ton	

* Mixed material has to be sorted according to its material composition

Driving force for implementation

Increase of recycling rates for deconstruction waste (also legal requirements like landfilling bans).

Reference organizations

- 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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5.2.4 Plasterboard/Gypsum recycling

<u>Description</u>

Plasterboards (also known as drywall, gypsum board, wallboard, placoplatre, Sheetrock®, Rigips®) 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. [230, 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.

<u>Achieved environmental and health benefits</u>

Since both the gypsum and paper is recycled from the waste plasterboard, it can be assumed that for every one ton of waste plasterboard recovered one ton of waste is diverted from landfill. For a low transport scenario (50 km to recycling facility) compared to landfill, recycling process such as that employed by New West Gypsum Recycling save 47 kg of CO_2 for every tonne of plasterboard. [232, 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 the 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.

Environmental indicators

- Tonnes of waste diverted from landfill, tonnes of saved new materials [t]
- CO_2 reductions due to recycling [kg CO2/t] (no data at hand)

Cross-media effects

Large transportation distances may lead to an increase of emissions (or reduction of CO_2 savings potential of the technique)

Operational data

Table 5-15 gives an overview of quality paramters of recycled gypsum and flue gas desulphurization gypsum. It can be seen, that no major quality restrictions exist for recycled gypsum.

Table 5-15: Comparison of quality parameters of recycled and FGD (flue gas desulphurization) gypsum [128, LFU, 2007]

Quality Parameter	Determined as	Unit	Quality criteria FGD-Gypsum	Quality criteria 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

UK facility Roy Hatfield Ltd.: At the Roy Hatfield Ltd.'s recycling facility (UK), 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.

UK facility 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 percent 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.

UK facility 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

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. For example in Denmark already over 60% of plasterboard waste is recycled. [230, WRAP, 2006]

Economics

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 compare 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. [231, WRAP, 2008]

Table 5-16 gives some cost indications from one of the case studies described above. It can be seen that transportation cost is the only reason for lacking competitiveness of gypsum recycling in this case.

Table 5-16: Cost information from the Staffordshire case study [231, 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

Information from Denmark indicates, that with a country-wide system already collecting most of plasterboard waste, the cost per tonne charged is lower than the cost of disposing of the waste to landfill. [230, WRAP, 2006]

Driving force for implementation
Reduction of waste streams to landfills. With the introduction of the EU Landfill Directive in 2005, high sulphate wastes (including plasterboard) have been reclassified as non-hazardous non-inert wastes. This directive requires plasterboard to be landfilled in separately engineered cells, segregated from other waste types, in non-hazardous landfill sites. This directive provides an additional driver to increased recycling of plasterboard. Denmark already recycles over 60% of plasterboard waste. [230, WRAP, 2006]

Reference organizations
- http://www.nwgypsum.com/
- www.gypsumrecycling.biz
- www.plasterboardrecycling.co.uk
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5.2.5 Use of recycled concrete in building construction

Description
Splittings from deconstruction concrete are used as part of new concrete mixtures. This reduces waste, raw materials consumption and transportation. Recycled concrete has some different characteristics (not suited for prestressed concrete), but is a good substitute for conventional concrete in many cases.

Achieved environmental and health benefits
A reduction of new raw materials consumption (splittings) in building construction is achieved, as well as a reduction of concrete waste in low-grade applications and used landfill space. This means, that resource depletion is reduced through reduced need for gravel mining. Transport of materials can also be reduced.

Environmental indicators
- Content of splittings from deconstruction concrete in new concrete mixtures: 25-70% (depending on required exposition and stability classes).
- Concrete waste and consumption of mineral resources are reduced by the same number [www.eberhard.ch]

Cross-media effects
Some energy and in some cases water is consumed for crushing and washing concrete waste. However, 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 may for some applications lead to higher cement consumption; this has to be minimized due to the energy intensive production of cement.

Operational data

Concrete waste that is to be recycled has to come from selective deconstruction and mass flows have to be controlled for achieving required purity of material. After crushing in impact and jaw crushers, material is sieved and washed for removing light impurities (washing not applied in all installations). Analyses showed complete fulfilment of requirements of DIN EN 12620. No large process changes are necessary, however sand should be primary material and some changes in logistics are necessary, as an additional raw material has to be added to the process.

Experiences with hardened recycled concrete in Switzerland [source: www.eberhard.ch]:

- Strenght class: Up to strength class C30/C37 (current applications up to C35/45)
- Exposition classes: X0 – XC4/XD1/XF1 (95% of concrete market covered)
- Modulus of elasticity: > 30 000 N/mm2

Applicability

Recycled concrete can be used in numerous applications; it fulfils the quality requirements of exposition classes for building construction. Recycled concrete can for example be used in ready-mixed concrete, especially use in foundations, sprayed concrete, blinding concrete and general building construction.

Application in pre-stressed concrete or construction of bridges is not possible.

Economics

No data available.

Driving force for implementation

Increasing amounts of waste concrete from deconstruction or redevelopment of buildings (i.e. demolition or refurbishing of post-war buildings; increase of legislative pressure to recycle construction waste in high-grade uses and bans on landfilling construction waste.

Reference organizations

The technique is currently applied in Switzerland and some research projects and pilot projects have been realized in Germany. According to [145, N.N., 2009], the city of Zürich often demand a recycling concrete quota of 60 % for invitations for tenders and recycled concrete has a market share of 20-30% in this region.

The airport hotel Radisson SAS in Zürich was constructed using 15000 m³ recycled concrete delivered by Eberhard Bau AG. The recycled concrete (RC-Beton B C30/37 XC3 and C30/37 XC4, XF1, XD1) was distributed from a mixer truck by one central cementation pump and constantly controlled to be in line with Swiss SIA standards. [www.eberhard.ch]

Reference literature

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www.rc-beton.ch
www.urbanmining.ch
www.eberhard.ch
www.rc-beton.de
www.scherer-kohl.de

6 INDUSTRIAL AND CIVIL CONSTRUCTION

6.1 Introduction: cilvil construction processes

6.1.1 Road and pavement construction

6.1.1.1 Bituminous road construction

Road construction encompasses processing of bitumen, mounting of bitumen and its compaction. Bitumen is a very environmental-friendly road construction material and is fully applicable for recycling due its thermoplastic features. Nearly 100% of used bitumen is recycled and thereof about 80% (about 11.5 million tons out of 14 million tons per year) is recycled in the asphalt production. Bitumen processing is done by asphalt mixing plants, which are available in many different sizes and performances. It is distinguished between mixing performance and dry material performance of mixing plants. As it is common to use old bitumen coatings, these are removed with a rotary cutter and crushed in usually by an impact mill. Within the mixing plant bitumen and aggregates are mixed with heat supply. The mixed material is then transported by trucks on site and filled in the respective container of the paver. Pavers are produced with wheel or crawler chassis. They distribute, allocate and compact the bitumen compound to the desired height. Uniform compaction and high quality is very important for roads, with respect to the durability of the pavement, hence usually re-densification through rollers becomes necessary. Through modifying additives the quality and resistance of asphalt can be enhanced [119, KÖNIG, 2005; 11, ASPHALT, 2010].

Two techniques have been developed to repair roads by recycling the existing high quality construction material. With the hot-recycling technique up to ten centimetres of the upper asphalt surface is renewed. In the cold-recycling technique the asphalt surface as well as the road foundation is restored. Both techniques are performed on site, so that reductions of time, transport, energy and resources of 20 to 30% are possible [119, KÖNIG, 2005].

6.1.1.2 Concrete pavement

Concrete pavement is often used for road constructions, such as highways, bridge pavements and airports and for flooring in the industrial sector, as it is usually more resilient, dimensionally stable towards heat and owns a higher durability in contrast to bituminous pavements. Nevertheless, the production of bitumen requires 20% of the energy consumed for cement production and therefore 1 m^3 asphalt pavement requires only 50% of the energy necessary for 1 m^3 concrete [119, KÖNIG, 2005; 11, ASPHALT, 2010].

6.1.1.3 Other road related construction aspects

Energy-efficient lighting systems for roads and healthy road marking paints have to be considered with regards to environmental-friendly construction of roads as well [57, DENA, 2010a]. Additional techniques to ensure safety on roads during use and to maintain their quality, such as regular cleaning and winter services, need to be performed during the operation phase by the owner or the company being responsible for the operation. This is part of facility management, further described in chapter 4.

6.1.1.4 Maintenance of roads

Open topic. Related to facility management works.

6.2 Available Techniques concerning civil construction processes

6.2.1 Infrastructure construction, pavement and coating methods

6.2.1.1 Recycled asphalt as a sustainable pavement material

Description
Recycled asphalt is already used for several years for road pavement all over the world. Old asphalt from previous construction projects can be 100% recycled. Therefore the old asphalt is 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 concrete features by modifying additives.

Bitumen is to 100% and easily recycleable, due to its thermoplastic feature. Softening and hardening of bitumen is a reversible process. Recycling of bitumen is either performed in mixing plants or on site. For the production in mixing plants the old asphalt is crushed and the recycled material is reused as additives in the production of new asphalt, for loose binder and base courses as well as for bounden base courses. On site the old road surface is heated, removed and placed again directly after adding extra aggregates and bitumen.

Achieved environmental and health benefits
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, as making of bitumen consumes only 20% of the energy needed for cement production. Recycled asphalt reduces use of natural resources through aggregate mining and extraction and refining of crude oil. Used asphalt is 100% recycled, hence transportation of old asphalts and land use for landfills is reduced.

Environmental indicators
Less energy is consumed.
Land use for landfills and extraction and transport of new material is reduced due to the great amount of used recycled material.

Cross-media effects
Not mentioned.

Operational data
Not mentioned.

Applicability
Bitumen and recycled bitumen is regularly applied in road construction activities all over the world.

Economics
In general the construction of a road out of concrete is more expensive than out of asphalt. For instance, in Germany one square metre road inclusive installation works costs 22-25 €/m^2 by using asphalt and about 30 €/m^2 by using concrete. Hence asphalt pavement costs at least 5 €/m^2 less than concrete pavement. The construction material asphalt costs about 50 €/m^3 and a typical concrete (C25/30) costs about 75 €/m^3.

Driving force for implementation
Not mentioned.

Reference organisations
Deutag GmbH & Co.KG: www.deutag.de

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6.2.1.2 Warm mix asphalt (WMA)

Description
Warm Mix Asphalt (WMA) is a technology, which allows asphalt production slightly above 100°C (100°-140°C) with properties and performances equivalent to that of Hot Mix Asphalt (HMA) with production temperatures above 160°C. Hence WMA is asphalt mixed and distributed by about 20° to 40°C lower temperature than existing conventional HMA. In order to achieve such a lower production temperature, organic, mineral or chemical additives are applied or a foaming technique is used. There are research activities towards low temperature asphalts, which might result in production temperatures less than 100°C in the future.

Achieved environmental and health benefits
The environmental benefits of using/producing WMA are less emissions and energy consumption due to the lower production and application temperature. Fumes emitted from bitumen are halved for every 10°C reduction in temperature.
Plant stack emissions from WMA production are significantly reduced as compared to a classical HMA production:

- CO_2 emission minus 20-40%
- SO_2 emission minus 20-35%
- volatile organic compounds (VOC) emission minus up to 50%
- carbonmonoxide (CO) minus 10 to 30%.
- fine dust minus up to 85%

WMA includes up to 100% utilisation of reclaimed asphalt and secondary aggregates, which results in less wastage and consumption of natural resources. Already 14% recycled material in asphalt can reduce CO_2 emissions by 4% and the overall environmental impact by 9%. Additionally, the technique provides also social, safety and technical benefit. The construction process is fastened, hence traffic is less disrupted. The workability is increased and the method offers more comfort and safety for workers. For instance, unhealthy vapors and aerosol of 60 mg/m³ are reduced to less than 10 mg/m³. The short term aging of the asphalt is reduced, as it is highly deformation resistant and the temperature and loading sensitivity is decreased.

Environmental indicators
Reduced emissions per m^2 produced and placed street asphalt [kg/m^2].

Cross-media effects
Not mentioned.

Operational data
There are several techniques available creating a WMA with properties and performances as HMA. It is already a common method in road construction in severel countries in Europe and all over the world. One technique to achieve WMA is to add special waxes (rheological

modification) to the mix, which lower the viscosity of the bitumen and the temperature required to make the asphalt mix workable is reduced up to 110°C. Another technique, applicable to create so called half warm asphalt with even lower production temperatures but still above 100°C, includes the use of bitumen emulsion or foamed bitumen reducing viscosity of the binder through emulsification or volume expansion (foaming).

Applicability

WMA technology is generally applicable. European Standards for "Bituminous mixtures" (EN 13108-1 to 7) include only maximum temperatures, but there are no minimum temperatures stated. The standards also provide mixture additives with equivalent performance.

WMA results in risks regarding the clothing of filter systems and the performance of some WMA mixtures at low temperatures. Furthermore, there could be difficulties in adjusting burners in the plant.

Economics

On the one hand costs are reduced due to lower fuel consumption while producing WMA, as up to 50% less heavy oil fuel is used during production. More reclaimed asphalt pavement is used, which decreases the mineral and extraction costs. Additionally, less wear occurs in the asphalt production plant at lower temperature. On the other hand the use of additives and technology licensing can increase costs. Usually the existing HMA can be used, but sometimes further investments might be necessary due to plant modifications.

The economic value is dependent on the interactions of these factors. At present the costs are considered slightly higher as compared to HMA production in 2010.

Driving force for implementation

Increasing focus on CO_2 reduction is likely to stimulate the wider use of WMA. At some point it may be appropiate to stimulate WMA technologies in the procurement process to encourage their use (government policy). Any "green" procurement needs to take in account the LCA approach (sustainable development) to ensure equivalent performance. Various objective models are being developed to assist in this process.

Reference organisations

Nynas AB: www2.nynas.com/start

Reference literature

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6.2.1.3 Road pavement robot

Description
A road consists of several layers, including several base layers and the pavement, the surface of the road. Especially the upper layer has to be of high quality by protecting underlying layers from moisture to secure the road`s strength and durability and providing a safe surface for traffic. Usually diverse equipment is needed successively to spread the asphalt, compact, level and profile the surface of the road. The use of robots for fully automatic road pavement improves quality and reduces costs, noise and emissions. All functions connected to road pavement, such as conveyance and spreading of the asphalt, levelling, profiling and compacting are computer controlled and motion and paving speed is regulated.

Achieved environmental and health benefits
The two major environmental benefits, gained trough robotization of the road paver, are the reduction of noise and exhaust emissions. The use of a diesel-electric drive system reduces the noise from formerly 93 dB(A) to 81 dB(A) and the quantity of hydraulic oil, carried with the paver is minimized from formerly 380 litres to 20 litres.

Environmental indicators
Noise reduction measured in fewer decibels [db].

Cross-media effects
Not mentioned.

Operational data
The road paver robot automatically receipts asphalt, controls asphalt conveyance and spreading, provides steering control with mechanical sensors and automatic control of paving speed. All paving functions are started and stopped by automatic control.

The robot includes a 55 kVA three-phase A.C. generator, driven by a diesel engine rated at 61 kW drives. The generator supplies a 380 V three-phase output voltage and serves three-phase asynchronous motors operating at constant speed as well as the system for screed heating. Frequency converters lead to optimal match between power unit output and the various operating functions of the drives for rotary movements. Senors measure the distance to the feed vehicle and the height of asphalt on the conveyors. Dependent on the quantity of asphalt in the tank of the paver the paving procedure is started or stopped, so that a constant head of asphalt in front of the screed is assured.

The technique allows the full automisation of the steering process, which is a central paving activity, but often connected to mistakes due to the monotony of the job on the one hand, and the necessary high concentration on the other hand. With an accuracy of +/- 2 mm the robot allows precise steering along a given reference.

Applicability
The road paver robot was developed in the European research project ESPRIT. First results had been presented in 1996. Following demonstrations of the robot on site had been successful and satisfying. It is not mentioned, if the application of the robot is limited to certain roads.

Economics
Through the implementation of a diesel-electric drive system the efficency of the road paver robot is enhanced and the electrical drive output is better adaptable to the paving functions. As a result the power of the diesel engine is being reduced by 50% without a decrease in performance.

Driving force for implementation

Regarding the competitiveness of the European construction industry there is a high demand for automation and use of Information Technology (IT) in the construction industry, including flexible, automated heavy-duty machines and integral concepts for automated construction sites, which is until now little considered. Furthermore noise and emission reduction is an important aspect on construction sites.

Reference organisations

Joseph Vögele AG: www.voegele.info/de

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6.2.1.4 Green bridges, crossing facilities for wild animals

Description

The increase in mobility and therefore the expansion of roads and railways results in extensive land use and disconnects and cuts natural habitats. Furthermore there is a high risk of accidents with wild animals especially when roads cut wild life habitats and busy streets, highways and railways are close to or surrounded by forests and woodlands. In Germany for instance about 3000 humans were injured by accidents with wild animals in 2008. The building of bridges over those busy streets, highways and railways can reconnect wild life habitat, reduce accident risks and safe life of humans and animals. Those bridges should be placed spaced and in connection to game fences, so that these bridges are the only opportunity for wild animals to cross roads and railways and that they will do this safely without risking their lives and those of human beings.

Achieved environmental and health benefits

The green bridge protects in the first place wild life. Risks of car accidents can be reduced and therefore human lives are saved as well. Furthermore, habitat loss for wild animals and habitat fragmentation is prevented, a larger generic pool and therefore biodiversity is enhanced.

Environmental indicators

Not defined.

Cross-media effects

Not mentioned.

Operational data

The traffic conditions on roads are maintained, as the bridges do not hinder the mobility here.

Applicability

It is useful to build green bridges in connection to game fences. The bridges can be constructed with the help of modular framework systems, so that the erection on site will be easy and fast and traffic interruptions are minimised. A green bridge is installed over the highway D 11 close to Zehun, east of Prague in the Czech Republic. It is ten meters high and spans the 36 m wide road.

The German economic stimulus plan makes 60 million Euros available for the construction of those green bridges.

Economics

The extra costs connected to the construction of those bridges are, cannot be compared to the lives, which will be saved potentially, apart from the minimisation of injured losses by these measures.

Driving force for implementation
Green bridges for wild animals are important installations in the context of the 'Natura 2000'. 'Natura 2000', the so called 'centerpiece of EU nature and biodiversity policy', targets the long-term protection of the European wild flora and fauna by applying to the 1992 Habitats Directive (92/43/EEC) and the 1979 Birds Directive being codified by 2009/147/EC.

Reference organisations
Peri GmbH: http://www.peri.de/ww/de/index.cfm

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6.2.1.5 Foamed ballast for rail systems

Description
Rail ways are an important part of our infrastructure and cause in less air pollution emission during their usage phase than automobiles, planes and ships. For the surrounding area of rail ways noise emissions and vibrations due to dynamic loading caused by trains is a problem. Noise barriers, which especially have major aesthetic impacts, are only a partial solution to the problem. It is more advantageous to approach the problem at its source. Hence a new track-bed system had been developed, where the voids between ballast stones in the load-dispersing zones are filled with flexible foam.

Achieved environmental and health benefits
The foamed ballast of the new developed track-bed system reduces vibrations and absorbs noise. With regards to the test track the emission of vibrations are reduced by approximately 40% and the air-borne noise is reduced by more than 2 db.

Environmental indicators
Noise reduction measured in fewer decibels [db].

Cross-media effects
Not available

Operational data
The bed of ballast of a traditional track system does not have a rigid particle structure and dynamic loading changes the particle structure of the ballast and leads to additional costs for putting it back into shape every four to six years. The foamed ballast of the new track-bed

system yields under the load of a passing train and returns to its original position once the train passed. Hence, no corrective shaping is needed.

Applicability
The new developed track-bed system is suitable for existing and new tracks as well as for local and long-distance traffic. It was tested in June 2007 on a 330-metre-long test track on the main railway line between Hamburg and Hanover. This line carries mixed traffic, including heavy freight trains (with axle loads of up to 25 tonnes) and fast passenger trains (with top speeds of up to 200 km/h). The test results had been very satisfying, as mentioned before due to environmental and economic benefits.

Economics
Besides no need of corrective shaping, the new system also increases service life and lowers maintenance costs. A new track bed is required only every 50 years instead of every 20. The test track showed that the lateral resistance is eight times higher than for a normal ballasted track.

Driving force for implementation
Driving forces are the reduced noise emissions caused by trains as well as the mentioned economic benefits.

Reference organisations
Frenzel-Bau GmbH & Co.KG: www.frenzel-bau.de/frenzel-bau/index.htm

References
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6.2.1.6 Reinforced earth as green noise protection

Description
Noise barriers are constructed along roads, railway tracks and other noise-emitting sources. Especially with regards to increasing mobility of society the construction of noise barriers increases. These barriers are usually out of concrete and steel frames with acrylic glass or wood. Besides the advantage of noise barriers in protecting the surrounding area against traffic noise, the major disadvantages of these constructions are land consumption and their aesthetic impact. To face these drawbacks, environmental friendly noise protection systems are developed, by using geotextile structures, so-called reinforced earth, which adapt to the green environment, contribute to the improvement of the microclimate and safe space, in addition to efficiently protect against noise.

Achieved environmental and health benefits
Reinforced earth has several environmental benefits. In the first place natural, recyclable resources, such as stones and sand, are used with little environmental impact on the environment. Existing material on site can be used; hence even no extensive transportation with trucks is necessary. Less space is required to meet the required noise insulation. The supporting structure can be used as a basis for greening, which fulfills additionally aesthetical aspects and contributes to improve the microclimate.

Environmental indicators
Noise reduction measured in fewer decibels [db].

Cross-media effects
No extensive maintenance operations are necessary with regards to reinforced earth and geotextile systems.

Operational data

Noise protection walls out of reinforced earth are systems of baskets with several champers. The main basket is divided by grids; between those grids a fleece sack is installed, which is filled with sand. Hence a joint-less sound insulation layer is given, which result in high quality noise protection of 37 dB. Additionally, a very high sound absorption of 20 dB can be gained by filling the outer chambers with open-pored material, such as lava.

Front and back wall of the construction is connected through a bottom and top grid, so that the structure is statically stabile.

Applicability

Reinforced earth can be used as an environmental-friendly substitute of noise protections out of steel and concrete, as they provide even higher sound protection and absorbing qualities. Furthermore they require less space than usual earth dams, as they can be constructed with steep slopes. Example installations in Germany are for instance in the area Grunwald-Villa in Berlin and in Wolfsburg along the new building area Kerksiek.

Economics

The environmental-friendly noise barrier out of reinforced earth is cost-saving. Detailed information is not available

Driving force for implementation

Not mentioned.

Reference organisations

Tensar International: www.tensar.co.uk
Tenax: www.tenax.net

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6.2.1.7 Pollution absorbing concrete

Description

Nano-crystalline titanium dioxide (TiO_2) can be used as an additive included in cement in any concrete structure or can be directly applied on surfaces of concrete structures. TiO_2 is a semiconductor which accelerates under illumination by daylight or solar radiation as a photocatalyst the speed of a chemical reaction, without being consumed, hence the photocatalytic reaction can be repeated any time. It absorbs and degrades mineral or organic molecules. Therefore, the surface of these concrete structures can remove hazardous substances, such as nitrogen oxides (NOx) and oxidizes them into nitrates.

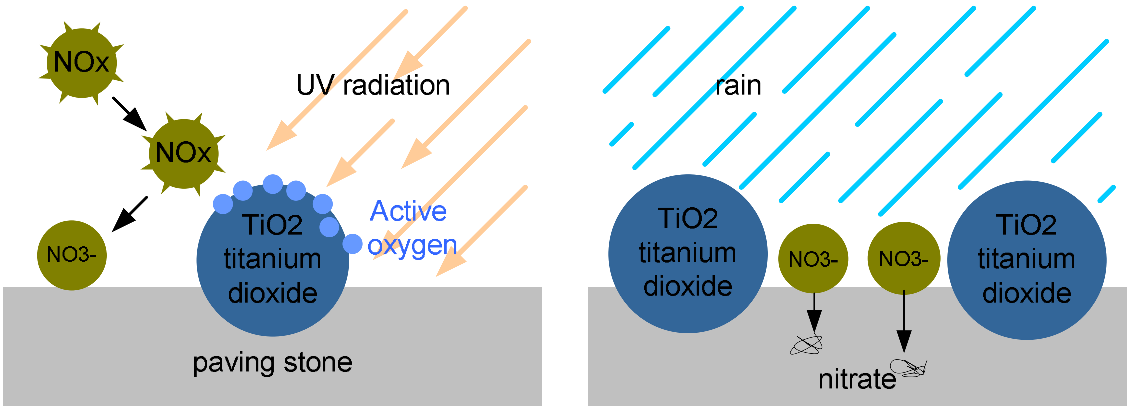

Figure 6-1: Reaction process of NOx oxidation through TiO2 [based on 116, JUSCHKUS, 2008]

Achieved environmental and health benefits

Concrete structures including or being applied with TiO_2 can oxidize diverse air pollutants, such as nitrogen oxides, aldehydes, benzene and chlorinated organic compounds, and convert them into less harmful substances to the environment. Up to 70% of the pollutants are still eliminated, when the sun is not directly shining and the UV radiation is low. NO_x is converted into nitrate. NO_3^- reacts with calcium hydroxide on the concrete surface and is washed off by rain.

Environmental indicators

The rate of the photocatalytical oxidation through TiO_2 depends on light intensity and air flow.

Cross-media effects

The assessment of health and environmental aspects of nanoparticles is not finished yet.

Operational data

Not available.

Applicability

In general all products 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 surrounding. The photocatalytic feature is not visible and does not influence other concrete processing and durability properties, hence concrete structures including TiO_2 look and function like conventional concrete structures. No special measures are necessary.
For instance, in Bergamo, Italy, 500 m of a highly frequented street was paved by photocatalytic active concrete and on further 500 m normal asphalt remained. Comparable measures show that the nitrogen oxide concentrations were reduced averagely by 45% by TiO_2.

Economics

Nano-crystalline titanium dioxide is a very expensive raw material. Only small amounts of TiO_2 are required for the concrete production, but the applied cement is still ten-times (about 3.20 Euros per kilo) more expensive than standard cement.

Driving force for implementation

A driving force is the enhanced living quality through better air conditions especially in alive cities.

Reference organisations

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6.2.1.8 Pavement minimising noise – open-pored asphalt layer

Description

By using open-pored asphalt or whispering asphalt with a high void content instead of normal asphalt for road constructions, noise emissions can be reduced directly at source without any deformation problems and other technical negative outcomes. Air-pumping noise, which occurs when the air within the tire 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.

Achieved environmental and health benefits

Open-pored asphalt with a void content above 22% minimises noise of 8 db and more.

Environmental indicators

Noise reduction measured in fewer decibels [db].

Cross-media effects

Besides noise reduction open-pored asphalt prevents aquaplaning and water slabs, as rain water is immediately drained off through the body of the road. The need to construct noise protection walls is reduced. Regular streetcleaning has to be performed, as the surface need to stay open-pored so that noise is reduced.

Operational data

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-relation of >3:1.

Open-pored asphalt is applied as single-layer and 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 contaminations.

Applicability

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 source results from the interactions between tries and the road surface. The technique is applied on various motorways all over Europe. For instance, since 2003 all new motorways in Italy are 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 of more than eight decibel. Older versions of open-pored asphalt led to problems in winter, as frozen water in the pores destoyed the surface, but recent products cover this issue.

Economics

The new variant of the open-pored asphalt is currently about 10% more expensive than regular asphalt and its durability is slightly less than of regular asphalt.

Driving force for implementation

Driving forces are regulations for noise reduction, such as the directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise and other regulations on national level.

Reference organisations

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6.2.1.9 Energy efficient street lights

Description

About one-third of European road and street lighting is based on old technologies of the sixties. The current energy consumption for street and road lighting can be reduced up to 50-70% by retrofitting of old installations. For Europe this would be about 36 TWh a year. But at the moment only 3% is exchanged every year.

Achieved environmental and health benefits

As with the energy efficient street lighting, energy consumption is reduced, related CO_2-emissions are minimised over the usage phase as well. An immanently replacement of all old street light systems by new technologies would save about 3.5 Million tons of CO_2 per year. Additional energy savings could be achieved by applying electronic ballast, which offer up to 10% less activity losses.

Environmental indicators

Luminous efficancy [lm/W] (alternatively energy efficiency class)
Minimum lifetime
Lumen maintenance [% over certain number of hours]

Cross-media effects

A concept to replace and improve the overall lighting systems of a city is connected to great management efforts and the availability of data about the current lighting situation.

Operational data

Especially quicksilver high pressure electric charging lights, which are widely spread, provide very bad energy efficiency. Hence especially those have to be replaced by efficient street lights, such as sodium and metal halide high pressure electric charging lights. The following table shows possible savings when switching to energy efficient lighting:

Table 6-1: Possible energy savings through energy efficient lighting systems

Old technology	New energy efficient technology	Possible energy savings

Fluorescent lamp	metal halide high pressure electric charging lights	25%
Quicksilver high pressure electric charging lights	sodium high pressure electric charging lights	50%
Quicksilver high pressure electric charging lights	metal halide high pressure electric charging lights	40%

An additional starting device is required to retrofit existing lights from quicksilver to sodium or metal halide. For lights older than 10 years complete replacement is more efficient.

Applicability
There are no limitations known for the application of energy efficient street lights.

Economics
To evaluate the economic efficiency of new street light systems investment costs for the lights and the installation, energy costs during the utilization phase, costs for the illuminant and maintenance costs need to be considered. Investment costs are higher, but the road keeper will achieve payback on investments within 4-6 years. An immanently replacement of all old street light systems by new technologies would save about 1 Milliard Euros of energy costs in Europe.

Driving force for implementation
Besides saving of energy costs, the European directive for energy using products (2005/32/EC) is the major driving force for energy efficient street lights. Within the directive minimum standards for durability, colour rendering and reduced lumen maintenance are set. Most important is the regulation of the 2005/32/EC, which should eliminate lights with high energy consumption and high polluting radiations within the next years. Hence for instance, quicksilver high pressure electric charging lights are not allowed to be taken into the market anymore from 2015, since they will have their CE-label cancelled.

Reference organisations
Not available.

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7 BENCHMARKS

7.1 Combustion of fuels for heating purposes

Appropriate benchmarks for environmentally-friendly combustion of fuels can be derived from the emission limit values (ELVs) of the new German 1st Federal Immission Protection Ordinance (1. BImSchV), which expresses the ELVs with respect to dust, NO_x and CO emissions for small combustion installations. This ordinance is in place since March 2010. Another type of source for benchmarks is the selection criteria for the eco-label “Blauer Engel” (blue angel), which honours very environmentally-friendly products.

Table 7-1: Selected relevant ELVs for solid fuel combustion according to 1. BImSchV [41 BUNDESIMMISSIONSSCHUTZVERORDNUNG (2010)]

Fuel	Installation size (net output in kW)	ELVs in mg/Nm³	
		Dust	CO
hard and brown coal	>4 and <500 kW	0.09	1.00
	> 500 kW	0.09	0.50
wood pellets	>4 and <500 kW	0.06	0.80
	> 500 kW	0.06	0.50
untreated wood	>4 and <500 kW	0.10	1.00
	> 500 kW	0.10	0.50
treated wood	>30 and <100 kW	0.10	0.80
	>100 and <500 kW	0.10	0.50
	> 500 kW	0.10	0.30
further biomass	>4 and <100 kW	0.10	1.00

Table 7-2: Selected relevant ELVs for liquid and gaseous fuel combustion according to 1. BImSchV [41 BUNDESIMMISSIONSSCHUTZVERORDNUNG (2010)]]

Installation size (net output in kW)	ELVs in mg/kWh	
	Light Oil	Natural Gas
<120 kW	110	60
>120 and <400 kW	120	80
>400 kW	185	120

Table 7-3: Selected relevant performance indicators for gas-fired condensing boilers and wood pellet boilers according to “Blauer Engel” (blue angel) criteria [170, RAL (2007), 171 RAL (2010)]

	Gas-fired condensing boiler	Wood pellet boiler
NCV	100-104%[118]	90%/88%[119]
CO	50 mg/kWh	90/200 mg/Nm³
NO_x	60 mg/kWh	150 mg/Nm³
OCV	n.a.	5 mg/Nm³
Dust	n.a.	20 mg/Nm³

118 NCV requirements vary according to net output.

119 Figures represent full load / partial load requirements.

7.2 Energy demand of buildings

The requirements concerning the primary energy demand of new constructed residential passive houses in Germany are provided in. The primary energy demand is provided in kWh per year and usable building floor area [kWh/(m²*a)]. These figures can be used as benchmarks for the moderate climate zone. For the warm and cold climate zone different benchmarks have to be taken into account.

Table 7-4: Requirements concerning the primary energy demand of new constructed residential passive houses in Germany in kWh per year and usable building floor area.[120]

kWh/(m²*a)	Maximum primary energy consumption for	
	Space heating	Space heating, water heating and electricity
Passive house	15	120

Reference values concerning the characteristic value of energy consumption (operational rating) of non-residential buildings in Germany are provided in BBSR [21, BBSR, 2009b]. These values provide an average of the existing buildings in Germany with respect to energy performance certificates. These figures can be used as benchmarks for the moderate climate zone. For the warm and cold climate zone different benchmarks have to be taken into account.

Table 7-5: Reference values for the characteristic value of energy consumption (operational rating) in non-residential buildings in Germany per year and net floor area [kWh/(m²*a)] [21, BBSR, 2009b]

Reference (average) values for existing non-residential buildings in kWh/(m²*a)			
Building type	Building sub types	Reference value	
		Heat	Electricity
Hotels, accommodation	Hotels without star, pension, bed and breakfast	215	70
	Hotels with 1 and 2 stars	120	75
	Hotels with 3 stars	135	85
	Hotels with 4 and 5 stars	150	95
	Hall of residence	125	25
Restaurant	No food, only beverages	340	100
	Food	290	135
	Cantina, catering	170	105
Buildings of performance	Cinemas	80	115
	Theatre buildings	150	75
	Large halls, municipal auditoriums	150	75
	Leisure centre, youth centre	150	75
Sport facilities	Sport hall	170	50
	Multipurpose halls	345	55
	Indoor swimming pools	550	150
	Association, club	115	25
	Fitness centre	140	170
Retail/services	Non-food and personal services < 300 m²	195	65
	Non-food < 2000 m²	105	85
	Food < 300 m²	180	105
	Food < 2000 m²	135	375
	Shopping centres	100	120
	Storehouse, shipping	45	50
	Small health care < 300 m²	285	50
	Hair cutting/barber	220	90
Health care	Hospitals > 250 beds	205	95

[120] Energiesparen im Haushalt: http://www.energiesparen-im-haushalt.de/, accessed 18.08.2010.

	Hospitals 251-1000 beds	250	115
	Hospitals > 1000 beds	285	115
Traffic infrastructure	Airport, terminal	190	290
	Airport, cargo hall	170	100
	Airport, maintenance, hangar	385	90
	Airport, workshop	220	210
	Train station < 5000 m^2	170	45
	Train station < 5000 m^2	165	140
Office building	Only heated	150	50
	Temperate, ventilated	160	120
	Air conditioned, conditioned independent from outside temperature	190	150

7.3 Lighting energy demand of buildings

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*a)]. It is calculated based on the wattage of installed lamps, their daylight and non-daylight time usage, an occupancy factor and other factors (for details on calculation like formula and factors [66, EN15193, 2008]). For more details see Table 2-42.

Table 7-6: Reference values for LENI indicator for several building types [66, EN15193, 2008] (shortened)

Building type	Reference installed wattage P_N (W/m^2)	LENI reference value (no constant illuminance control) [kWh/(m*a)]	
		manually switched	automatic
Offices	15	38.3	32.2
Education	15	31.9	24.8
Hospitals	15	63.9	50.7
Hotels	10	34.6	34.6
Restaurants	10	27.1	-
Sport locations	10	39.7	37.9
Retail	15	70.6	-
Production	10	39.7	37.5

7.4 Water demand of buildings

The IWU (Institut Wohnen und Umwelt) released standard water consumption data for different types of buildings, differentiated between cold and warm water use per person and per day which can be taken as a benchmark.

Table 7-7: Standard water consumption data in different types of buildings (IWU)

	Cold water use per person per day (litres)	Warm water use per person per day (60°C) (litres)
One-family house	100	34
Apartment building	100	30
Hotels /Hostels	100	30
Administration	15	0
Computing centers	15	0
On-call services	15	0
Schools (general)	15	0

Primary schools	10	0
Professional schools	20	0
Day-care centers	15	10
Gymnasiums	15	15
Baths	15	30
Halls/arenas	15	0
Laboratories	50	25
Hospitals	100	30
Restaurants	20	20
Factories	50	0

Regarding offices, the BRE (Building Research Establishment) sets the upper limit of potable water consumption for non-drinking use as 5.5 m^3 per year or 25 litres per day per full time equivalent employee as base benchmark for potable water consumption.

The BREEAM Offices standard, developed by the BRE, assigns credits depending on the predicted annual water consumption per person per year. The standard assessment procedure includes three ranges:

- 4.5 to 5.5 m3/person/year: 1 credit
- 1.5 to 4.4 m3/person/year: 2 credits
- less than 1.5 m3/person/year: 3 credits

7.5 Ecolabels for building products

Selecting building products with a generally accepted ecolabel is recommendable. Such labels check numerous criteria concerning the environmental impact of a product and are available for many construction-related areas; for more information see section 2.7.1. Such ecolabels can be regarded as benchmarks, too.

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9 ANNEX

9.1 Lifetime of building parts

Table 9-1: Lifetimes of building parts [20, BBSR, 2009a]

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:		
	o internal wooden stairs, softwood	50 - 80	60
	o internal wooden stairs, hardwood	80 - 150	90
	o external wooden stairs, softwood	30 - 50	45
	o 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		
	o aired	60 - 80	70
	o dressed	100 - 150	120
	- Natural stone, weathered	60 - 250	80

Building Structures / Components		Life expectancy [years]	Average life expectancy [years]
	- Brick, clinker		
	o aired	80 - 150	90
	o dressed	100 - 150	120
	- Sand-lime brick		
	o aired	50 - 80	65
	o 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