Chapter 3
The Role of Buildings in Energy Systems

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Abstract The construction sector consumes significant amounts of natural resources (raw materials, water, energy) during the various phases of its activity that covers construction, operation, and demolition of structures. A large amount of energy is required for the operation of buildings during their overall lives in order to meet their habitats needs—about 40 % of the final energy consumption in the EU in 2012. The EU has set a target for all new buildings to be "nearly zero-energy" by 2020. Considering that construction of new buildings has declined over the last few years and that there is a large stock of old buildings that were constructed without any thermal or energy regulations in several European countries, energy renovation in existing buildings has a high potential for energy efficiency. As environmental issues become increasingly significant, buildings become more energy efficient and the energy needs during their operation decreases, aimed at "nearly zero energy" buildings. Thus, the energy required for construction and, consequently, for the material production, is becoming more and more important. A significant contribution in the efforts to reduce the environmental impacts from construction activities is evaluating their environmental consequences in each stage of their life-cycle. This has led to the development of different "environmental life-cycle" assessment approaches.

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3.1 Sustainability and Construction Activity

The construction sector consumes significant amounts of natural resources during the various phases of its activity that covers construction, operation, and demolition of structures. The natural resources that are consumed during these phases are the raw materials and water used for the manufacture of the structural materials and structural components and the energy required for the extraction of the raw materials, production of structural materials and components, for the structures' construction and demolition. A large amount of energy is also required for the operation of buildings during their overall lives in order to meet their habitats' needs.

The construction and use of buildings in the EU accounts for about half of all extracted materials and about a third of water consumption in the EU, with amounts varying from country to country (COM 445 2014). Energy used in the manufacture of construction products and the construction process also plays a major role in the overall environmental impact of a building. Studies show that between 5 and 10 % of total energy consumption across the EU is related to the production of construction products with the embodied greenhouse gas emissions of a building increasing—which can comprise a significant share of total greenhouse gas emissions (COM 445 2014). The construction sector also generates about one-third of all waste and is associated with environmental pressures that arise at different stages of a building's life-cycle, including the manufacturing of construction products, building construction, use, renovation, and the management of building waste (COM 445 2014).

The construction sector is a very important economic sector. According to data from the European Construction Industry Federation (FIEC), in 2013 the construction sector contributed 8.8 % of the GDP of the EU-28, accounting for a €1.162 billion output. Buildings account for the majority of the construction activities, as civil works (e.g., roads. bridges, wastewater treatment, etc.) account for only by 21.0 % (Fig. 3.1) (FIEC 2014). Compared to 2006, a decrease was seen in the construction of residential buildings, while there was an increase in the maintenance and renovation works in existing buildings (Fig. 3.2) (Campogrande 2007).

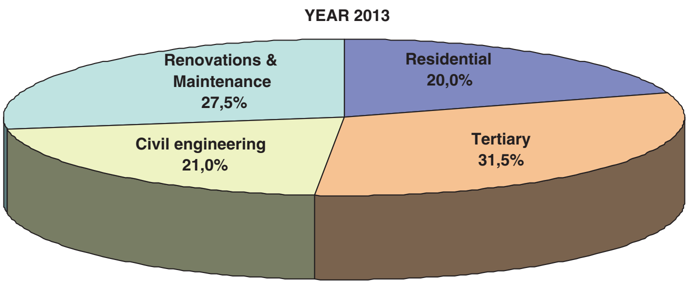

Fig. 3.1 Construction activity in Europe (based on data by FIEC 2014)

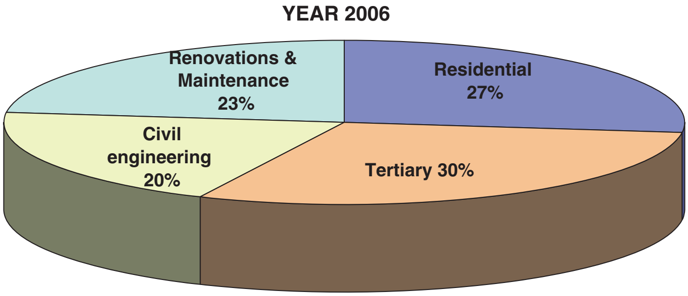

Fig. 3.2 Construction activity in the E.E.27 (based on data by Campogrande 2007)

For many years, the greatest importance from the environmental point of view was given at the operation phase of buildings—which is actually the longest period in a buildings life. After the first oil crisis in the 1980s, priority was given to a reduction of the energy that is consumed by buildings during their operation. However, since the beginning of the 1990s, when the environmental consequences from the other three construction phases began to increase (e.g., reduction of natural resource reserves, management of construction waste, difficulties in finding safe sites for construction waste deposits), a holistic approach was initiated that considered the environmental performance of structures and the consequences of the construction works on the environment. This approach resulted in implementing the "sustainability" as a new concept in structures consideration, aiming at the least possible burden on the environment during all phases of construction.

It is evident that even the construction of low-energy buildings, which do not depend very much on conventional fuel, consume, mainly through the use of construction materials and components, their manufacturing procedures and their construction, considerable amounts of non-renewable energy thus resulting in the release of pollutant emissions to the environment.

Since 2010, the EU2020 strategy has been setting the framework for the European economy for the following decade and beyond by focusing on three main priorities: smart, sustainable, and inclusive growth. As a follow-up, the "Resource Efficiency Roadmap" was adopted by the European Commission in September 2011. It concluded that existing policies on buildings, mainly linked to energy efficiency, need to be complemented with policies for resource efficiency looking at a wider range of resource use and environmental impacts, across the life-cycle of buildings. Such policies would "contribute to a competitive construction sector and to the development of a resource efficient building stock". As energy efficiency during the buildings' operation is already addressed by existing policies, the focus should be on resources such as materials (including waste), water, and embedded energy, addressing resource use and related environmental impacts all along the life cycle of buildings, from the extraction of building materials to demolition and recycling of materials (end of life) (EC–Sustainable Buildings 2015).

Energy efficiency measures should be considered in conjunction with their environmental impacts over the entire life cycle of a building; otherwise, impacts may be overlooked or additional problems may be created at a later stage of their life cycles, e.g., some solutions for improving energy efficiency of a building during its operation may make later recycling more difficult and expensive (COM 445 2014).

A question usually arises among designers, engineers, and users about the additional cost that new practices and requirements put at a building's cost. A study conducted by QUALITEL in France concluded that the extra cost for constructing sustainable residential buildings—as opposed to standard ones—has gone from 10 % in 2003 to below 1 % in 2014. A similar trend has also been noted in the UK (COM 445 2014).

3.2 Energy Consumption in Buildings

3.2.1 Overall Energy Consumption in the Building Sector

Buildings (both households and the tertiary sector) are the larger energy consumers in Europe, accounting for approximately 40 % of the overall energy consumption in 2012 (Fig. 3.3) (Saheb et al. 2015). While several countries exceed 40 %, such as Croatia and Greece sharing 43.1 and 42.1 %, while other countries account for lower percentages, such as Spain and Portugal, covering 30.7 and 28 % of the overall national energy consumption (Table 3.1) (EU 2014).

Residential buildings are the biggest energy consumers among building categories, in 2012 reaching up to 66 % of a building's total final energy consumption in the EU (Saheb et al. 2015). In 2012, the specific energy consumption was around 220 kWh/m^2, with a large difference between residential (200 kWh/m^2) and tertiary sector buildings (300 kWh/m^2) (Odyssee-mure.eu 2015).

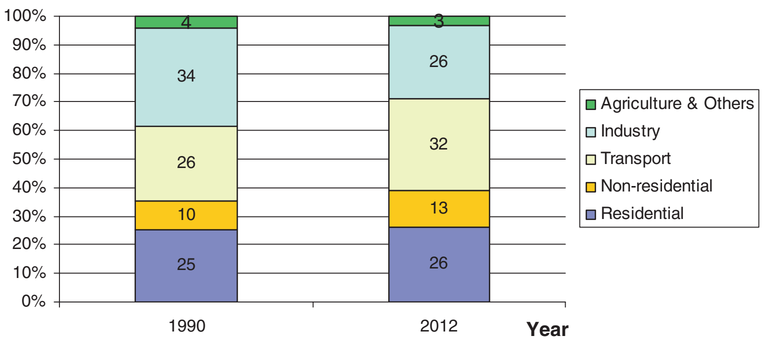

Fig. 3.3 Final energy consumption by sector in EU (based on data by Saheb et al. 2015)

Table 3.1 Final energy consumption by sector, in selected countries, in Mtoe for 1995–2012 (based on EU data 2014)

	1995	2000	2005	2010	2011	2012
GREECE						
Industry	4	4.5	4.2	3.5	3.3	3
Transport	6.5	7.3	8.2	8.2	7.4	6.4
Households	3.3	4.5	5.5	4.6	5.5	5
Services	0.9	1.3	1.9	2	1.9	2.2
Agriculture and fishing	1	1.1	1.1	0.8	0.7	0.3
Other	–	–	–	–	0.1	0.2
SPAIN						
Industry	20.5	25.4	31	21.4	21.4	20.8
Transport	26.4	33.2	39.9	37.2	36	33.3
Households	10	12	15.1	16.9	15.6	15.5
Services	4.3	6.7	8.4	9.8	10.2	10
Agriculture and fishing	2.2	2.6	3.1	2.2	2.4	2.7
Other	0.5	0	0.2	1.5	1	0.7
CROATIA						
Industry	1.3	1.4	1.6	1.4	1.3	1.1
Transport	1.2	1.5	1.9	2.1	2	2
Households	1.4	1.7	1.9	1.9	1.9	1.8
Services	0.4	0.5	0.7	0.8	0.8	0.7
Agriculture and fishing	0.2	0.3	0.2	0.2	0.2	0.2
Other	–	–	–	–	–	–
PORTUGAL						
Industry	4.9	6.3	5.8	5.5	5.3	4.7
Transport	4.9	6.6	7.2	7.3	6.9	6.5
Households	2.6	2.8	3.2	3	2.8	2.7
Services	0.9	1.4	2.2	1.9	1.8	1.8
Agriculture and fishing	0.5	0.7	0.6	0.5	0.4	0.4
Other	–	–	–	–	–	–

The average energy consumption per dwelling was reduced in about two-thirds of EU countries after 2000—a reduction of 1.5 % /year at the EU level between 2000 and 2010; this was mainly attributed to space heating, where a reduction of 3 %, amounting to 25 Mtoe, was reported. Space heating is the end-use that consumes the highest amounts of energy (67 % of total buildings' energy consumption), followed by water heating (13 %), electrical appliances (11 %), cooking (6 %), lighting only with 2 %, and a very small amount for space cooling (about 0.5 %) (Fig. 3.4). A relative growth in the energy consumption of electrical appliances was reported over the last years (from 9 to 11 % between 2000 and 2012), which resulted, looking at the overall energy balance, in a reduction of the relative fraction of energy attributed to space (Lapillone et al. 2014a, b).

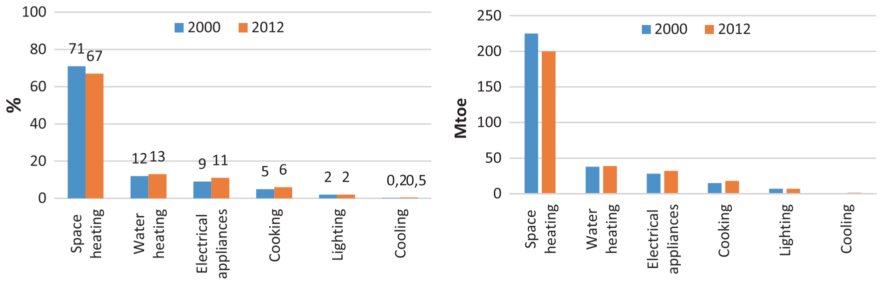

Fig. 3.4 Energy consumption breakdown in households in the EU countries (based on data by Lapillone et al. 2014b)

Regarding air conditioning energy consumption, although it can reach up to only 10 % of the total electricity consumption in countries using much air-conditioning (Cyprus, Malta, and Bulgaria), the average consumption per dwelling for this end-use is increasing as the installation of air conditioning units is increasing (Lapillone et al. 2014b).

3.2.2 Energy Consumption Per Fuel Type and Renewable Energy Sources (RES)

The main fuel consumed in 2012 in Europe (EU-28) was petroleum, with a share of 39 %, followed by gas, with a 22.9 % share (Fig. 3.5). Electricity was consumed by 21.8 % and renewable energy sources (RES) covered about 7.2 %. A decrease was reported in the use of conventional fuels, especially of petroleum, following the recession in Europe, while RES consumption is following an increasing trend as imposed by the 20-20-20 target in the EU (20 % energy reduction—20 % RES-produced energy—20 % CO_2 emissions reduction) (EU 2014).

In dwellings (Fig. 3.6), natural gas is the dominant energy source (37 %), followed by electricity (25 %) and wood (14 %), both of them presenting an increasing trend, as opposed to oil (with a 13 % share) that is gradually being phased out in the EU but remains significant in island countries (Lapillone et al. 2014b). In the tertiary sector (Fig. 3.6), the main energy carriers are electricity and gas, covering about 78 % of total energy consumption. A remarkable increase is observed in electricity consumption, from 33 % in 1990 to 43 % in 2011, while gas remains stable at 35 % since 2000 (Lapillone et al. 2014a).

Specific area electricity consumption varies significantly by building type and country, being higher in Nordic countries (Norway (166 kWh/m^2), Sweden, and Finland (128 kWh/m^2)), due the use of electricity for space heating, while the average value in the EU is 67 kWh/m^2.

Although energy efficiency measures have been introduced in several countries over the last years, about 25 % of the progress in energy efficiency for space

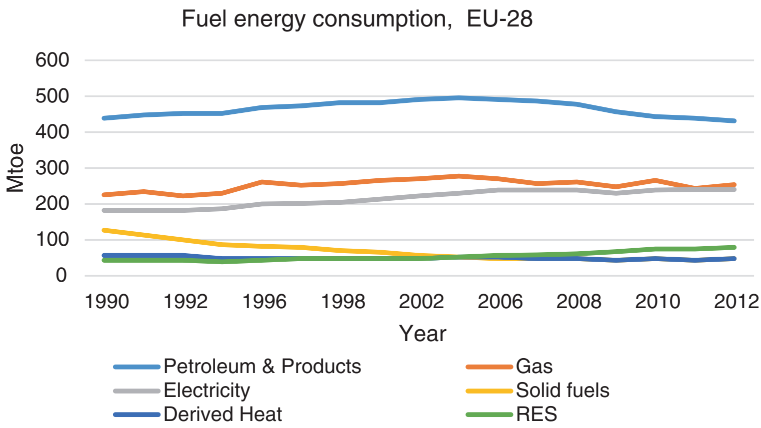

Fig. 3.5 Energy consumption trend in the EU-28 by fuel type (based on data by EU 2014)

heating has been offset by the larger area of new dwellings and by increased heating comfort standards (wider use of central heating systems). An increased use of RES (Fig. 3.7), especially in buildings, has been reported over the last years (Fig. 3.7 and Table 3.2); this is attributed to incentives introduced in all Member Countries for mandatory use of RES—e.g., the mandatory use of solar collectors to partially cover hot water needs in order to reach the renewable energy targets by 2020. The reduction in the cost of RES systems also contributed to this outcome.

The dominant renewable energy source in the building sector is solar energy, using collectors for heating production—mainly for domestic hot water—and photovoltaics for electricity production. Cyprus has the highest installed area of solar collectors in Europe, with 78 % of dwellings having installed solar collectors in 2011, followed by Greece with about 30 % (Fig. 3.8). Austria is in third place, with about 18 % of the dwellings having installed solar collectors in 2011 as compared to 3 % in 1990. Austria is considered the benchmark for solar collectors for countries with medium solar radiation, and Cyprus for countries with high solar radiation (Lapilloneet al. 2014b).

3.3 Means of Reducing Energy Consumption

3.3.1 Energy Efficiency

As buildings are responsible for 38 % of the EU's total CO_2 emissions (Saheb et al. 2015), the reduction of the energy demand of buildings and decarbonization of the energy supply for residential and tertiary buildings is of great importance in

Fig. 3.6 Energy consumption by fuel type in households and in the tertiary sector (based on data by Lapillone et al. 2014a, b)

order to achieve the EU climate and energy goals for 2020. The EU has set a target for all new buildings to be nearly zero-energy: 2020 (DIRECTIVE 2010). Energy efficiency is the first priority for reaching this target. “Nearly zero energy” buildings are characterized by very high energy performance, while the small amount of energy required should be covered by RES.

Considering that construction of new buildings has been declining over the last years (Fig. 3.1), and that many older buildings were constructed without any thermal or energy regulation in several European countries, the energy renovation of existing buildings has a high potential for achieving energy efficiency.

About 35 % of the EU’s buildings are over 50 years old. Residential buildings comprise the largest segment of the European building stock; these buildings are responsible for most of the building sector’s energy consumption and CO_2 emissions (Chadiarakou and Santamouris 2015). In Greece, there are approximately

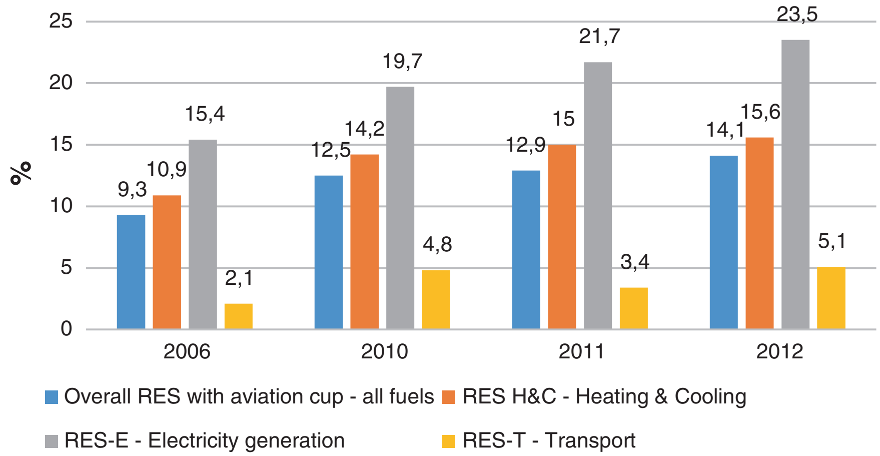

Fig. 3.7 RES share in the gross final energy in EU-28 (based on data from the EU 2014)

Table 3.2 RES for heating and cooling share in the gross final energy in selected countries (based on data from the EU 2014)

	2010	2011	2012
Country		%	
Greece	17.8	19.4	24.4
Croatia	13.0	15.6	18.3
Spain	12.6	13.6	14.0
Portugal	33.7	35.0	33.0

4,000,000 buildings; around 70 % of them were constructed before the implementation of the Thermal Insulation Regulation (TIR) in 1989 and so they do not have any kind of thermal insulation (Chadiarakou and Santamouris 2015). In Portugal, 50 % of dwellings were constructed before the enactment of the TIR in 1990, indicating that there is a great potential for energy efficiency renewal in these buildings.

New buildings in general consume less than 3–5 l of heating oil/m^2/ year, while older buildings on average consume about 25 l, even as many as 60 l/m^2/year. It is estimated that by improving the energy efficiency of buildings, the total EU energy consumption can be reduced by 5–6 %, resulting in a reduction of CO_2 emissions by about 5 % (EU—Buildings 2015).

The quality of the buildings determines the energy requirements, which in turn affects energy consumption and energy bills. The usual way to reduce energy expenses is to compromise on comfort for heating and cooling. In 2012, 11 % of the EU population was unable to keep their homes warm in the winter, and 19 % living in dwellings not comfortably cool in the summer. There is growing concern regarding the number of EU citizens facing fuel poverty, as over 30 % of people in EU member states with per capita GDPs below the EU average faced fuel

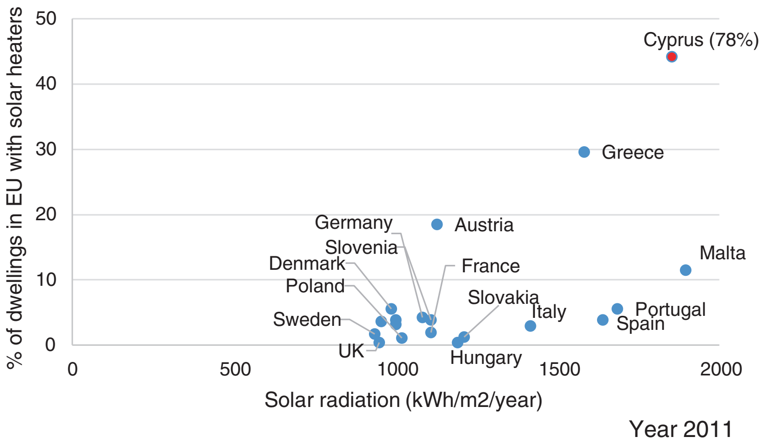

Fig. 3.8 Illustration of % installation of solar water heaters in dwellings and solar radiation (Year 2011) (based on data by Lapillone et al. 2014b)

poverty in Europe (Saheb et al. 2015). In a survey carried out in a sample of about 600 households in Greece, it was found that 2 % of the higher income households and 14 % of the lower-income households were below the fuel poverty threshold (Santamouris et al. 2013).

The key to reducing energy needs and consequently household energy bills is the improvement of a building's quality by insulating the building's envelope (walls, roof, and floor), replacing windows with new, high thermal performance ones, and maintaining or replacing heating and cooling systems by the best available technologies. At the EU level, energy renovation is given high priority in the "Strategy for a Resilient Energy Union" in order to meet the targets of its climate change policy (COM 2015, 80). Energy renovation costs should be less than 25 % of the value of the home; otherwise it is considered more sensible to construct a completely new building than to renovate the existing one (Saheb et al. 2015).

In order to achieve high energy efficiency and even buildings that produce energy, new technologies are required. Energy renovation will stimulate technological innovation in the chain of the building sector (Table 3.3). In the future, buildings need to become "smart," connected to storage systems, smart grids, and vehicle/transport systems.

3.4 Embodied Energy of Structural Materials and Components

The fossil fuel consumed by the construction sector is not only restricted by the amounts of energy required for the operation of buildings (operation of electrical and mechanical installations for heating, cooling, lighting, etc.), but it also

Table 3.3 Technological innovation needs for the building sector (based on Saheb et al. 2015)

Economic activity	Building component and/or systems	Technology
Floor and wall covering	Building envelope	Advanced insulation material such as VIPs for nZEBs and space constrained applications
		Air sealing testing methodologies
		Reflective surfaces for roofing materials for southern Europe and dense urban areas
Painting and glazing	Windows	Double low-e conductive frames
		Triple glazing for northern Europe with low-e and low-conductive frames
		Energy plus windows with dynamic solar control and glass that optimize daylight
		Automatic solar controls and exterior solar shades and blinds with low e-film and high insulation
Plastering, joinery installation	Joinery	Air sealing
Plumbing, heat, electrical and air conditioning installation	Heating systems	Active solar thermal systems fully integrated to buildings
		Thermal energy storage (TES) materials and full systems with integrated ICT
	Heating cooling and hot water systems	Cost-efficient heat pumps
	Heating cooling and electricity production	Efficient and smart CHP
	Cooling systems	Sorption cooling systems driven by hot water
Building completion and finishing	Energy management	Building information and management (BIM)
		ICT for grid integration and consumers information

covers the fossil fuel energy consumed during the manufacture of structural materials and components, the energy required during the construction, maintenance, replacement and demolition works of structures. The amounts of energy hidden in building materials and components and associated construction work are called "embodied" or "embedded energy."

The amounts of energy needed for the production of structural materials and components include the energy needed for the extraction of the raw materials, transportation from the extraction site to the manufacturing installation, and for the manufacturing process. The energy used for the transportation of the raw materials depends on the availability of the raw materials in the region and on the means of transportation (e.g., truck, train, ship) and the distance. For local materials, which are usually simple materials, such as wood, stone, or adobe, transportation distances are relatively short. For high technology materials, such as metals or plastics, transportation distances may be long, and in some cases even several thousand kilometers. The energy consumed for the manufacturing process depends on the different machinery types used in the process. Ideally, secondary energy consumption during the manufacturing process should be considered that includes the energy consumed for the operation of the manufacturing installation e.g., for heating, cooling, lighting systems, the energy to manufacture major machinery and for machinery maintenance. The amount of energy required for the manufacture of building materials and components is known as "cradle-to-gate" embodied energy, which includes all the energy (in primary form) required to produce a finished product until it leaves the factory gate, without any further considerations. It is the most common specified boundary condition.

The energy needed for the transportation of finished products to a construction site also depends on the distance of the site from the factory and means of freight transportation. When all energy required for all phases, including raw materials extraction to delivery of the products to the construction site is considered, then the "cradle-to-site" embodied energy is implied. This definition is useful when looking at the comparative scale of building components and neglects any maintenance or end-of-life costs (Anderson 2015).

The amounts of energy required for the construction, maintenance, replacement and demolition of structures include the energy consumed by the mechanical equipment for the construction (referred to as "initial energy" accounting for all phases since raw material extraction), for maintenance and replacement (recurring energy) and for the demolition of structures, transportation of structural waste to the waste deposit site, and for waste management (demolition waste). The whole life cycle energy of a structure component is known as "cradle-to-grav": embodied energy, which defines energy spent by a building component or the whole building throughout its life. This embodied energy does not imply that waste is landfilled. If products are recycled at the end of life (Anderson 2015), assessment would account for this, ensuring that the benefits of recycling for a material are not doubly counted for both the use of recycled content and its recycling at the end of life. The definition of "cradle-to-grave" embodied energy is a far more useful one when looking at a building or project holistically, although it is much more complicated to estimate it (Anderson 2015). In order to determine the magnitude of the embodied energy, an accounting methodology is required that sums up the energy inputs over the major part of the materials supply chain or the whole life-cycle (Hammond and Jones 2008).

The emissions related to energy consumption that are responsible for global warming and climate change, e.g., CO_2 and other greenhouse gases, are also considered and give rise to the concept of "embodied carbon." Thus,the embodied carbon footprint is the amount of carbon (CO_2 or greenhouse gases that cause climate change added up as CO_2 equivalents (CO_2 eq)) released to the atmosphere for the manufacturing of a product and/or construction work.

The embodied energy is commonly expressed in terms of MJ per unit weight (kg or tonne) or area (m^2). It is significant to split the required energy into conventional energy and renewable energy. The environmental implications of the energy needed to make a kilogram of product are expressed in terms of the quantity of gas emissions of "CO_2"and "SO_2" that are emitted at the atmosphere during the construction activity. The amounts of produced CO_2 and SO_2 emissions depend on the fuel type (oil, gas, etc.) that is used during the various stages of the construction activities but also at the equivalence that exists on the national level between the quantities of gas emissions per produced kWh of fuel.

In order to determine the embodied energy, it is necessary to trace the flow of procedures and energy-related actions in the various stages of the life cycle of construction—depending on the boundaries set for the analysis, i.e., whether the factory, site, or whole life cycle. Any change in the production process will have an impact on the embodied energy and the associated environmental parameters of the produced structural materials. Knowledge of the quantities of raw materials and the amounts of energy used throughout the various stages of the production procedure (e.g., extraction and manufacturing) are needed to estimate the embodied energy of a product.

Values of embodied energy and carbon (dioxide) emissions for common structural materials are depicted in Table 3.4, as drawn from the *Inventory of Carbon and Energy* (ICE) (Hammond and Jones 2011), an open-access database listing almost 200 different materials, developed at Bath University (UK).

3.5 Assessment Methods

3.5.1 Introduction

As environmental issues continue to become increasingly significant, buildings become more energy efficient and the energy needs during their operation decreases, aimed at "nearly zero energy" buildings. Thus, the energy required for construction, and consequently for the material production, is becoming more and more important.

A significant contribution to the efforts for reducing the environmental impacts from construction activities is to evaluate the environmental consequences of a

Table 3.4 Embodied energy and equivalent emissions of CO_2 of structural products

Material	Embodied energy (MJ/kg)	Embodied carbon (kg/CO_2/kg)	Embodied carbon (kg/$CO_{2\,e}$/kg)
Stone	(Difficult to select data, high standard deviations)		
General	1.26 (?)	0.073	0.079
Granite	11.00	0.64	0.70
Limestone	1.50	0.087	0.09
Marble	2.00	0.116	0.13
Marble tile	3.33	0.192	0.21
Sandstone	1.00 (?)	0.05	–
Slate	0.1–1.0	0.006–0.058	0.007–0.063
Steel			
Steel (General UK (EU)—Average recycled content of 59 %)	20.10	1.37	1.46
Virgin	35.40	2.71	2.89
Recycled	9.40	0.44	0.47
Stainless steel	56.70	6.15	–
Aluminium			
Aluminium general, incl. 33 % recycled	155	8.24	9.16
Virgin	218	11.46	12.79
Recycled	29	1.69	1.81
Copper			
Copper (average incl. 37 % recycled)	42	2.60	2.71
Bricks			
Common clay brick (simple baked, incl. Terracotta and bricks)	3.0	0.23	0.24
Mortar			
Mortar (1:3 cement: sand mix)	1.33	0.208	0.221
Mortar (1:6)	0.85	0.127	0.136
Mortar (1:1:6 cement: lime: sand mix)	1.11	0.163	0.174
Mortar (1:2:9)	1.03	0.145	0.155
Tiles – Flooring			
Clay tile	6.5	0.45	0.48
Ceramic tiles and cladding panels	12.00	0.74	0.78
Terrazzo tiles	1.40	0.12	–
Vinyl flooring (General)	68.60	2.61	3.19
Insulation			
General insulation	45.00	1.86	0.24

(continued)

Table 3.4 (continued)

Material	Embodied energy (MJ/kg)	Embodied carbon ($kg/CO_2/kg$)	Embodied carbon ($kg/CO_{2\,e}/kg$)
Rockwool (Slab) (gradle to grave)	16.80	1.05	1.12
Fiberglass (Glasswool)	28.00	1.35	–
Mineral wool	16.60	1.20	1.28
Cellular glass insulation	27.00	–	–
Cellulose insulation	0.94–3.3	–	–
Expanded polystyrene	88.60	2.55	3.29
Polyurethane insulation (rigid foam)	101.50	3.48	4.26
Woodwool (board)	20.00	0.98	–
Wool (recycled)	20.90	–	–
Cork	4.0	0.19	–
Straw	0.24	0.01	–
Perlite expanded	10.00	0.52	–
Perlite natural	0.66	0.03	–
Windows			
Glass (primary)	15.00	0.86	0.91
1.2*1.2 double glazed (air or argon filled):			
Aluminium framed	5470	279	–
PVC framed	2150–2470	110–126	–
Timber framed	230–490	12–25	–

construction activity or product manufacture during each stage of its life cycle. This has led to the development of various environmental life cycle assessment approaches, in which not only is the embodied energy used, but the raw materials and water (input), together with the pollutants and wastes (output) released into the environment (air, soil, water) during the construction activity or manufacturing procedure, are traced and quantified.

The environmental assessment methods can be classified thus:

Environmental assessment of structural materials and processes:

- assessment of the manufacturing procedure where all phases of the production procedure, up to the delivery of the final construction product, are assessed
- assessment and classification of structural materials and components through certification schemes (e.g., eco-label).

Pieces of information obtained from both approaches can be used for environmental assessment of alternative structural materials that can be used in construction.

Environmental assessment of the overall construction project, considering the environmental assessment of the individual construction materials and components.

The *Life Cycle Analysis* (LCA) was introduced in 1997 with the International Standard ISO 14040, which described the principles and framework of LCA (ISO 14040: Environmental Management—Life cycle Assessment—Principles and Framework). In 2006, two new standards were released, covering all relevant standards issued up until this year, the ISO 14040 2006 and ISO 14044 2006, with ISO 14040 referred to the *Principles and Framework* and 14044 to the *Requirements and Guidelines of LCA*. These standards stimulated the development of several national methodologies of structural products. One of the first ones was the "Environmental Profile Methodology" developed by Building Research Establishment (BRE) (UK) in 1999 (*BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*), for assessing the cradle-to-grave environmental impact of construction materials (BRE 2007).

A set of international standards was issued dealing with environmental labelling (ISO 14020 to 14025) with ISO 14025, published in 2006 (ISO 14025:2006: *Environmental Labels and Declarations-Type III Environmental Declarations—Principles and Procedure*) that established the principles and specified the procedures for developing *Environmental Product Declarations* (EPD). An ISO specialized-for-construction materials was published in 2007, the ISO 21930 (ISO 21930:2007: *Sustainability in Buildings and Civil Engineering Works—Environmental Declaration of Building Products*) that provides the principles and requirements for Type III environmental declarations (EPD) of building products and encompassed the different national approaches while ISO 21931 (ISO 21931-1:2010. Sustainability in building construction—Framework for methods of assessment of the environmental performance of construction works—Part 1: Buildings—identifies and describes issues to be taken into account in the use and development of methods of assessment of the environmental performance for new or existing buildings in their design, construction, operation, maintenance and refurbishment, and in the deconstruction stages. The suite of standards covering issues of sustainability of buildings is synoptically described in Fig. 3.9.

The need for harmonization into a common methodology across Europe of the different approaches for assessment of the environmental impacts associated with construction products and buildings, was covered with the issue of European Standards:

- the EN 15804 (EN 15804+A1: 2012. Sustainability of construction works—environmental product declarations—core rules for the product category of construction products) for development of EPDs of construction products and services and
- the EN 15978 (EN 15978: 2011. *Sustainability of Construction Works—Assessment of Environmental Performance of Buildings—Calculation Method*) that specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building, where a set of environmental indicators are assessed over the full life cycle of a building. The approach to the assessment covers all stages of the building's life cycle and is based on data obtained from EPD (EN 15804) and other information necessary and relevant for carrying out the assessment (Fig. 3.10).

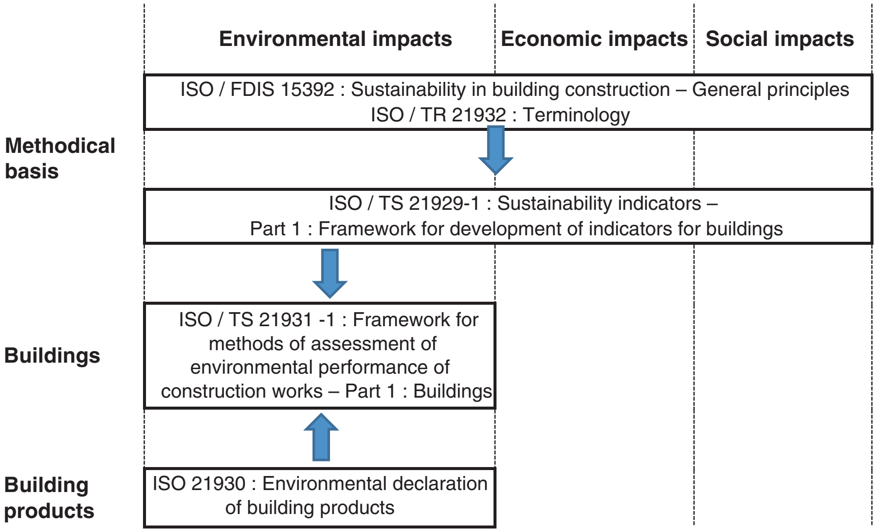

Fig. 3.9 Schematic representation of international standards dealing with sustainability in building construction (based on ISO 21930:2007(en): ISO-Online Browsing Platform)

Several countries, such as the UK, France, Germany, the Netherlands, Sweden, Norway, Spain, Portugal, Italy, and the United States have adopted the EN 15804 for structural materials.

The European Commission recognized the need to complement existing energy policies for buildings with policies for resource efficiency, looking at a wider range of resource use and environmental impacts during the life cycles of buildings, and thus the *Resource Efficiency Roadmap* was adopted in September 2011 (EU Roadmap 2015). It also explained in the publication on *Strategy for the Sustainable Competitiveness of the Construction Sector and Its Enterprises* on July 31, 2012 (COM 2012, 433), that among the main challenges that the construction sector faces up until 2020—in order to grow stronger and more viable in the future—is improvement in resource efficiency and environmental performance. It thus highlighted the need for the development of methods to assess the “environmental performance” (EC-Sustainable Buildings 2015).

As stated in *Resource Efficiency Opportunities in the Building Sector*’ (COM 2014, 445), the European Commission will establish a common framework of core indicators to be used to assess the environmental performance of buildings throughout their life cycles, and thus allow comparability and provide users and policy makers with easier access to reliable and consistent information. The framework will focus on the most essential aspects of environmental impacts and be flexible so that it can be used on its own or incorporated as a module in existing and new assessment schemes next to their larger sets of indicators. It will be based partly on existing work, such as the EN15978 technical standard, as well as existing voluntary commercial certification schemes for buildings.

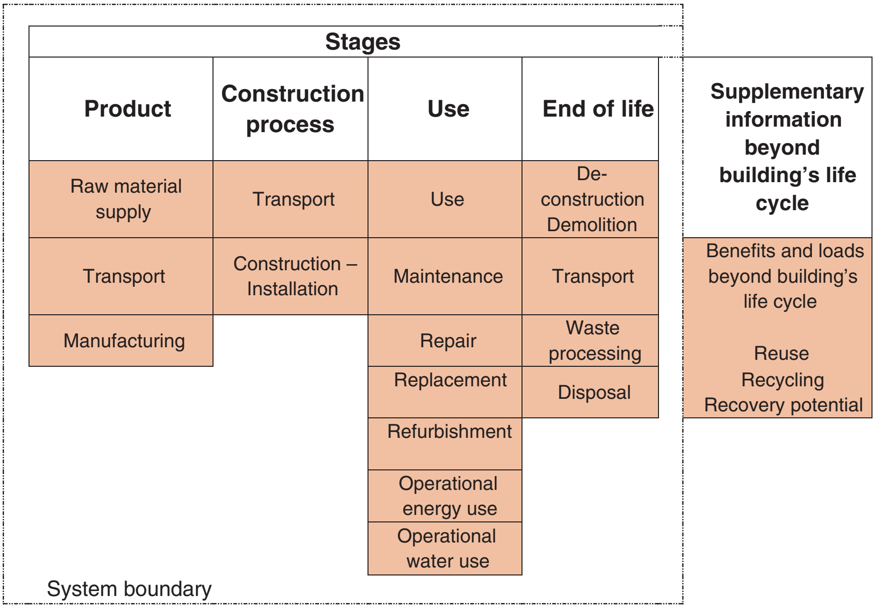

Fig. 3.10 Illustration of the modules considered in analysis of EN 15804/15978

3.5.2 Environmental Assessment of Structural Products and Processes

The LCA is one of the most popular techniques used as an analytical tool for the assessment of the environmental impacts caused by a material, a process, or an application during its whole life cycle. It identifies and quantifies great amounts of input about the raw materials, ingredients, products, manufacturing process, and energy use, as well as input for the environmental aggregation during all stages of the life cycle of the products and processes. This means:

- the environmental destruction from the raw materials extraction
- the pollutant emissions produced during the production process
- the availability of raw materials
- the recovery of materials
- the energy consumed for the manufacture of the final products
- the amounts of waste produced during the manufacturing process and the degree of pollution caused, and
- the implications for air quality and human health.

A wide range of the environmental aspects of building materials could be aggregated and quantified with an inventory analysis into a limited set of the recognizable impact indicators (e.g., global warming, ozone depletion, acidification) that are used to quantify and aggregate all environmental aspects of building materials and processes. LCA models differ, depending on the boundaries of the system they examine (linked to the goal and scope of the environmental assessment and the boundaries set e.g., cradle-to-grave), the input/output environmental flows examined (linked to the life cycle inventory (LCI) model), and the type and number of indicators assessed (associated with the evaluation model). The differentiation among the available assessment tools depends on their user friendliness, the magnitude of their data bases, and their subject specification as well as purchase cost.

The tools can be classified into:

1. Those assessing construction products such as the detailed SimaPro (UK) and GaBi (Germany) tools, the Ide-Mat (Netherlands), EQUER (France), KCL-ECO (Finland), BEES-Building for Environmental and Economic Sustainability (USA), ATHENA Impact Estimator for Buildings (Canada), and LISA-LCA in Sustainable Architecture (Australia) tools, and
2. the tools for environmental assessment of production processes, such as the GEMIS (Germany), UBERTO (Switzerland), TEAM-Tool for Environmental Analysis and Management (France), and BOUSTEAD (UK).

The LCA requires a great amount of input, and in several cases the collection and process of the required pieces of information was difficult and time-consuming, with a high overall cost because many companies consider these data to be confidential, or else they do not have detailed records.

3.5.3 Environmental Assessment Methods for Buildings and Construction Works

There has been a growing movement towards sustainable construction since the second half of the 1980s, leading to the development of various methods for evaluating the environmental performance of buildings. This category covers methods and rating schemes for environmental assessment of the entire construction project. Most existing building assessment systems attempt to serve two functions at once (Larsson 2014): to guide developers and designers in their attempts to design for high performance, and to measure and assess building performance in as objective a way as possible.

The first rating tool was launched in 1990 with the introduction of the British BREEAM rating tool, and five years later was followed by the French HQE system, and the GBTool launched by the Natural Resources Canada in 1996, and by LEED in 2000 in the USA. A year later, the GASBEE followed in 2001 (Japan), in 2002 the Green Globe (BREEAM Canada) and the Green Star in Australia, and in 2006 the DGNB from the German Green Building Council (GBC).

3.5.3.1 BREEAM (BRE Environmental Assessment Method)

The BREEAM method was developed by the Building Research Establishment (BRE) in the United Kingdom and was first launched in 1990 (www.breeam.org). It is one of the first methods developed for the environmental assessment of new and existing buildings and one of the world's foremost environmental assessment methods and rating systems for buildings. It assesses the environmental performance of buildings in the following areas (BREEAM 2015):

- Management: overall management policy, commissioning site management and procedural issues, waste recycling, pollution minimization
- Energy: energy consumption and CO_2 emissions
- Health and well-being: indoor and outdoor environment issues affecting health and well-being, such as adequate ventilation, lighting, thermal comfort
- Air and water pollution issues: leakage detection systems, in situ processes, RES, pollution prevention plan
- Transport: transport-related pollutants and location-related factors
- Land use: greenfield and brownfield sites, reuse of site soil, polluted soil use
- Ecology: ecological value conservation and enhancement of the site, land with low or the lowest ecological value, preservation of significant ecological systems in the land's vicinity, minimization of the impact in the biodiversity of the area
- Materials: environmental implications of structural materials throughout their life cycle
- Water: water consumption and efficiency, reduction of consumption, leakage detection.

Developers and designers are encouraged to consider these issues from the earliest phases of the project in order to achieve a high BREEAM rating. A credit is awarded for each area and a set of environmental weightings enables the credits to be added together to produce the final overall score of the project. The certificate awarded to a building has one of the following ratings: Pass, Good, Very good, Excellent, Outstanding, or a five-star rating system is provided.

The BREEAM method covers not only various building types in the tertiary sector, residential buildings and communities at the design stage, but also existing buildings. It covers offices, schools, healthcare buildings, retail outlets and shopping malls, industrial buildings, etc., while for the residential buildings there are various certification schemes: (1) The British Government's Code for Sustainable Homes (CSH) replaced EcoHomes for the assessment of new housing in England, Wales and Northern Ireland; (2) BREEAM EcoHomes for new homes in Scotland; and (3) BREEAM Multi-residential covering buildings housing many individuals and offering shared facilities. BREEAM Communities is a certification scheme to certify development proposals at the planning stage. BREEAM In-Use is a scheme to help building managers reduce the running costs and improve the environmental performance of existing buildings. BREEAM is used not only in the UK but in several other countries under National Scheme Operators (NSOs) as well.

3.5.3.2 SBTOOL (Sustainable Buildings Tool)

The SBTOOL is an international system of environmental and sustainability assessment of buildings. It is a generic framework to support the sustainability performance assessment of buildings that can be easily adapted to regional and building type variations, and to the use of different languages. It has been under development since 1996, and various versions of the system have been tested since 1998. It is the successor of the GBTool software tool (green building tool) that was launched by Natural Resources Canada for the needs of the International Initiative “Green Building Challenge” (GBC), an international program of more than 25 countries that aimed at setting common criteria for naming a building a “green building.” Since 2002, the responsibility of the tool has been handed over to the International Initiative for a Sustainable Built Environment (iiSBE) (www.iisbe.org). The tool is in spreadsheet form and includes criteria for various parameters, such as site selection, energy program and development, indoor environmental quality, long-life efficiency, and social and financial criteria. Weighting factors are defined for each criterion, based on national or local assessment conditions and construction practices. The scoring process in SBTool relies on a series of comparisons between the characteristics of object building and national or regional references for minimally acceptable practice, “good” practice, and “best” practice. Buildings are rated in the range of −1 for non-acceptable performance, and from +1 up to +5 for “minimum accepted” performance, to “best practice” accordingly, with +3 corresponding to “good practice.”

The SBTool system consists of two distinct assessment modules that are linked to phases of the life-cycle; one for Site Assessment, carried out in the Pre-Design phase, and another for Building Assessment, carried out in the Design, Construction or Operations phases (Larsson 2014). The SBTool has been improved and updated over the years; the last version, which was updated in 2014, is calibrated from the countries participating at iiSBE and its results have been presented at the SB-Sustainable Buildings Conferences.

3.5.3.3 Green Globes

Green Globes (Greenglobe 2015) is an online green building rating and certification tool that is used for the assessment of existing and new buildings, primarily in Canada and the USA. There are three Green Globe modules, for:

- New construction/significant renovations (for commercial, institutional and multi-residential building categories, including offices, school, hospitals, hotels, academic and industrial facilities, warehouses, laboratories, sports facilities, and multi-residential buildings)
- Interiors of commercial buildings (i.e., office fit set-ups)
- Existing buildings (offices, multi-residential, retail, health care, light industrial).

The Green Globes for Existing Buildings initially developed in 2000, is based on the BREEAM Canada edition and shortly afterward the New Buildings Canada module was launched. The system was adopted in the US in 2004 as an alternative to the LEED building rating system with the US rights acquired by the Green Building Initiative. It is an online assessment protocol, rating system, and guidance for design, operation, and management of sustainable buildings. It is questionnaire-based with pop-up tips that show the applicable technical tables that are needed to reply to the questions, and is structured as a self-assessment to be done in-house, by a design team and the project manager. Users can see how points are being awarded and how they are scoring.

Green Globes for Existing Buildings utilizes weighted criteria where projects earn points relative to their impact on (or benefit to) the sustainability of the building on a 1000-point scale, in seven categories. A minimum number of points in each category is required. The three key performance indicators with the highest points are energy efficiency, materials choices and resource consumption, and indoor environmental quality. Additional environmental assessment areas include project management, water, and emissions and other impacts (e.g., site for new constructions).

3.5.3.4 LEED® (Leadership in Energy and Environmental Design)

The LEED® is one of the dominant assessment methods in the USA and worldwide. It was initially developed in the US in 1998; its development was supervised by the USGBC (USGBC 2015), a non-profit coalition of building industry leaders.

It encompasses five rating systems: (1) building design and construction (new construction, core and shell, schools, retail, hospitality, data centers, warehouses and distribution centers, and healthcare); (2) interior design and construction (commercial interiors, retail and hospitality); (3) operation and maintenance of existing buildings (schools, retail, hospitality, data centers, and warehouses and distribution centers); (4) neighborhood development, i.e., new land development projects or redevelopment projects containing residential uses, nonresidential uses, or a mix; and (5) homes (single family, low-rise multi-family, i.e., one to three stories, or four to six story mid-rise multi-family, including homes and multi-family low-rise and mid-rise).

Each rating system comprises different credit categories, such as materials and resources, energy and atmosphere, water efficiency, location and transportation, sustainable sites, indoor environmental quality, innovation, and regional priority credits. Additional credit categories are examined for neighborhood development: smart location and linkage, neighborhood pattern and design, and green infrastructure and buildings.

A project receives LEED certification if it satisfies prerequisites and earns points in each credit category. Prerequisites and credits differ for each rating system; there are four levels of certification according to the points awarded to a project: certified (40–49 points); silver (50–59 points); gold (60–79 points); and platinum (>80 points).

3.5.3.5 CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)

The CASBEE method has been in existence since 2001 from the “Japan Sustainable Building Consortium” for the needs of the Japanese construction market CASBBEE (2015). An English version is also available (www.ibec.or.jp/CASBBEE/english).

CASBEE considers the whole architectural design process, starting from the pre-design stage and continuing through design and post-design stages, covering the various building categories, e.g., offices, schools, and apartments. It is composed of four basic assessment tools: (1) CASBEE for Pre-design; (2) CASBEE for New Construction; (3) CASBEE for Existing Building; and (4) CASBEE for Renovation. Tools for specific applications were also developed—for example CASBEE for Market Promotion, CSABBE for Heat Island, CASBEE for Urban Development, CASBEE for Cities, and CASBEE for Home (detached houses).

It recognizes four assessment fields: (1) energy efficiency; (2) resource efficiency; (3) local environment; and (4) indoor environment. An indicator is derived, and the “built environment efficiency” (BEE), which is the core concept of CASBEE, is calculated as the ratio of parameters describing the ”built environmental quality” (Q) to parameters describing the “built environment load” (L).

$$\text{Built Environment Efficiency (BEE)} = \frac{Q\,(\text{Built environment quality})}{L\,(\text{Built environment load})}$$

The “built environmental quality” (Q), is defined in terms of $Q1$ indoor environment, $Q2$ quality of services, and $Q3$ outdoor environment on site and the “built environment load” (L), in terms of $L1$ energy, $L2$ resources and materials, and $L3$ off-site environment.

Some local governments in Japan have introduced as mandatory for building permits to include assessment with the CASBEE method, in the same way as the Energy Saving Plan. Since December 2011, 24 local governments have been introduced the reporting system as their environmental policies.

3.6 Discussion

Buildings are the largest energy consumers in Europe, accounting for approximately 40 % of the final energy consumption in 2012, while the construction and use of buildings accounts for about half of all extracted materials and about a third of water consumption in the EU. The construction sector also generates about one-third of all waste.

For many years, the greatest importance from the environmental point of view was given at the operation phase of buildings—which is actually the longest period in a construction’s life. After the first oil crisis in the 1980s, priority was given to reducing the energy that is consumed from a building during its operation. However, since the beginning of the 1990s, when the environmental consequences from the other three construction phases began to increase (e.g., reduction of natural resources reserves, management of construction waste, and difficulties in finding safe sites for construction waste deposits), a holistic approach was initiated that considered the environmental performance of structures and the consequences of the construction works on the environment. This approach resulted in implementing "sustainability" as a new concept in structures' consideration, aiming for the least possible burden on the environment during all phases of construction.

Environmental concerns resulted in an increased use of RES and especially in buildings over the last few years, attributed to incentives introduced in all EU member countries for the mandatory use of RES and reduction in the cost of RES systems. The dominant renewable energy source in the building sector is solar energy, with the use of solar collectors, mainly for domestic hot water and photovoltaics for electricity production.

But a growing concern in the EU is the increasing number of people facing "fuel poverty," as more than 30 % of people in EU member states with per capita GDPs below the EU average face fuel poverty. The key to reducing energy needs, and consequently household energy bills, is the thermal improvement of buildings (envelope insulation, window replacement, and maintaining or replacing heating and cooling systems by the best available technologies). Considering also that construction of new buildings has declined lately and that there are many old buildings in several European countries that were constructed without any thermal or energy regulations, the energy renovation of existing buildings has great potential for energy efficiency.

At the EU level, energy renovation is given high priority in the *Strategy for a Resilient Energy Union* in order to meet the targets of its climate change policy. It is also expected that energy renovation will stimulate technological innovation in the chain of the building sector. In the future, buildings need to become smart, connected to storage systems, smart grids, and vehicles/transport systems. It is estimated that by improving the energy efficiency of buildings, the total EU energy consumption can be reduced by 5–6 %, resulting in a reduction of CO_2 emissions by about 5 %.

The European Commission recognized the need to complement existing energy policies for buildings with policies for resource efficiency, looking at a wider range of resource use and environmental impacts, across the life cycle of buildings (*Resource Efficiency Roadmap,* 2011). Such policies would "contribute to a competitive construction sector and to the development of a resource efficient building stock." But energy efficiency measures should be examined, taking into consideration their environmental impacts over the entire life cycle of a building; otherwise, impacts may be overlooked or additional problems may be created at a later stage of their life cycle—for example, some steps tp improve a building's energy efficiency during its operation may result in expensive and difficult recycling in the future.

The fossil fuel consumed in the construction sector is not only restricted by the amounts of energy required for the operation of buildings (operation of electrical and mechanical installations for heating, cooling, lighting, etc.), it also covers the fossil fuel energy consumed during the manufacture of structural materials and components, the energy required during the construction, maintenance, replacement, and demolition of structures. These amounts of energy hidden in building materials and components and associated construction work are called "embodied or embedded energy," while the corresponding environmental implications are expressed in terms of the quantity of emissions of CO_2 and SO_2 that are emitted into the atmosphere during the construction and give rise to the notion of "embodied carbon."

As environmental issues continue to become increasingly important, buildings become more energy efficient and the energy needs during their operation decrease, aiming at "nearly zero energy" buildings. Thus the energy required for construction and, consequently, for the material production, is becoming more and more important.

A significant contribution in the efforts for reduction of the environmental impacts from construction activities is to evaluate the environmental consequences of a construction activity or product manufacture in each stage of its life cycle. This has led to the development of various environmental life cycle assessment approaches. In these approaches, not only the embodied energy, but the raw materials and water used (input), together with the pollutants and wastes (output) released into environment (air, soil, water) during the construction activity or manufacture procedure are traced and quantified. Across these lines, a set of International and European Standards was issued on environmental labelling of products (ISO 14020 to 14025), specialized for construction materials (ISO 21930, EN 15804), or assessment methods of the environmental performance for the whole building (ISO 21931, EN 15978) was developed.

As buildings are responsible for about 38 % of the EU's total CO_2 emissions, reduction of the energy demand of buildings and decarbonization of the energy supply in buildings is of great importance in order to achieve the EU's climate and energy strategy for 2020. Decarbonization of the construction sector is the challenge for the future in order to develop environmental friendly construction.

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