Energy in Buildings and Communities Programme

International Energy Agency

Evaluation of Embodied Energy and CO_2 equivalent for Building Construction (Annex 57)

Guideline for Policy Makers

2016

EBC is a programme of the International Energy Agency (IEA)

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)

Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long Term Performance of Super-Insulating Materials in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior Simulation
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational Strategies for High IAQ in Low Energy Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

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1. Introduction and summary

This document is the deliverable “Guideline for Policy Makers”, developed within the Subtask 1 of IEA - EBC Annex 57 “Evaluation of Embodied Energy and CO_{2eq} for Building Construction”. It also includes guideline for including Embodied Energy and CO_{2eq} considerations into the procurement process

The main goal of Subtask 1 is to clarify the connections between actors and targets related to embodied energy (eE) and embodied greenhouse gas emissions (eCO_{2eq}) for building construction. Building eE and eCO_{2eq} are affected significantly not only by the construction methods adopted, but also by the energy efficiency of the material production processes and by the energy generation mix.

In such a context, the guideline for Policy Makers aim towards informing about eE and eCO_{2eq} in the building sector, give recommendations about standardization of methodological principles and technical data requirements, as well as guidance and tools to support planning.

POLICY MAKER

2. Guideline for Policy Makers

The guideline can provide an insight to Policy Makers on the main issues related to eE and eCO_{2eq} in building construction, with an aim at wider integration of eE and eCO_{2eq} assessment into local policies. The main objectives of the guideline are:

- To inform Policy Makers about the importance of eE and eCO_{2eq} (referring to the embodied contributions from the production of materials, the production of a building and end-of-life of a building, opposed to the “use” of the same building), in relation to energy consumed in building operation in the context of life-cycle environmental impacts
- To inform and support the planning, design and assessment of policy instruments and programs
- To provide insights to Policy Makers about the main tools aimed to push the market towards low eE and eCO_{2eq} building design.

In particular, these guideline:

- Provides definitions of energy use, eE and eCO_{2eq}
- Assesses the state of art of eE and eCO_{2eq} in buildings
- Examines the importance of measuring and managing eE and eCO_{2eq} in building sector to reduce the GHG emissions
- Considers the importance of the life-cycle perspective in building energy efficiency
- Provides guidance for Policy Makers on the elements to include in legislation
- Provides Policy Makers guidance to confirm their policies by tracing items in suitable checklists.

2.1 Overview

Buildings are responsible for around 20-40% (according to the country) of yearly energy consumption, thus the construction sector is critical for reducing the energy demand and CO_{2eq} emissions linked to buildings. This should be a top priority: in fact the reduction of energy requirements and the mitigation of environmental impacts in the building sector have become key targets of energy policies in different countries, to be matched by means of strategies aimed at enhancing energy efficiency and the diffusion of renewable energy technologies.

However, the standard response to these needs all over the world is the continued tightening of the equipment and building regulations' requirements for improving the operational efficiency of the building. Plug loads are also being investigated and energy ratings are developed (e.g. for televisions, computers, monitors) in an effort to improve the energy efficiency of technologies used in residential and non-residential buildings.

But this is not enough: a building is a complex system that undergoes a large chain of developments and transformation: raw materials are extracted and transformed, the building itself is designed and built, and then at the end of the building operational phase demolition would eventually occur.

The building regulation requirements typically only touch the operational phase, in which the building is actually used. But what if the building causes high energy consumption and CO_{2eq} emissions during the construction stage?

What if it is built with materials that require very energy and CO_{2eq} intensive processes to be manufactured?

For these reasons, the legislative approach pursued in the last years in most regions of the world may have, in some cases, the unintended consequence of causing undesired CO_{2eq} emission increases for new buildings in comparison to standard buildings. This would be caused by an increase in eE and eCO_{2eq} that may be higher than the corresponding energy and CO_{2eq} reductions in the operational phase.

Already in practice, for both residential and non-residential applications, the common approach in recent decades was to neglect the eE and eCO_{2eq}. Until recently, in many building regulations it was only a single year of operational energy that is considered, owing to its significant share in the total life-cycle energy consumption of a standard building (70- 90%). Conversely, eE of building materials and components has been traditionally neglected when performing building energy analysis, as in standard buildings it accounted for a small fraction of the life cycle energy consumption (10-20%). This made most building regulations and directives overlook this issue.

From a life-cycle perspective, when shifting from conventional houses towards low energy buildings the relative share of operational energy decreases, while the relative share of eE increases. Therefore, the lower the operational energy, the more important it is to adopt a life-cycle approach including eE and eCO_{2eq} to compare the energy savings achieved in the building operation to the overall energy consumption.

Even the Net Zero Energy concept that has been pushed by the EPBD recast directive in 2010, contributes to shift the focus towards eE and eCO_{2eq}: if the building has to reach Net Zero Energy, that would mean that the energy required during the use phase would be null by definition. Thus all energy (and carbon) requirements would fall under the ‘embodied’ contributions.

The embodied contributions need to be standardized as well. If the aim is the reduction of energy uses and, in the long run, of the greenhouse gases concentration in the atmosphere, it is the whole life- cycle of the building that needs to be investigated.

Or, in other words, it is both the eE/eCO_{2eq} and the operational phase that should be taken in consideration by policies.

For these reasons, the role of policies is crucial: the development of regulations in the field of eE and eCO_{2eq} is as relevant as to those in the field of building performance to be developed as a parallel and harmonized approach.

2.2 EU policy tools for building sector

Many policy tools in Europe have been adopted to increase the energy efficiency of the existing building stock, as part of the plan aimed to reach a low CO_{2eq} economy. In such a path, the first milestone is the 2002/91/EC Directive on the Energy Performance of Buildings (EPBD). It promotes the required measures to increase the energy performance of buildings for all the EU Member States and introduces environmental performances as the most relevant driving force for energy saving in buildings.

According to the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD recast), which makes the minimum requirements more stringent and to pursue more ambitious targets, such as achieving nearly-zero energy buildings, all new buildings should be built as nearly zero energy buildings from 2021 onwards.

Measures adopted in EPBD covers the following seven core themes:

1. Certification schemes
2. Inspection of heating and air-conditioning systems
3. Training of experts and inspectors
4. Energy performance requirements using the cost-optimum methodology
5. Towards 2020: High performance buildings / Nearly Zero energy and Zero CO_{2eq} buildings.
6. Compliance and control of EP requirements and certification system / Independent control system
7. Effectiveness of support initiatives

However, even with the wide focus on building performance in the EU context, taken as example, **these EU policies do not include eE and eCO_{2eq} reduction as allowable solution to reduce the overall GHG emissions**.

Energy and environmental assessments of buildings are run on the basis of different methods and sustainable construction certification schemes such as LEED, BREEAM, VERDE and Passivhaus. For a thorough assessment using the life cycle assessment method, European Committee for Standardization (CEN) 350 has developed a full set of standards addressing environmental, economic and social aspects, based on life cycle assessment (SIA 2010; SIA 2011a; SIA 2011b; KBOB 2014) (Figure 1).

FRAMEWORK	**ISO 21931–1 | 2010** Framework for methods of assessment of the environmental performance		**EN 15643–2 | 2011** Framework for the assessment of environmental performance	**SIA 2040 | 2011** Energy Effiecency Path			
BUILDING	**ISO 21929 – 1 | 2011** Sustainability in Building Construction Sustainability Indicators		**EN 15978 | 2011** Assessment of environmental performance of buildings – Calculation-method	**SIA 2032 | 2010** Grey Energy of Buildings	**PAS 2060 | 2010** Specification for the demonstration of carbon neutrality	**VDI 4600 | 2012** Cumulative energy demand (KEA): Terms, definitions, methods of calculation	
PRODUCT	**ISO 21930 | 2007** Environmental declaration of building products	**ISO/TS 14067 | 2013** Carbon Footprint of Products	**EN 15804 | 2012** Environmental product declarations – Core rules for the product category of construc-tion products		**PAS 2050 | 2011** Specification for the assessment of life cycle greenhouse gas emissions of goods and services		Greenhouse Gas Protocol Product life cycle accounting and reporting standard

2.3 Life-cycle energy

Life-cycle energy analysis emerged in the late 1970s and focuses on energy as the only measure of environmental impact of buildings or products. The purpose of the life-cycle energy analysis is to present a more detailed analysis of energy attributable to products, systems or buildings. Life-cycle energy analysis is often used to estimate the energy use and savings over a product or building life, and to compare energy payback periods.

2.4 Energy

Energy is needed to construct and operate a building. This energy is often generated through the combustion of fossil fuels, such as coal, gas and oil. The combustion process generates the energy used, for example, in the construction and operations of a building. However, this process also produces as by-products CO_2 and other gases, emitted into the atmosphere. Energy consumption is therefore linked to carbon emissions when (fossil) fuels are used. However, other forms of energy, such as solar energy or wind energy, do not generate carbon emissions during the energy conversion process.

The energy consumption associated with buildings and construction materials can be categorised as follows:

- Operation Energy (oE)
- Embodied Energy (eE).

2.4.1 Operation energy (oE)

oE is the energy requirement of the building during its life from commissioning to demolition (not including maintenance or renovations), primarily for space heating, water heating and lighting and appliances. Reduction in oE demand through more efficient buildings brings benefits for the global environment as well as lower operating costs.

2.4.2 Embodied Energy (eE)

eE is the energy consumed by all of the processes associated with the production of a product, from the acquisition of natural resources to product delivery, including all the transport steps. Therefore, eE is the sum of all energy needed for the product to be manufactured and dismissed, spent during all its life cycle.

Building eE is the total energy required to construct it - that is to extract the raw materials, process and manufacture them as necessary, transport them to site and put the building together. eE is the energy that has "gone in with the bricks" and which cannot be recovered during the lifetime of the building.

In literature there are different ways of defining eE depending on the chosen boundaries of the study. The three most common options are: cradle-to-gate, cradle-to-site, and cradle-to-grave, explained as follows:

1) **A cradle-to-gate** model simply describes the energy required to produce the finished product without any further considerations.

2) **A cradle-to-site** study defines the eE of individual building components to the point of on-site construction. This includes the energy required to extract the raw materials, process them, assemble them into usable products and transport them to site, neglecting any maintenance or end of life costs.

3) **A cradle-to-grave** approach defines eE as that 'consumed' by a building throughout its life. This definition is more useful when looking at a building holistically, though it is much more complex to estimate.

With regard to the cradle-to-grave approach, eE includes:

- **Initial eE**, estimated as the primary energy of the building related materials, components, and technical installations, including all the steps from the raw material acquisition to manufacturing processes. Energy consumption, owing to the transportation from the manufacturing gate to the construction site and to the erection step is included in accounting for the initial eE.
- **Recurring eE**, which represents the primary energy consumption related to the maintenance and/or refurbishment of some building components and technical installations, over the building lifetime. Any materials or components that will require maintenance or replacement during the life of the building are accounted for and modelled. The recurring energy is quite critical in eE calculations, particularly for appliances, which usually only comprise a small fraction of initial eE. However, their high maintenance/replacement nature means that over the life cycle of the building their contribution to eE can be very large. The transport energy for the recurring materials and components must be calculated.
- **Demolition eE**, which is the energy necessary to demolish and dispose of the building at the end of its life.

eE does not include the oE required to use the final product. In other terms, eE does not account for the heating, cooling, lighting and power of any appliances that allow the building to serve its intended function. Therefore to understand the total life-cycle energy impact of buildings it is necessary to add the oE and eE.

2.5 Life-cycle carbon

Life-cycle carbon assessment is connected to life-cycle energy analysis and relies on prevailing energy structures to convert joules of energy to kilograms of CO_2. It can be performed for a 'full' life-cycle assessment, from extraction of raw materials to disposal or recycling of the final product after use. However, often life-cycle assessments are only carried out for parts of the full life-cycle.

2.5.1 Carbon emissions

It is important not to confuse the term 'carbon', as generally used in this report, with the chemical element of the same name. The term "carbon", in the context of these guideline, refers to CO_2 equivalent emissions, while in general, it refers to the chemical element "carbon C", which occurs as element in form of graphite, diamond or amorphous carbon (the element's free, reactive form), or as a compound in, by example, CO_2, carbonate rock (e.g. limestone, dolomite and marble) and hydrocarbons (e.g. coal, petroleum and natural gas). Plants can absorb CO_2 from the air, storing the carbon element in form of carbohydrates (sugar). This storing of carbon is referred to as carbon sequestration or carbon capture. This means that chemical carbon can be contained, as a chemical compound, in materials, which are used in building construction, e.g. building stones and timber. However, this storage of carbon in a raw material does not relate to the CO_2 emissions released in the process of making a building product out of the raw material.

The life-cycle carbon of the building is given by (Figure 2):

- Embodied CO_{2eq} (eCO_{2eq})
- Operation CO_{2eq} (oCO_{2eq}).

Understanding the relationships between eCO_{2eq} and oCO_{2eq} can assist in determining the overall optimum CO_{2eq} reductions.

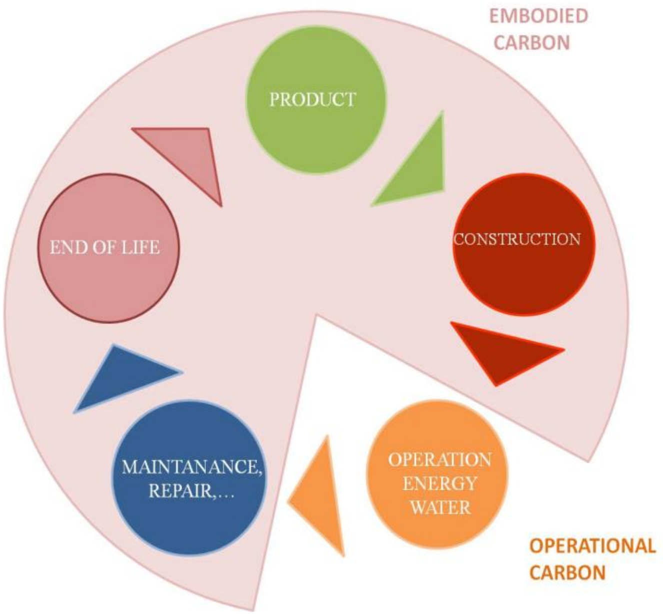


Figure 2: eCO_{2eq} and oCO_{2eq} in the building life-cycle

2.5.2 Operation CO2eq (oCO2eq)

Operation CO_{2eq} (oCO_{2eq}) is the carbon dioxide equivalent (CO_{2eq}) or greenhouse gas emissions associated with the building operation phase, arisen from heating, cooling, powering, providing water, etc.

2.5.3 Embodied CO2eq (eCO2eq)

Embodied CO_{2eq} (eCO_{2eq}) is the carbon dioxide equivalent (CO_{2eq}) or greenhouse gas (GHG) emissions associated with the non-operational phases of the building. **This includes CO_{2eq} emissions associated with construction, maintenance and demolition of a building, not with using it**, and more precisely, GHG emissions that arise from the extraction, manufacture, transportation, assembly, maintenance, replacement, deconstruction, disposal and end-of-life aspects of the materials and systems that make up a building.

The phases of the building lifetime may be split into four broad categories[1].

Over its lifetime, buildings are responsible for CO_{2eq} emissions through the following different phases:

- **Production**, including materials extraction, manufacture and transportation
- **Construction**, including transportation of product to site, storage of products, waste processing of packaging and product waste,

[1] These are laid out and described within BS EN 15978: 2011. Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.

installation of product into the building, including ancillary materials and water and energy required, and construction activities

- **Use**, in terms of building maintenance, repair, replacement and refurbishment

- **End of life**, as de-construction or demolition, transportation, waste processing and disposal.

If all life-cycle stages are included, then the assessment is known as “cradle to grave”, although this doesn’t mean that the assessment assumes products are destined to sanitary landfill. If products are normally recycled at end of life, then a “cradle to grave” assessment would account for this, but ensuring (in line with ISO 14044) that the benefits of recycling for a material are not double counted for both the use of recycled content and recycling at end of life.

The definitions given for eE in the previous paragraph are equally valid when considering eCO_{2eq}. When correctly measuring eCO_{2eq}, the sequestration of carbon within building materials, such as timber, and the emission (or sequestration) of carbon dioxide through chemical reactions during the production of materials such as cement and the lifetime use of materials such as in the carbonation of concrete, must be included.

In contrast to oCO_{2eq} for new buildings, which are usually regulated through Building Regulations, eCO_{2eq} is currently not regulated. However, eCO_{2eq} is receiving increased attention e.g. at the European level, with eE defined as one of the proposed core indicators in the EU Framework for Building Assessment.

There remains a significant, and still largely untapped, opportunity to address the eCO_{2eq} of a building or project, alongside its operational efficiency. The greatest opportunity for impact on eCO_{2eq} comes at the design stage, in particular in the building structure. If opportunities are not taken at this early stage, the eCO_{2eq} savings are lost for the entire lifetime of the building.

2.6 eE and eCO_{2eq} assessment: the life-cycle perspective

Life Cycle Assessment (LCA) methodology applied in the building sector is aimed at providing the actors of the building industry, with the environmental “performance” (eco-profile) of buildings. This is useful to establish in which way every decision acts, through a complete and analytical instrument that takes into consideration all the impacts of the “building system”.

The relevance of considering environmental-related product information by Life Cycle Assessment (LCA) is broadly recognised. It is a methodology suitable to estimate the eco-profile of a building, including all the phases in which built structures and facilities are procured and erected (manufacturing and transportation of the construction materials and components to the building site), operation, maintenance, renovation, the disassembly and the waste management.

In building and energy analyses, LCA allows for:

− The integration of the building environmental performance targets into the certification programmes and policies by the authorities, which are traditionally mainly focused on energy use as electricity and fossil fuels in building operation do not encompass the other relevant life-cycle phases

− The assessment of the most effective actions addressed to save energy and to minimize environmental impacts along the whole building lifecycle.

Nevertheless a LCA of a building is a complex task due to several factors like the long lifespan (often more than 50 years), the number of involved stakeholders and the singularity of each building. Besides, during its life a building may undergo significant changes in its shape, technical equipment, and/or function, involving significant changes in the environmental burdens. **When the energy performances of a building increase by means of retrofit measures, additional materials and components are applied, resulting in a higher eE. Thus, it is useful to assess the life-cycle environmental impacts and the eE of the retrofit measures, and the post-retrofit building energy consumption**. In this case, proper design and material/component selection of the retrofit actions are critical to minimize the related environmental impacts.

The LCA takes its origin from the industrial sector but, when its methodology is applied to the building sector, some obstacles may be encountered, mostly due to the complexity of buildings as a system. In fact, in the final product of the building sector, each "piece" that left the factories cannot be considered like a final product, but only like one of the many components of the building.

In building LCA analysis, the life cycle includes all the phases that characterize the life of a building, from its construction (analysing also the impact related to the production of the materials), through the real "use" of the building (considering not only the energy and water use, but all the operations needed to ensure a good maintenance state of the building), to the final phase of the building life, its demolition and disposal of the debris.

2.6.1 LCA steps

One of the first decisions to take is the definition of the Goal and Scope of the LCA analysis to be performed, in order to "set" the bases of the analysis.

The first step must be the definition of the goal of the analysis and the determination of the different alternatives to study and compare, and the level of detail to be achieved.

In this phase, the analyst and the public to whom the analysis is directed must be clearly identified.

After that, the functional unit and the stages to be considered must be decided, in order to compile the Inventory of Materials and processes. This is basically the "recipe" of the building production process, where information on all the inputs (in terms of materials, labour, processes, etc.) and the outputs (waste, emissions, etc.) should carefully collected.

It is clear that the setting of the Goal and Scope Definition determines the target of the analysis and its level of accuracy.

This flexibility in the determination and calculating of the LCA leads at the same time either to a "customization" of the purposes, but also to the possible distortion of the final results.

To optimize the measures and all the computational phases, the EN15978 subdivides the LCA into three main phases:

1. Production and construction phase (Cradle to gate if stages A1-A3 are considered, Cradle to site if the stage A4 is included too)
2. Use phase (B1-B7 stages are considered)
3. "End of life" phase (Cradle to grave considers not only the A1-A5 stages but also the C1-C4 stages), as represented in Figure 3.

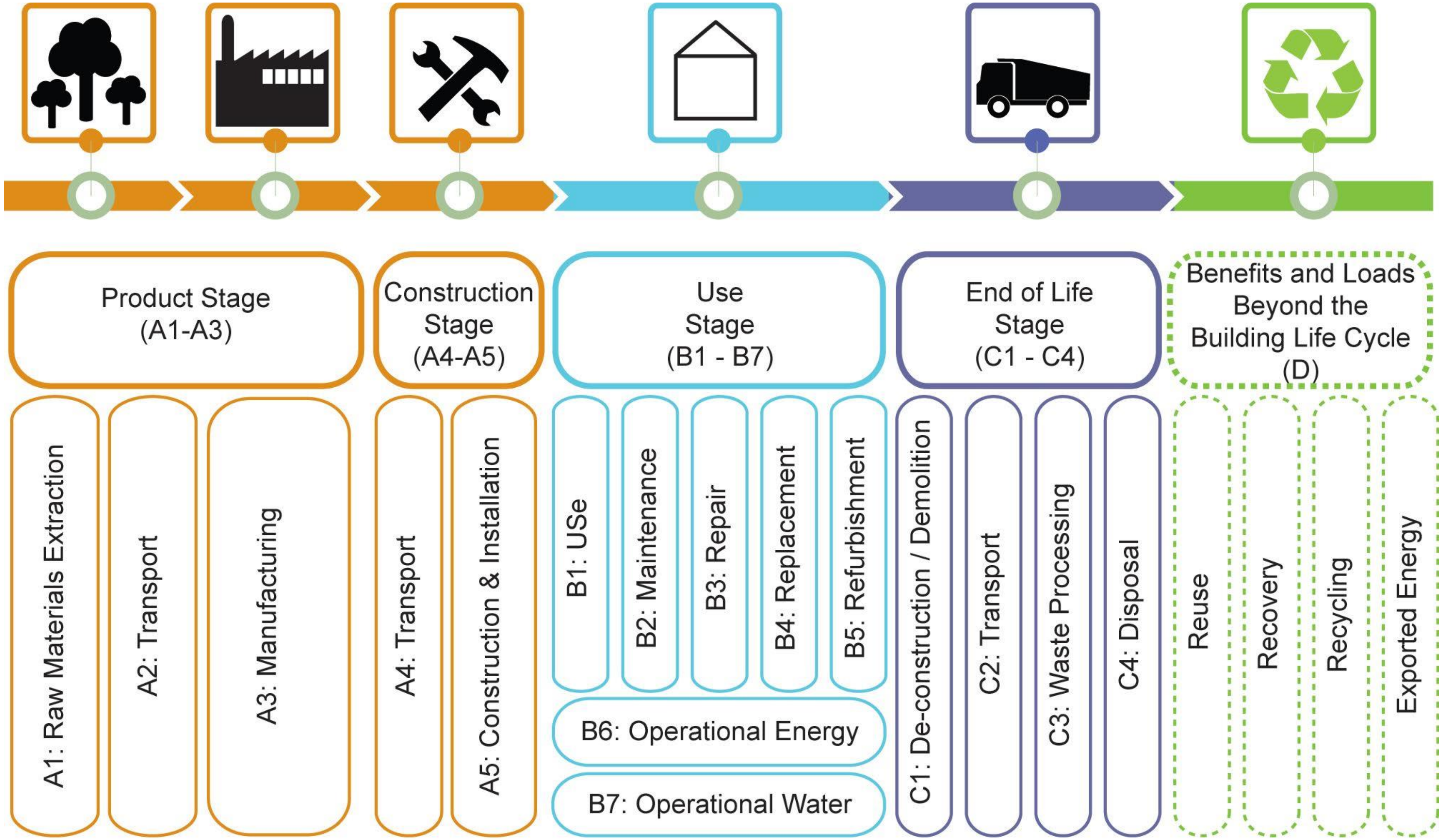


Figure 3: Stages of the Life Cycle (authors' elaboration of the contents of the EN 15978: 2011)

2.6.2 System Boundaries of Life Cycle Assessment

When analysing the data on impacts of a construction product, or an entire building, the definition of the system boundaries of the life cycle is a crucial methodology step.

In simple terms, the more stages of the lifecycle that are included in the LCA study, the more of the eE and eCO_{2eq} associated with the product or building that are brought into the analysis.

Some of the common boundaries of assessment are outlined below in Figures 3. The setting of the boundaries establishes the analysis' accuracy.

The assessment of the energy and environmental performance must cover upstream and downstream processes needed to establish and maintain the function of the building. In detail, the life-cycle steps and processes that represent a major source of eE and that are usually taken in consideration are (Figure 4):

• **production of the building**, which includes the production processes of all the building related materials and components, and the construction step of the building, taking into account raw material acquisition and resource supply;

• **material and component replacement**, including production and installation processes of the replaced components;

• **end-of-life of the building**, which includes all the process from the demolition/dismantling to the disposal/recycling.

• **transports**, including all the transport steps occurring during the whole life-cycle of the building, as the transportation of materials and components from the manufacturing gate to the construction site; the transportation of the replaced components from the factory gate to the building site; the transportation of wastes to recycling plants and/or disposal sites, when the end-of-waste state is reached.

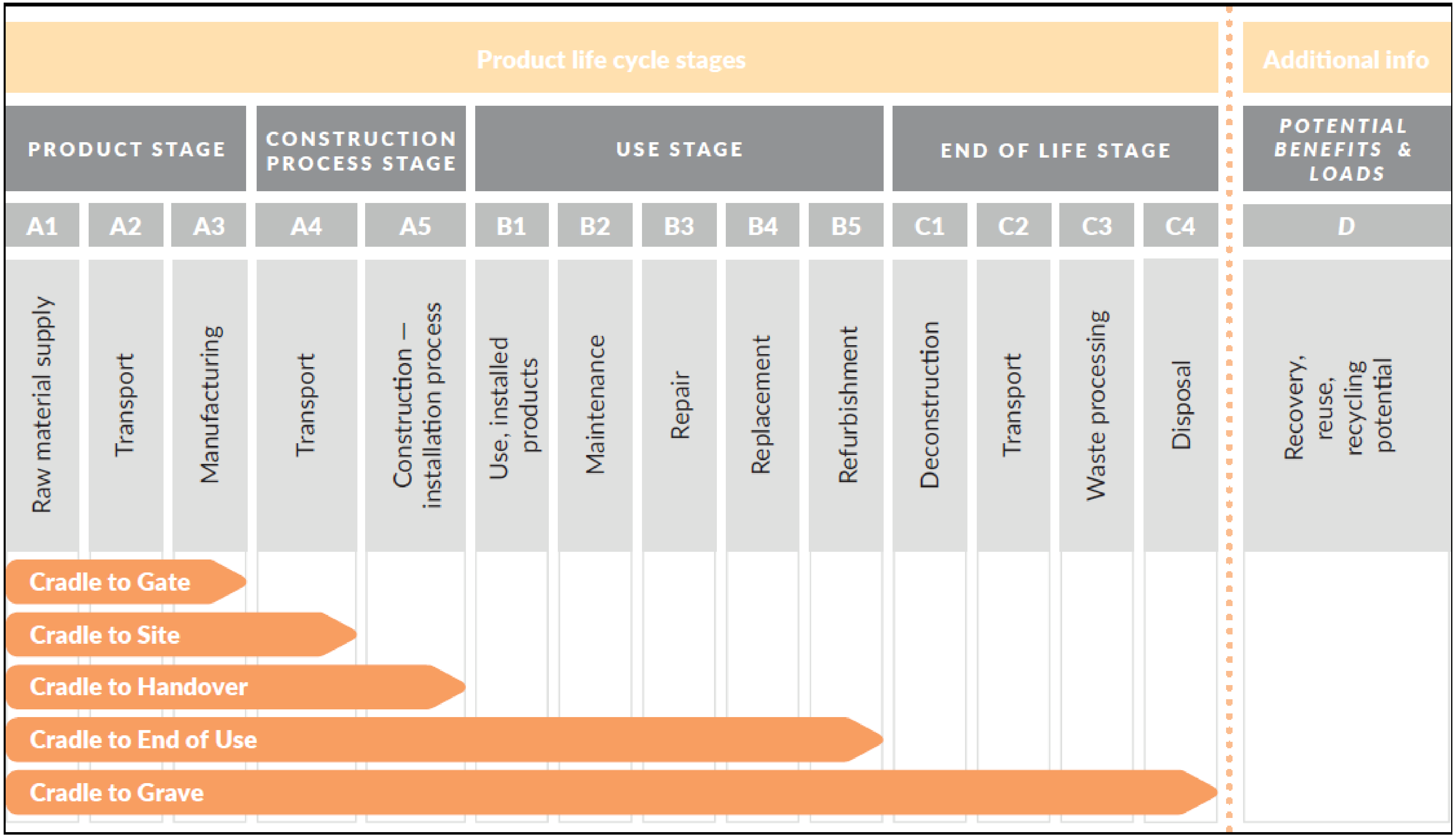


Figure 4: Illustration of the building system boundaries option in eE and eCO_{2eq} assessment (adapted from EN 15978:2011)

2.7 LCA methodologies

There are a number of recognised LCA approaches. These include process analysis, input-output analysis and hybrid analyses, and simplified/alternative approaches.

2.7.1 Process analysis

Process life cycle analysis (P-LCA) is the most commonly used method, involving the assessment of direct and indirect energy inputs to each product stage. It usually begins with the final product and works backwards to the point of raw material extraction. The main disadvantages lie in the difficulties in obtaining data, and time intensity. These result in compromises to system boundary selections (which are generally drawn around the inputs where data are available). Furthermore, it is likely to ignore some of the processes, such as services, inputs of small items, and ancillary activities. The magnitude of the incompleteness varies with the type of product or process and the depth of the study. P-LCA is better used to assess or compare specific options within one particular sector.

2.7.2 Input-output analysis

Originally developed as a technique to represent financial interactions between the industries of a nation, the input-output life cycle analysis (I/O-LCA) can be used in inventory analysis to overcome the limitations of process analysis. This method is based on tables which represent monetary flows between sectors and can be transformed to physical flows to capture environmental fluxes between economic sectors. The number of sectors and their definition vary within each country. The great advantage of this method is data completeness of system boundaries: the entire economic activities of a nation are represented. However, despite the comprehensive framework and complete data analysis, I/O-LCA is subject to many uncertainties, due mainly to the high level of aggregation of products. Many dissimilar commodities, or sectors containing much dissimilarity, are put into the same category and assumed identical; assumptions are based on proportionality between monetary and physical flows. In some countries I/O tables are not updated frequently, resulting in temporal differences with irrelevant or unrepresentative data.

I/O-LCA is suitable for strategic policy making decisions (comparing sectors) as well as providing complementary data on sectors not easily covered by P-LCA. To assess life cycles of older buildings, I/O-LCA would be impractical, as the economic input and output data for the time of construction is not, or at least not easily, available.

2.7.3 Hybrid analyses

The disadvantages of the previous methods can be reduced if a hybrid LCA method, combining both P-LCA and I/O-LCA methodologies, is employed. In this model, some of the requirements are assessed by P-LCA, while the remaining requirements are covered by I/O-LCA. The main disadvantage of these techniques is the risk of double counting.

2.8 eE and eCO_{2eq}: climate and building energy performance

It is a known fact that the climate has large implications on the optimal design of envelopes.

Constructions in cold climates usually use thin but highly insulated walls; buildings in hot zones make wide use of thermal inertia in order shift demand loads; in tropical climates natural ventilation is of paramount importance. In other words, a building properly designed under bioclimatic principles for Denmark (Figure 5) would not perform as well in Italy (Figure 6).

Figure 5: Example of building design for cold climate, Energy Flex house, Denmark

Figure 6: Example of building design for Mediterranean climate, Leaf House, Italy

This has particular relevance for the eE and eCO_{2eq}: **a well-designed building, consuming reasonably low energy during its use, will require different eE and eCO_{2eq} to be produced and dismantled**. There cannot be a threshold level to be indicated firmly in legislation, a good building in the Mediterranean area would require high availability of thermal mass in the structure. A good one built in a cold country might as well use a wooden structure. eE and eCO_{2eq} in the two cases would vary largely.

According to a selection of literature studies, authors have selected some case studies reported in Figure 7 that well represent the concept hereby discussed. It is however clear that Figure 7 represents only some relevant case studies and that the concept is not generalizable to all buildings in any cold or hot area of the world. For clarity's sake, the reported case studies refer to Europe, the hot area being the Mediterranean one and the cold area being the Scandinavian region.

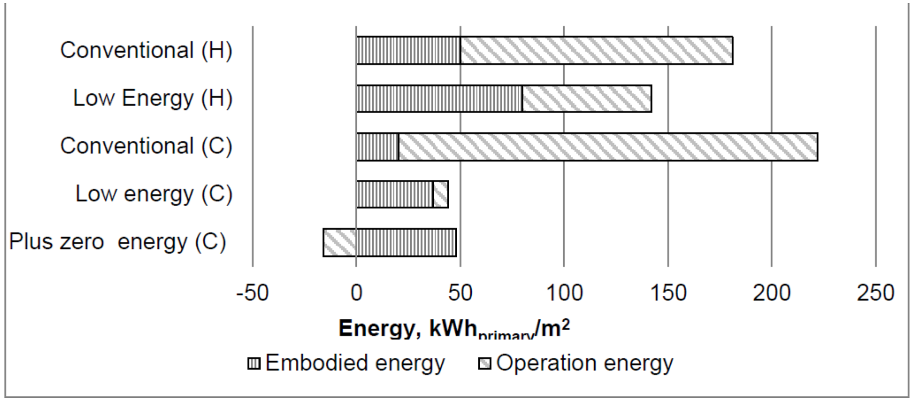


Figure 7: eE – Overview of embodied and operation energy in different case studies

Figure 7 puts on evidence that **light buildings constructed in cold climate (C) areas usually show lower values of specific eE (kWh/m^2) if compared to the more massive ones located in hot (H) countries**.

Figure 7 reports also the definition of 'low energy' buildings as opposed to 'conventional' ones. Standing in a region of 'grey' concepts, where there cannot be a univocal and universal definition of 'low energy' buildings, it is however possible to briefly discuss the most relevant factors influencing this definition.

Design of 'low energy' buildings in the mind of Policy Makers and designers refers to an occupied building that is characterized by a net energy use during the operation phase significantly lower than the average of buildings in the same zone.

The target of a low energy building may be achieved through a careful design that takes in consideration the features of the climate. Therefore for example, for a cold country:

- Maximization of solar gains through optimal shaping of the body of the building
- Low transmittance double or triple glazing adopted for the windows
- Highly insulated walls to reduce thermal losses
- Use of some thermal mass to offset peak power requirements for heating
- Development of natural ventilation strategies to remove excess heat from the building during summer
- Use of high efficiency energy systems to guarantee thermal comfort (e.g. HVAC systems, heat recovery systems, centralized heat pump units, energy generation systems)
- Use of low energy consuming appliances
- Use of 'smart' management system that optimize the use phase of such complexity systems
- 'Smart' occupants as well, and the development of a environment-friendly conscience in the people occupying the building

Most of the bullet points reported in the previous list, however, aiming towards the **reduction of the operating energy demand, involve an increase in eE of the building due to energy intensive materials** used in the building shell and technical equipment.

In other words, from a life-cycle perspective, when shifting from conventional houses towards low energy buildings the relative share of operating energy decreases, while the relative share of eE increases. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach to compare the energy savings achieved in the building operation through the local energy generation with respect to the overall energy consumption. **A Net ZEB would have zero operation energy by definition and the whole energy needs would be connected just to the eE required for its construction**. The example Plus zero energy building in Figure 9 shows, in fact, negative operating energy, owing to the higher energy generation in comparison to energy consumption.

2.9 Benefits of measuring eE and eCO_{2eq}

One of the most useful benefits from measuring eE and eCO_{2eq} is the possibility to look at sustainability from a more holistic perspective.

In the last few years, a general growth of interest related to the reduction of the GHG emissions and of energy consumption on a global scale is spreading. So far, such attitude has been based quite exclusively on the energy consumption during the use of the products (i.e. less CO_2 emission for cars, less thermal dispersion for houses, low consumption appliances).

The critical issue of this approach is given by the lack of interests related to the previous processes that are necessary for the realization of the goods (buildings, in this particular case).

The quantification of eE and eCO_{2eq} through the LCA analysis can lead to a more realistic vision of the environmental impacts of our actions. In fact, LCA analysis can be used to determine the real sustainability (analysing the entire life cycle and so the entire energy consumptions and GHG emissions) of each product.

Thanks to its holistic approach LCA can determine the incidence of the environmental impact of each different phase of the product (building), so it is possible to compare different solutions without misinterpreting the “green washing” marketing strategy.

The easy to read results (numerical values ensure a relatively easy comprehension on the observation between the results of some comparative analyses of two or more alternatives) of the LCA analyses based on eE and eCO_{2eq} should permit a more comprehensive understanding not only of the operator involved on the building-design process but also of a public as wide as possible.

LCA analysis could represent a useful design decision instruments or a final evaluation system to verify the sustainability of the realized object.

2.10 Benefits of managing eE and eCO_{2eq}

The managing of the eE and eCO_{2eq} could lead to multiple benefits. These are related to the possibility to tackle those sectors or production phases that are responsible for the higher impacts so to to focus the attention on them, in order to help the involved companies to apply particular systems/solutions that lead to a reduction of the environmental impacts.

During the design phases of a building, a comparative analysis between the various existing alternatives based on eE and eCO_{2eq} can lead to the adoption of the most suitable solutions from a sustainability point of view.

If all products that form a building had a mandatory declaration of their eE and eCO_{2eq} (as well as other parameters resulting from a cradle-to-gate LCA) the actors of the building industry would have the possibility to make informed decisions on the choice of materials and components for buildings. Nowadays some sustainability-oriented documentation and certification (i.e. the energy-consumption declaration) must be presented during the proposal of each new building-construction operation. In the future, a preliminary LCA analysis might be one of the documents requested for the project approval.

Ultimately, a rating system with the results explain with an easy accessible label (A+, A, B, and so on) could be implemented to describe the environmental performances of buildings, and could become an accessible tool for the occasional customers (i.e.: the final users of a building) so as to facilitate the achievement of the ultimate goal: the reduction of the eE and eCO_{2eq} of the building sector.

2.11 Direct inclusion of eE and eCO_{2eq} in regulations

The inclusion of eE and eCO_{2eq} in regulations for buildings would be likely to have a significant impact on the attitudes and practices of clients, designers and contractors. However, while in some cases their integration is encouraged, most building regulations do not currently include eE/eCO_{2eq}.

One exception is the Netherlands, where there is now a mandatory calculation of material impacts, although there are still no standards set. Plans to include the measurement of eE/eCO_{2eq} in building regulations are currently under development in Austria and the UK. However the regulations are currently still focused on operational impacts; for example, the next iterations of the UK building regulations will require the demonstration of ‘zero carbon’ in domestic buildings from 2016 and in non-domestic buildings from

2019, but the definition of 'zero carbon' still currently excludes all embodied impacts.

As already discussed in previous paragraphs, the focus of legislation needs to change from the operational level to the whole life-cycle of the building including operation phase and all the other steps.

Regulations may require e.g. that eE and eCO_{2eq} must be calculated and shown as a 'labelling' to be included in legal documents when buildings are constructed/sold as it is the case for energy performance certifications in most countries. A labelling certification scheme may be defined for certain climates and construction features and/or eE and eCO_{2eq} regulative limitations may be set for each country.

This is the most impactful measure that may be discussed and carried out by Policy Makers and may be the turning point for a more sustainable building design in the practice.

2.12 Voluntary certification

Non-mandatory certification has also been shown to have considerable impact in changing behaviour and improving standards. A "greener" design is always appealing in a market – the one of green products – that has undergone continuous growth in the last years and has not been impacted largely by the economic crisis all over the world.

Several countries use their own certification schemes, including: Green Star and NABERS (National Australian Built Environment Rating System) in Australia, Casaclima and Itaca in Italy, Selo Casa Azul in Brazil and CASBEE (Comprehensive Assessment System for Built Environment Efficiency) in Japan. Others use a combination of different schemes: Germany, Austria and Denmark use the DGNB (German Sustainable Building Council) certification. BREEAM (Building Research Establishment Environmental Assessment Methodology) was developed in the UK as a general 'design and assessment method for sustainable buildings' (http://www.breeam.org/), now used across many other countries. The Netherlands uses several schemes including GPR (Green Performance of Real Estate), BREEAM and GreenCalc.

In the Netherlands, LCA tools are related to certification schemes such as GPR, BREEAM, GreenCalc, whilst in the Czech Republic, the LCA tool is included in the country's database (envimat.cz). In Australia and the UK, there are numerous tools used for this purpose. LCA tools in Australia include 'LCA Design', a BIM based LCA tool for commercial buildings and 'eTool', a web-based LCA tool for buildings. In the UK, LCA tools are generally developed by academic research or engineering consultancies (Butterfly tool, Embodied Carbon Metric tool, Rapiere, LifeCYCLE), the Building Research Establishment (Envest, Green Guide Calculator, IMPACT) and the Environment Agency (Carbon calculator for construction projects).

The development of tools, labelling and national certifications is of a high appeal to practitioners and valuable for the diffusion of low eE and eCO_{2eq} building design.

In order for data on eE and eCO_{2eq} of a building material or product to be robust and reliable, it is important that it is gathered using a recognised and verifiable methodology.

As clients, developers, and contractors increasingly perform eE and eCO_{2eq} assessments on their buildings, the industry is responding by creating and providing more data.

At present, not all construction product data is collected using consistent boundaries of assessment, and product specific data emerging from manufacturers is not always comparable with the more generic product data.

Much of the data on building products available covers only cradle to gate stages and data on the impacts covering more life cycle stages are still developing.

Another potential source of product data is an environmental Product Declaration (EPD). Importantly, the rules that guide how a product's environmental impacts are assessed and communicated through the EPD allow for the definition of different boundaries.

In addition, although there is one international standard (ISO 14025) that sets out the standards any EPD should meet, it allows for different sets of Product Category Rules to be defined by different countries and programmes.

Therefore EPD for a construction product that is developed under different Product Category Rules are not comparable. In an effort to standardize EPD across the European Union, the a European Standards Technical Committee (CEN TC 350) has developed a suite of standards, which includes the BS EN 15804 which provides the core rules for the creation of EPD for the Product Category “construction products”.

However as yet there is no compulsory harmonized European standard on EPD preparation. In the UK the national scheme was developed by BRE called the 15804 EPD scheme.

2.13 The role of Policy Makers

Any efforts to measure and mitigate eE and eCO_{2eq} would be a mitigation measure toward climate change for Governments. Until now the global attention of Policy Makers involved in GHG emissions reduction has been focused on predominantly focused on operational energy/CO_{2eq} use and therein, the Zero Carbon/Energy Buildings Policy. To support the vision of a low carbon future, local planning authorities should:

- Plan for new development and ways which reduce GHG emissions
- Support energy efficiency improvements to existing buildings
- When setting any local requirements for a buildings sustainability, do so in a way consistent with Government's zero carbon buildings policy and adopt nationally described standards.

Since eE and eCO_{2eq} are not included formally by most governments as part of the Zero Carbon/Energy policy, and not recognized as allowable solutions to reduce the GHG emissions, they are often neglected within local plans nor does it carry meaningful weight within the planning process.

However, the regulation and practice of measurement and reduction of eE and carbon is growing rapidly. The UK is widely recognised as having been a leader in the field for a number of years, with the Bath ICE database in particular used across the world despite of its often-limited relevance for their region and industry.

Northern European countries such as Germany and Austria may now be overtaking those in the UK, with widespread research programmes underway. In Australia, innovation credits for Lifecycle Impacts are already available as a part of the Green Star rating system and likely to be included as a firm credit in future updates, which has led to major developers making the eCO_{2eq} measurement a standard feature of all of their projects.

In January 2013, the Netherlands became the first country to regulate for the measurement of greenhouse gases embodied in buildings: as of the 1st January 2013, a new environmental requirement in the Dutch Building Decree requires two new environmental indicators to be reported with respect to building materials being greenhouse emissions and depletion of resources (i.e. an LCA) for residential and office developments over 100 m^2 according to the Environmental Assessment Method for buildings. Other countries have developed national databases of the environmental impacts of products and materials, including those used in construction.

Collections of manufacturers EPDs concentrating on construction products have also been developed - see for example www.environdec.com, www.bau-umwelt.de (Germany) and www.inies.fr (France), as well as the BRE Green Book in the UK

As well as the EU and International Standards, which have been developed over the last few years, some countries have developed their own voluntary national standards and regulations. Examples are:

- Germany - VDI 4600 (2012) Cumulative energy demand: Terms, definitions, methods of calculation
- Switzerland - SIA 2032 (2010) Grey Energy of Buildings
- Britain - PAS 2050:2011 – Specification for the assessment of life cycle greenhouse gas emissions of goods and services, and PAS 2060:2010 - Specification for the demonstration of carbon neutrality
- In DGNB (Germany), a building level LCA, incorporating the life cycle impacts from regulated energy use, is mandatory to provide the majority of the environmental credits
- The Netherlands, which also has a national construction LCA database (essential for the regulated LCA assessments)
- The German construction LCA database
- The Sustainable Energy Authority of Ireland, which has also carried out work on embodied CO_{2eq}.

To make the transition to a low-carbon economy happen in the future, Policy Makers have a strong role to play today. Energy demand in buildings will rise by almost 50% between 2010 and 2050 in a business-as-usual scenario. Following energy efficient and low-carbon pathway can lead to a 25% reduction in total energy use compared to business-as-usual. In such a context, since the building sector involves several complex processes, tasks, requirements, and knowledge, Policy Makers are leading actors in designing and implementing policies effectively.

In particular, moving from standard houses toward the ambition of zero carbon/energy buildings, Policy Makers play key roles in realizing the importance of eE and eCO_{2eq} in the assessment of the building sustainability. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach to compare the energy savings achieved in the building operation with respect to the overall life-cycle energy consumption. In the same way, as we build increasingly energy efficient buildings that use less and less energy to run and rely increasingly on locally-generated low or zero carbon heat and power sources, the proportion of the building's lifecycle CO_{2eq} that comes from the eCO_{2eq} becomes more significant.

An important determinant of success in reducing greenhouse gases from buildings lies in the capacity of Policy Makers in the building sector to design and implement policies effectively.

Policies to reduce greenhouse gas emissions from buildings are usually multi-faceted and involve more than one stakeholder. Building activities must therefore involve the relevant parties to have the desired effects.

Today, many governments have dedicated agencies and staff working for the promotion of energy efficiency. According to a survey of 70 countries conducted by the World Energy Council and ADEME in 2008, about two thirds of the countries surveyed have a national energy efficiency agency and over 90% have a Ministry Department dedicated to energy efficiency. The European Union has even created an “Intelligent Energy Europe” Agency to manage energy efficiency projects including for buildings, as well as help establish local and regional energy efficiency agencies (European Commission Intelligent Energy Europe web site). These agencies often play a coordinating role to facilitate consultative processes and communications between stakeholders, including between different branches of the government itself.

To select the most appropriate policies toward a low carbon building sector, Policy Makers should support the enforcement of regulatory policies and the creation of goals and standards, aimed at the reduction of the building eE and eCO_{2eq} issues. Broadly speaking, they should aim at the following main targets:

- Support collection, analysis and use of data about eE and eCO_{2eq} of building materials, in order to create suitable energy and CO_{2eq} indicators for policy measures. Without the capacity to collect, analyse and use data pertaining to eE in buildings, government officials and building professionals alike will not be able to use them. Building this capacity requires both training as well as the availability of equipment to measure energy use. The availability of reliable data could also facilitate the application of energy use simulation software for buildings, which are proving to be effective tools for building designers and engineers.
- Enhance regulatory policies, which require appropriate training and understanding of what the policies are and what steps are needed if the object, which is subject to the regulation, falls short of the legal standard.
- Encourage the adoption of codes, which are enforced and periodically updated
- Participate in the development of national codes and standards

- Enforce mandatory labelling and certification programs, which are more effective than voluntary ones. Effectiveness can be boosted by combination with other instrument and regular updates
- Promote economic and market-based instruments
- Promote fiscal instruments and incentives
- Support information and voluntary action.

2.14 Desired targets

Clearly there is a role for every stakeholders in the reduction of eE and eCO_{2eq} of buildings. National and international Policy Makers should include eE and eCO_{2eq} in compulsory regulations for buildings, in order to involve a significant impact on the behaviour of different actors of the building sector (Figure 8).

1. Establish national regulations that make investments for eE and eCO_{2eq} reduction mandatory in new buildings and in renovation of existing buildings.

2. Collect data and carry out inventories of eE and eCO_{2eq}, from the national building stock to establish baselines and set performance goals to reduce life-cycle energy consumption and carbon emissions in existing and new buildings, depending on their site, typology and final use.

3. Fix a benchmark value for eE and/or eCO_{2eq}, as a target value not to overcome, for the particular building type in a country. If this target is met, a fund, which is established to promote initial investments and/or renovations of buildings, can be used. Such a fund can be financed through taxations of energy use above the national average, thereby always providing additional incentives to high energy users to reduce energy use.

4. Support the development and reform of all flexible mechanisms to encourage investment in reducing not only energy demand and greenhouse gas emissions from building operations, but also eE and ECO_{2eq} in building life-cycle.

Figure 8: Desired targets and strategies to be implemented by Policy Makers

2.15 Detailed checklists

By definition, policy-making is the process by which governments translate their political vision into programmes and actions to deliver 'outcomes' (desired change in the world). Thus, Policy Makers are individuals (usually members of the board of directors) who have the authority to set the policy framework of an organization. In detail, the role of the Policy Maker is act as a funnel to gather information through consultation and research and to reduce and extract from the information, a policy or a set of policies, which serve to promote what is the preferred course of action. Some of the skills that Policy Makers need to ensure the development of effective policies are:

- Collecting statistical information
- Convening and chairing discussion forums
- Be able to write policy documents in appropriate language and without ambiguity
- Seeking information from experts from outside the organisation (this may include government personnel, other sport and recreation managers and academics in sport and recreation management).

Policy Makers rely on information and advice from many other specialists and organizations. Information sources that Policy Makers use include:

- Statistical and analytical organizations
- Specialist research institutes
- Mass media
- Individuals
- Lobbyists
- International organizations and NGOs.

Given the complexity of the process, the following checklists might be a helpful tool for Policy Makers. By means of such checklists, Policy Makers can check their policies and/or the progress of them in order to reduce. Policy Makers can confirm their policies by tracing items in the checklists, taking into account the following activity categories:

- Collecting information
- Dissemination
- Performance assessment
- Legislation
- Subsidy.

Checklist are reported in Tables 1, 2, 3, 4 and 5.

Table 1: Collecting information

COLLECTING INFORMATION
☐ Support the review of the eE and eCO_{2eq} state of art
☐ Support the collection of eE and eCO_{2eq} eco-profiles of buildings, from national building stocks, depending on their site, typology and final use
☐ Collect methodologies to assess eE and eCO_{2eq}
☐ Identify hotspots in building life-cycle to reduce eE and eCO_{2eq}
☐ Collect building life-cycle costing
☐ Get news on eE and eCO_{2eq} from websites, blogs, conferences, evaluation reports, etc.

Table 2: Dissemination

DISSEMINATION
☐ Creation of website to provide news on eE and eCO_{2eq}, about: - *Related changes in legislation, conferences, seminars, workshops, academic events, etc.* - *Tools and database* - *Innovative low-energy technologies and materials* - *Innovative buildings: low energy buildings, net Zero Energy Buildings, Zero Carbon Buildings, etc.*
☐ List of available databases, distributed by website, at national level, open or close
☐ Characterization of available databases, by methodology, user addressed, system boundaries, assessment indicators
☐ Creation of tools and codes to evaluate eE and eCO_{2eq} in buildings
☐ Characterization of created tools and codes, by target, typology, procedure, and outputs
☐ Updating of created tools and codes

Table 3: Performance assessment

PERFORMANCE ASSESSMENT
☐ Goal assessment: - *energy supply assumption* - *energy source assumption* - *product specification* ☐ System boundaries ☐ Completeness and accuracy of study ☐ Comparison with conventional items: - *relative share among eE and oE, and* eCO_{2eq} *and* oCO_{2eq} ☐ Tool to be used for eE and eCO_{2eq} assessment ☐ Methodology of the used tool: - *Process LCA* - *I/O-LCA* - *Hybrid approaches* ☐ Baseline scenario - *To establish baselines and set performance goals to reduce eE and* eCO_{2eq} *in existing and new buildings* - *To set reduction targets related to specific programs or policy changes*

Table 4: Subsidy

SUBSIDY
☐ Fix a benchmark value for eE and/or eCO_{2eq} to match, depending on the building type in a country ☐ Establish a fund to promote initial investments and/or renovations of buildings ☐ Provide additional incentives to high energy users to reduce energy use ☐ Support the development and reform of all flexible mechanisms to encourage investment in reducing eE and eCO_{2eq} in building life-cycle

Table 5: Legislation

LEGISLATION
☐ Support national regulations that make investments for eE and eCO_{2eq} reduction mandatory in new buildings and in renovation of existing buildings
☐ Subject to regulations items related to construction site, such as transports, heavy machines, waste materials, energy consumption
☐ Subject to regulations items related to building design, building materials and components
☐ Subject to regulations maintenance, demolition and recycling steps
☐ Make mandatory documents for building application, in order to certificate the eE and eCO_{2eq} levels
☐ Building codes, as standard system for key elements of design and construction which affect the sustainability:
- *Designed for the building regulations in relation to building eE and* eCO_{2eq}
- *Able to differentiate different levels of eE and* eCO_{2eq}*, i.e. low energy buildings, zero carbon buildings, zero energy buildings, etc.*

Finally, the whole discussion reported in these guideline is reported in the following final synthesis Table 6 , including the most relevant facts highlighted in the document and the most relevant challenges Policy Makers would need to face when dealing with the topics of embodied energy and $CO_{2\ eq.}$ in buildings.

Table 6: Key messages and challenges

KEY MESSAGES					
1.	The consistency of measuring eE and eCO_{2eq} must improve.	**2.**	Calculation should focus on major structural elements with the notion that granularity can be adressed at a later date.	**3.**	Design teams must be challenged to come up with innovative solutions that adress eCO_{2eq}.
4.	Closed loop systems should be promoted so to maximise resource efficiency and lower eE and eCO_{2eq} (i.e. new build should be designed for re-use).	**5.**	It is unlikely that legislation will address eCO_{2eq} in a sufficient manner in the near future. In light of this industry should lead.	**6.**	The focus for reducing eCO_{2eq} should be on every day builds rather than iconic ones.
7.	oE and oCO_{2eq} should be maintained as priority. Embodied and operational energy and GHG are not conflicting issues, but they should be dealt with in tandem.	**8.**	Data should be trasparent and openly available across the industry.	**9.**	Better benchmarking and data sources are required.
10.	A business case for reducing eE and eCO_{2eq} is needed.	**11.**	eE and eCO_{2eq} modelling does not have to be overly complicated to be useful.	**12.**	Stronger links between researchers and practitioners should be forged.
13.	eE and eCO_{2eq} savings made now are important and will help to offset climate change.	**14.**	Architectural approaches exist that can reduce both embodied and operational energy and GHG.		

On the basis of the above messages the following challenges and recommendations are identified:

Challenges Identified:

1. Improving consistency in eE and eCO_{2eq} calculation methods.
2. Availability of comparable data
3. Opinion on whether there should be a single source of industry data for eE and eCO_{2eq}
4. Finding a way to involve and engage the entire supply chain.
5. Creating a methodology of eE and eCO_{2eq} measuring robust enough for legislation
6. Finding sources for funding and promotion to help develop and promote existing.

Final Recommendation:

1. eE and eCO_{2eq} reduction (both operational and embodied) must be better related to cost savings
2. eE and eCO_{2eq} needs to be incorporated into the energy planning
3. Better link design and procurement decisions to eE and eCO_{2eq} reduction
4. A base calculation methodology must be agreed upon
5. Clients must be informed on the benefits of low carbon outcomes
6. Industry must take the lead and not wait for legislation
7. Freely available buildings benchmarking tool are advised
8. Potential funding sources for improving databases and tools should be identified
9. Better acknowledgement should be made of material supply chains that are reducing their impacts
10. More materials carbon intensity data should be developed and verified.

3. Guideline for procurers

The aim of this section is to provide guidance provides procurers with orientation on how to effectively integrate the environmental criteria for reducing building eE and eCO_{2eq} in the procurement process. Such criteria can be introduced in tenders for the construction of new buildings, as well as in relation to contracts for repair and maintenance.

The criteria provide contracting authorities and their procurers with the opportunity to set requirements that address the most significant opportunities for environmental reduction of building eE and eCO_{2eq}. They provide procurers with a basis for selecting tenderers according to their competencies, set technical specifications at different levels of ambition, as well as encouraging tenderers to bring forward innovative design solutions. In such a context it is important that procurers have appropriate practical skills on environmental theme (Figure 9).

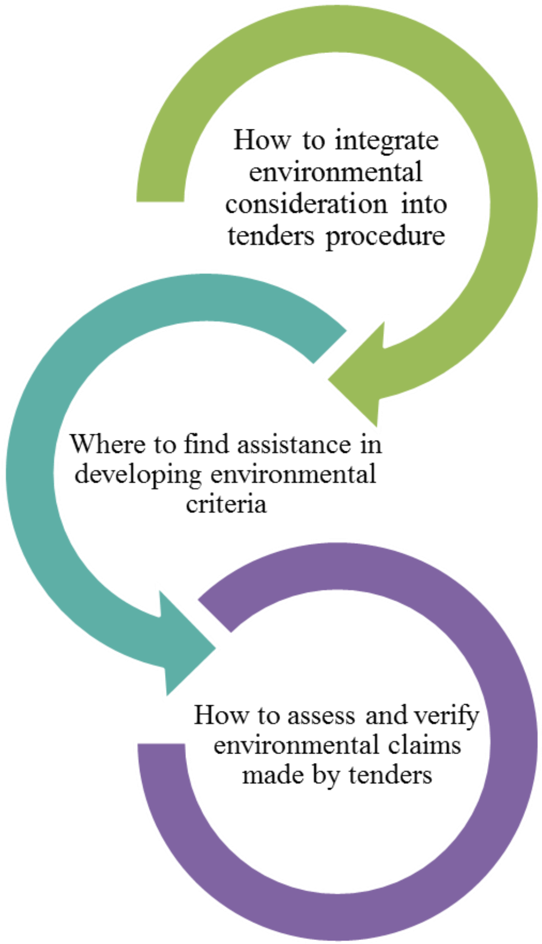


Figure 9: Required procurers skills (Adapted from EC, 2016)

3.1 The procurement process

Public procurement is about matching supply and demand, in order to deliver the goods, services and works which the public sector is responsible for providing. To identify the most economically advantageous tender does not necessarily mean going only for the cheapest offer. It means finding a solution, which meets the requirements that procurers have identified in the most cost-effective way. Protection of the environment can be one of these requirements and can therefore act as an equal consideration amongst others for the award of the contract. Each of the available procurement procedures (open procedure, restricted procedure, etc.) offers a number of stages where green considerations can be applied, among which:

- Subject matter and technical specifications
- Selection and exclusion criteria (e.g. compliance with environmental laws, technical and professional ability)
- Award criteria.

In deciding which procedure to use, and how best to include environmental criteria within the sections outlined above, it is useful to have some knowledge of the market – e.g. the availability, cost and possible practical implications of greener alternatives.

Letting the market know well in advance about tenders which will include environmental criteria is advisable. This will give suppliers sufficient time to prepare for requirements.

Environmental criteria can be of two type:

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

When defining the subject-matter of a contract, contracting authorities have great freedom to choose what they wish to procure. This allows ample scope for including environmental considerations. Technical specifications can provide measurable environmental requirements against which tenders can be evaluated.

Technical specifications may be formulated by reference to international or national standards and/or in terms of performance or functionality. They may also refer to appropriate criteria that are defined in labels. Selection and exclusion criteria focus on an economic operator’s ability to perform the contract they are tendering for. When assessing ability to perform a contract, contracting authorities may take into account specific experience and competence related to environmental aspects which are relevant to the subject matter of the contract. They may ask for evidence of the ability of operators to apply environmental and supply chain management measures when carrying out the contract. They may also exclude operators who are in breach of environmental law. Procurers should set out in advance in tender documents the types of evidence which bidders can submit to demonstrate the compliance with technical specification. This is often done by providing an indicative list, and stating that other equivalent forms of evidence will also be accepted.

The main difference between technical specifications and award criteria is that whereas the former are assessed on a pass/fail basis, award criteria are weighted and scored so that tenders offering better environmental performance can be given more marks.

According to Buying Green Handbook it is possible to apply environmental award criteria, provided those criteria:

- Are linked to the subject-matter of the contract
- Do not confer an unrestricted freedom of choice on the contracting authority
- Ensure the possibility of effective competition
- Are expressly mentioned in the contract notice and tender documents, together with their weightings and any applicable sub-criteria
- Comply with the Treaty principles on public procurement.

Procurers may allocate points during the award stage to recognise environmental performance beyond the minimum requirements set in the specifications.

3.2 Environmental criteria in building design, construction and maintenance procurement process

Key environmental areas connected with eE and eCO_{2eq} building design, construction and maintenance are depletion of natural resources, primary energy consumption and GHG emissions associated with the manufacturing and transportation of building materials, building construction, transports and decommissioning of building. Environmental criteria can be proposed for each of the stages of the construction project, such as design stage, construction, transports and decommissioning of building. The proposed environmental criteria may relate to design with reduced embodied impacts, as use of construction products with a minimum use of energy for their manufacture and eventual disposal, or products that can be recycled or are biodegradable, long life and material efficiency, the use of lower impact modes of transport such as rail or shipping for construction products, etc. A technical evaluator specialized in LCA shall assist in preparing the Invitation to Tender (ITT). The procurer shall award points based on the improvement in eE and eCO_{2eq} of the main building elements listed in Figure 10 in comparison with a reference building or other competing designs.

New-build

- The structural frame, including beams, columns and slabs;
- External walls, cladding and insulation;
- Floors and ceilings;
- Internal walls;
- Windows;
- Roofs.

Renovation

- External walls, cladding and insulation;
- Re-roofing and insulation;
- Windows.

Figure 10: Scope of the building elements to be evaluated

Table 7 and 8 shows non-exhaustive environmental criteria that can be considered to evaluate the ability of tenderer and to the most environmental aspects of a building for eE and eCO_{2eq} reducing, respectively.

Table 7: Criteria related to the ability of the tenderer (Dodd et al., 2016)

Project manager – Experience and expertise in the management of:

- Contracts with environmental performance requirements;
- Implementation of environmental technologies and design innovation;
- Etc.

Competencies of the design team - Experience and expertise in:

- Specification of resource efficient construction materials;
- The specification, procurement and installation of low environmental impact construction materials;
- Use of multi-criteria building assessment and certification schemes;
- The development and implementation of staff travel plans, including infrastructure for low emission vehicles and bicycles;
- Etc.

Competencies of the lead construction contractor and specialist contractors - Experience and expertise in:

- Procurement of resource efficient construction materials;
- The procurement, installation and verification of low environmental impact construction materials;
- Implementation of demolition site waste management plans.

Table 8. Environmental criteria refer to the most important environmental aspects of a building for eE and eCO_{2eq} reducing (Adapted from JRC, 2012)

Building Design:

- Design for long life, using durable low maintenance materials
- Use efficient building envelope design and fittings to minimise materials
- Leaner design
- Designing out waste

Building materials:

- Exclusion of certain building materials
- Use of environmentally friendly materials
- Long life cycle and material efficiency
- Increasing recovery and reuse of materials (higher recycled content)
- Specific criteria for materials: wood, iron, etc.

Waste management:

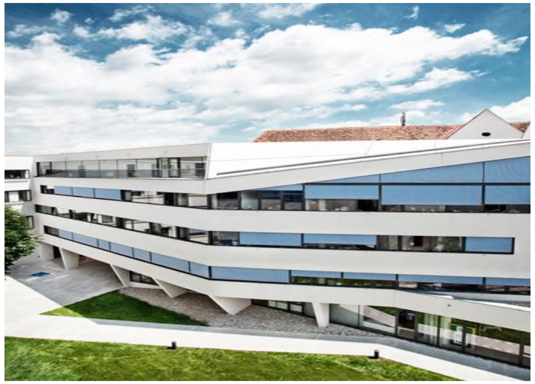
- Waste prevention
- Recycling and reuse of materials;

Other:

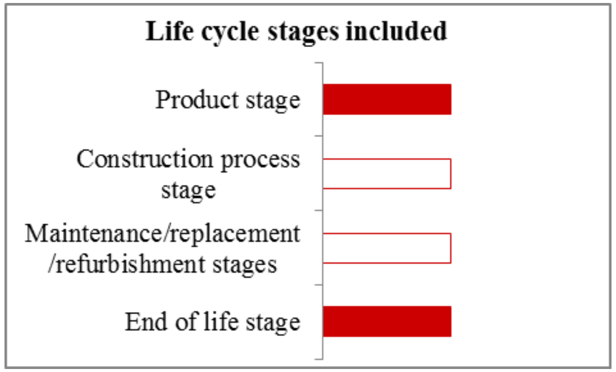
- Transport reduction (using locally sourced materials)

Annex: Case - Studies

Office building, Graz (Austria)

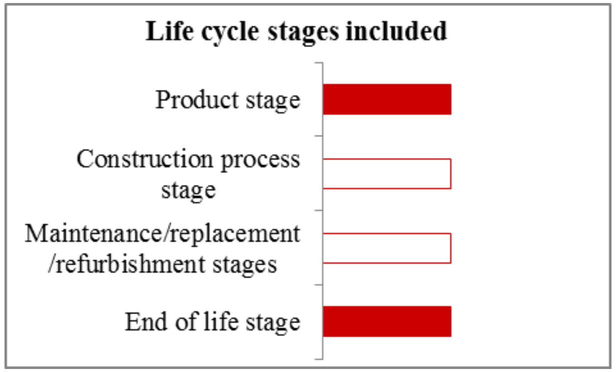


Lifetime	50 years
Building description	Load bearing walls are constructed in concrete and bricks. The heat insulation composite system consists of 16 cm expanded polystyrene (EPS). The roof consists of 20 cm reinforced concrete, 16 cm heat insulation and fibre cement panels assembled on an integrated sub construction. Inner walls are constructed as plasterboard. Double glazing with aluminum frame are used. The building is heated by district heating supplied via underfloor heating.
Energy reference area	2,034 m^2
Number of storages	-
eE	326 MJ/(m^2year)
eCO_{2eq}	4.69 $kgCO_{2eq}$/(m^2year)



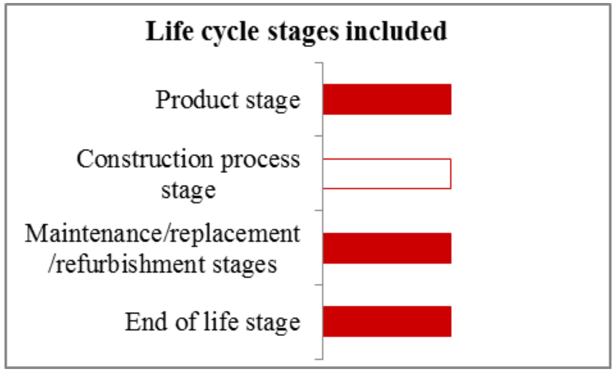
School building, Diedorf (Germany)

Lifetime	50 years
Building description	The structural components of the foundation and the floor slab are made of reinforced concrete, all other structural parts are wood or wood based products. The facade is made of wood, glass, with aluminium lamellas for the sunscreen. The roof is covered with a sealing membrane. 2600 m² of photovoltaics are installed on the roof.
Energy reference area	17,292 m^2
Number of levels	3
eE	93 MJ/(m^2year)
eCO_{2eq}	4.7 $kgCO_{2eq}$/(m^2year)



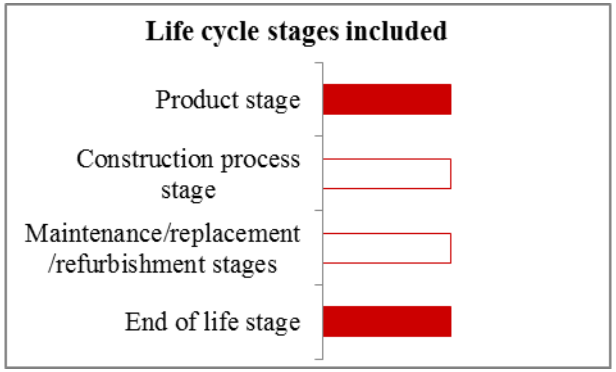
School building, Postdam (Germany)

Lifetime	50 years
Building description	The structural components of the fundament and the floor slab are armed concrete, all other structural parts are wood or wood based products. The façade is composed of wood, glass, with aluminium lamellas for the sunscreen. The roof is covered with a sealing membrane. A photovoltaic system of 370 m² is installed on the roof.
Energy reference area	1,035 m^2
Number of levels	2
eE	216.5 MJ/(m^2year)
eCO_{2eq}	9.36 kg CO_{2eq}/(m^2year)



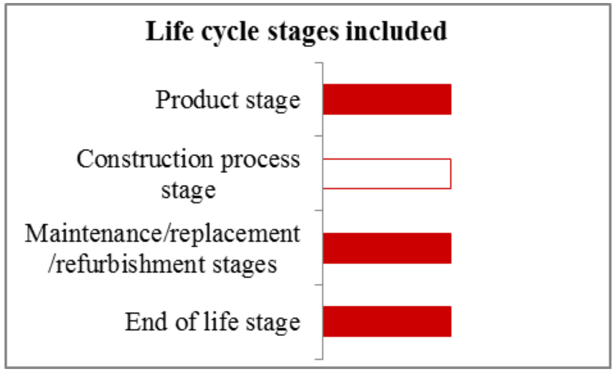
Residential building, Berlin (Germany)

Lifetime	50 years
Building description	The structural components of the foundations, the basement, the floor slab and the ceilings are made of reinforced concrete, all other structural parts are made of limestone. The façade and the insulation are composed of wood based products. The windows are composed of wood, glass, with aluminium lamellas for the sunscreen. The roof is covered with brick tiles. A photovoltaic system of 75 m² of is installed on the roof.
Energy reference area	2,118 m^2
Number of levels	4
eE	97.3 MJ/(m^2year)
eCO_{2eq}	5.7 kgCO_{2eq}/(m^2year)



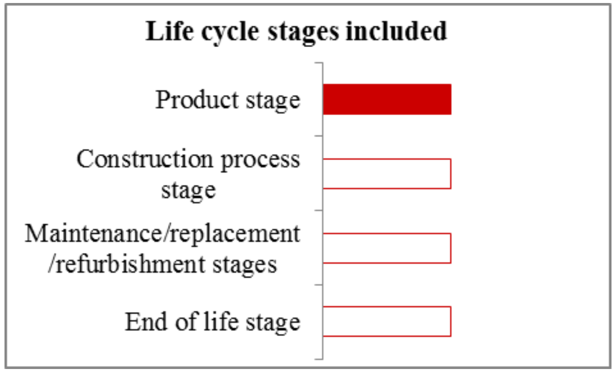
Office building, Bagsværd (Denmark)

Lifetime	50 years
Building description	The structural components are armed concrete and construction steel, and the façade is composed of glass, white glazed tiles and white aluminum lamellas. Above the atrium, a glass dome makes the top roof section. It is a low energy building.
Energy reference area	33,000 m^2
Number of levels	-
eE	89 MJ/(m^2year)
eCO_{2eq}	7.9 $kgCO_{2eq}$/(m^2year)



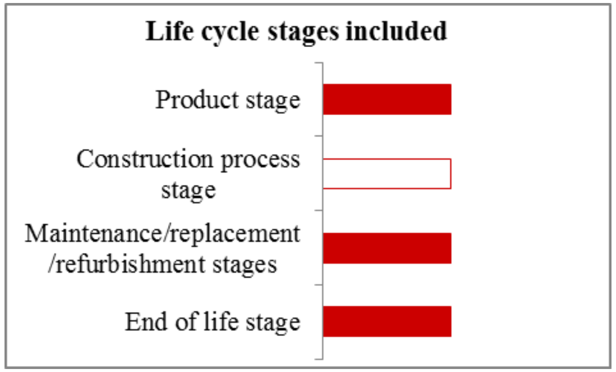
Residential building, Nyborg (Denmark)

Lifetime	50 years
Building description	The building is a 162 m^2 single family house constructed by use of two 40 feet high cube freight containers. The building is isolated with paper wool and clad in wood boards indoors and paper/plastic composite materials outdoors. The roof is sloping and clad in a steel sheet.
Energy reference area	129 m^2
Number of levels	1
eE	55 MJ/(m^2year)
eCO_{2eq}	1.04 $kgCO_{2eq}$/(m^2year)



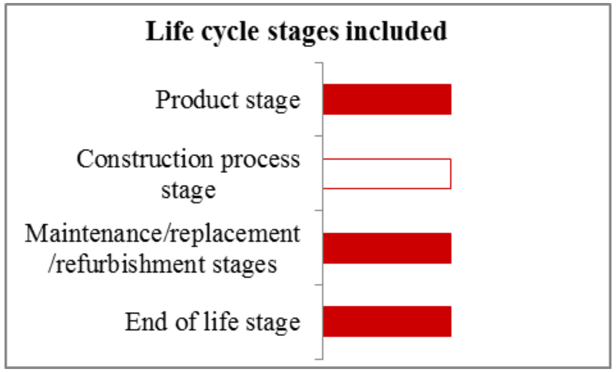
Single family residential buildings, Zero maintenance house, Nyborg (Denmark)

Lifetime	50 years
Building description	The building is a single family house with a concrete strip foundation. All walls are made of insulating cavity bricks, the outer wall with a complementing shell of regular bricks. The roof is constructed with timber, insulated with paper wool and clad in tile. Inside flooring is parquet on wood construction and insulation of EPS.
Energy reference area	136 m^2
Number of levels	2
eE	31 MJ/(m^2year)
eCO_{2eq}	2 $kgCO_{2eq}$/(m^2year)



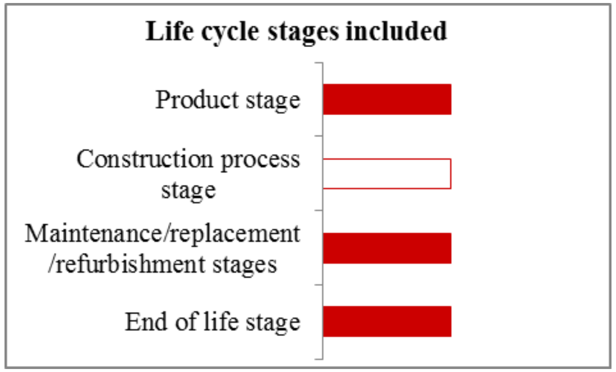
Single family residential buildings, Zero maintenance house, Nyborg (Denmark)

Lifetime	50 years
Building description	The building is a single family house constructed with pre-fabricated elements of wood constructions with insulation of foam and mineral wool. The building is founded on pier foundations. The building is clad in tempered glass.
Energy reference area	156 m^2
Number of levels	2
eE	46 MJ/(m^2year)
eCO_{2eq}	1.6 $kgCO_{2eq}$/(m^2year)



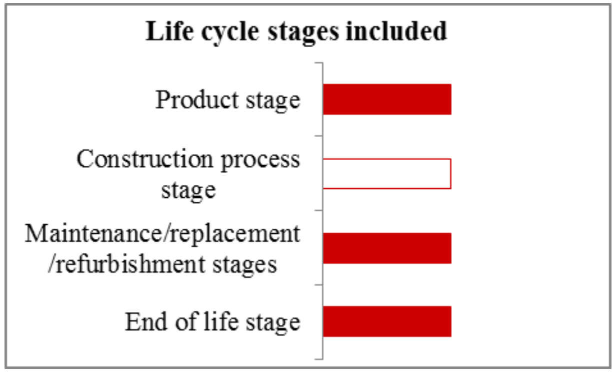
Single family residential buildings, Nyborg (Denmark)

Lifetime	50 years
Building description	The building is a single family house constructed in two floors with a concrete strip foundation and polished concrete floor slab on EPS. The lower floor walls are made of insulating aerated concrete bricks. The upper floor is designed with light façade elements of wood cladding on a wood construction. The roof is clad with a double bitumen membrane.
Energy reference area	147 m^2
Number of levels	2
eE	91.3 MJ
eCO_{2eq}	5.7 $kgCO_{2eq}$



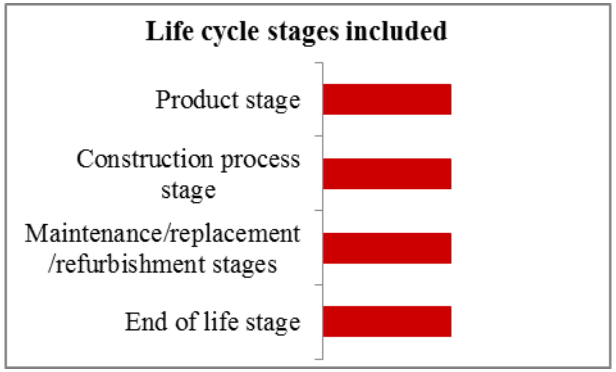
Single family residential buildings, Nyborg (Denmark)

Lifetime	50 years
Building description	The building is a single family house with a concrete strip foundation and a concrete floor slab. Walls are made of aerated concrete with an insulation of mineral wool and a cladding of fibre cement panels. The roof is clad with a double bitumen membrane.
Energy reference area	138 m^2
Number of levels	1
eE	120 MJ/(m^2year)
eCO_{2eq}	6.1 $kgCO_{2eq}$/(m^2year)



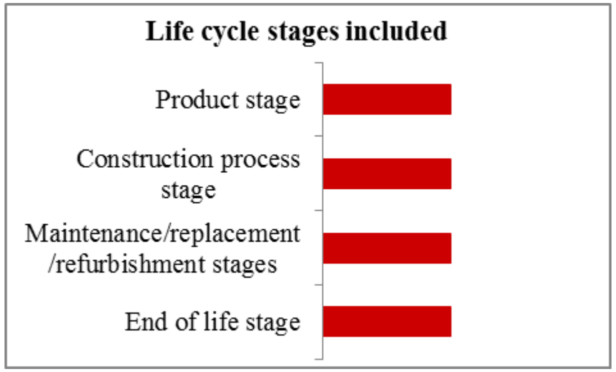
School building, Cambridge (United Kingdom)

Lifetime	68 years
Building description	The building uses prefabricated engineered timber I-beams fully filled with cellulose insulation for the external wall and roof. The façade is covered using a plasterboard system in some areas and in others untreated cedar cladding. A green roof is also used. Mineral materials are used for mass, contributing 85% to the total, with timber and steel following with 10% and 3% respectively.
Energy reference area	195 m^2
Number of levels	1
eE	620 MJ/(m^2year)
eCO_{2eq}	40 $kgCO_{2eq}$/(m^2year)



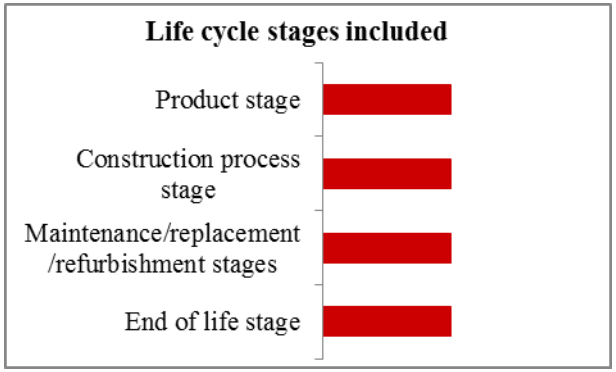
Residential building, Zurich (Switzerland)

Lifetime	60 years
Building description	The structural components are concrete and building. The windows have wood-aluminium frames.
Energy reference area	2,156 m^2
Number of levels	-
eE	115.5 MJ/(m^2year)
eCO_{2eq}	8.82 $kgCO_{2eq}$/(m^2year)



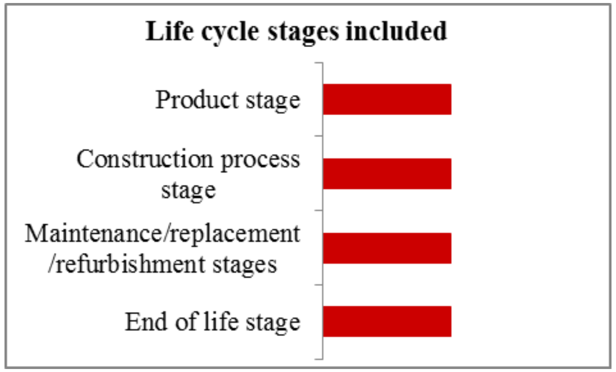
School building, Zurich (Switzerland)

Lifetime	60 years
Building description	The structural components are sandstone blocks, concrete and building bricks. The windows have wooden frames.
Energy reference area	8,033 m^2
Number of levels	-
eE	61.7 $MJ/(m^2 year)$
eCO_{2eq}	4.34 $kgCO_{2eq}/(m^2 year)$



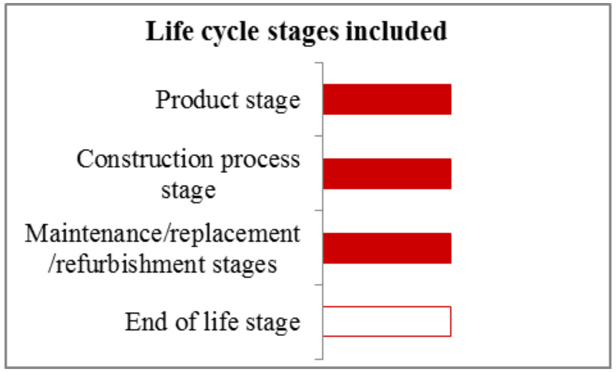
Residential building, Zurich (Switzerland)

Lifetime	50 years
Building description	The buildings are constructed in concrete with pre-fabricated shell elements which are filled with concrete on-site. Thus, the construction becomes very air-tight. It is a low energy building.
Energy reference area	11,003 m^2
Number of levels	5
eE	80 $MJ/(m^2 year)$
eCO_{2eq}	8.9 $kgCO_{2eq}/(m^2 year)$



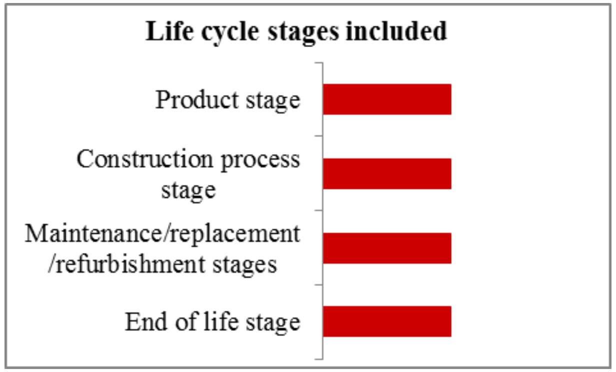
Educational building, Himachal Pradesh (India)

Lifetime	50 years
Building description	The building structure is based on reinforced concrete. All the outer walls are made of stone and inner walls are brick masonry. All laboratories have concrete cement flooring, in class rooms, seminar halls, faculty rooms and corridors high density limestone is used while in toilets ceramic tiles are used. All the frames of doors, vents and windows are of standard section cast iron. For the roof corrugated galvanized iron sheets and steel framed structure is used.
Energy reference area	3,920 m^2
Number of levels	3
eE	54.7 MJ/(m^{2}year)
eCO_{2eq}	9 $kgCO_{2eq}$/(m^{2}year)



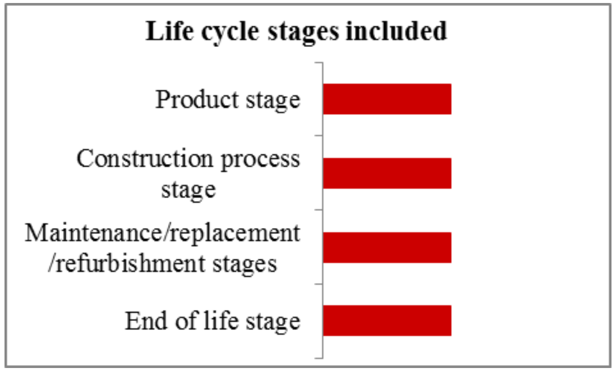
Residential building, Gaziantep (Turkey)

Lifetime:	50 years
Building description	The building structure is realized with concrete and steel. The external walls are made with 150 mm concrete block (30/40 Mpa) and 24 mm of plaster inside and outside. The internal walls are realized in 100 mm concrete block and 24 mm of plaster inside and outside. The roof consists in 300 mm polyurethane and 150 mm concrete.
Energy reference area	7,445 m^2
Number of levels	13
eE	156 MJ/(m^{2}year)
eCO_{2eq}	14.7 $kgCO_{2eq}$/(m^{2}year)



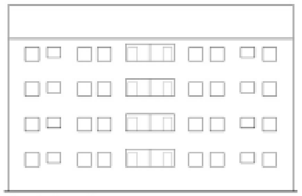
Residential building, Gaziantep (Turkey)

Lifetime	50 years
Building description	The building structure is made with concrete and steel. The external walls are made of 150 mm concrete block (20/30 Mpa) and 24 mm of plaster on both the internal and external side. The internal walls are made of 100 mm concrete block and 24 mm of plaster inside and outside. The roof includes 300 mm polyurethane and 150 mm concrete.
Energy reference area	2,110 m^2
Number of levels	3
eE	94 MJ/(m^2year)
eCO_{2eq}	9 $kgCO_{2eq}$/(m^2year)

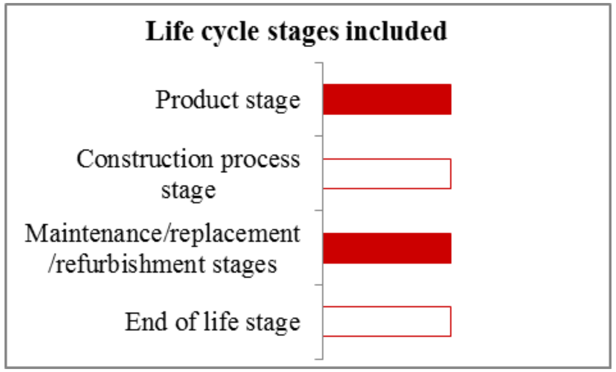


Residential building, Lisbon (Portugal)

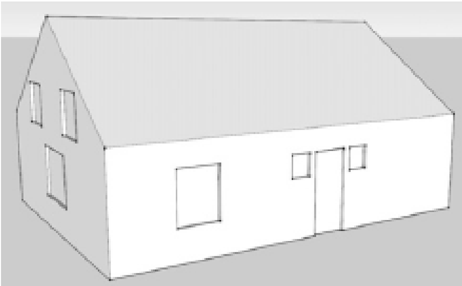

Front façade


Back façade

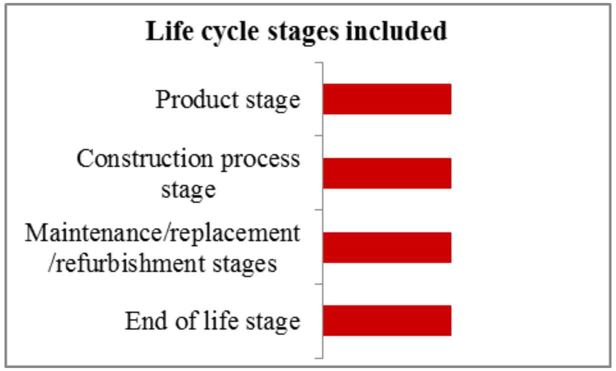
Lifetime	75 years
Building description	The building external walls are realized using hydraulic stone masonry and hollow brick masonry, interior walls using solid and hollow brick masonry; floors are realized with wooden beams/planks and reinforced concrete slabs, staircases in concrete with reinforced concrete landings, roofs with wood structure and roof tiles, fenestrations in glass and interior doors in wood.
Energy reference area	1,041 m^2
Number of levels	4
eE	50 MJ/(m^2year)
eCO_{2eq}	3,2 $kgCO_{2eq}$/(m^2year)



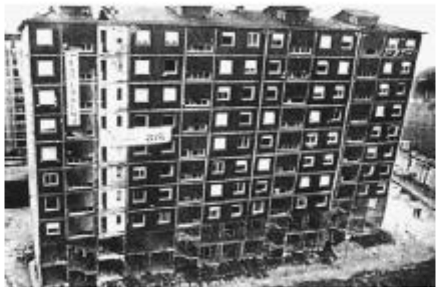
Residential building, Lisbon (Portugal)



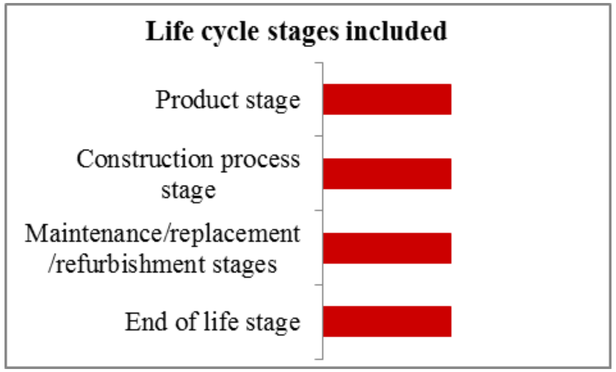
Lifetime	50 years
Building description	Basement slab: slab on grade, expanded polystyrene, slab (cement mortar), plywood sheathing, plaster slab; External wall: clay brick, expanded polystyrene, concrete blocks, plaster; Roof: ceramic roof tiles, plywood sheathing, rockwool insulation, timber, plaster board; Floor: slab, reinforced light, concrete slab, plaster; Internal walls: plaster, concrete blocks, plaster.
Energy reference area	192 m^2
Number of levels	2
eE	87.8 MJ/(m^2year)
eCO_{2eq}	4.6 $kgCO_{2eq}$/(m^2year)



Residential building, Turin (Italy)

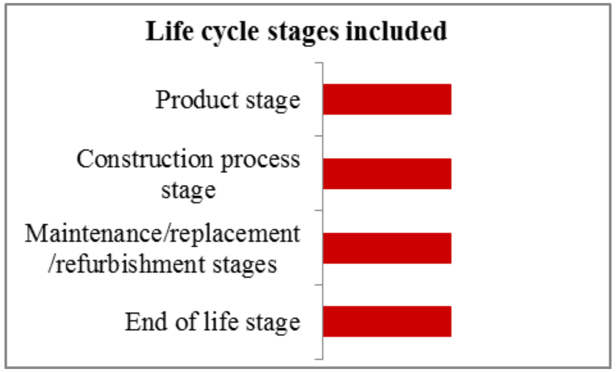


Lifetime	40 years
Building description	Basement: concrete, reinforcing steel bars. Structural walls: concrete, reinforcing steel bars and insulating materials. Non-structural walls: bricks, mortar and paint. Roof: concrete, bricks, roof tiles and wood. Floors: concrete, reinforcing steel bars, wire net and insulating materials. Door and windows: wood, glass, plastic and aluminium.
Energy reference area	611 m^2
Number of levels	10
eE	70.5 MJ/(m^2year)
eCO_{2eq}	6.6 $kgCO_{2eq}$/(m^2year)



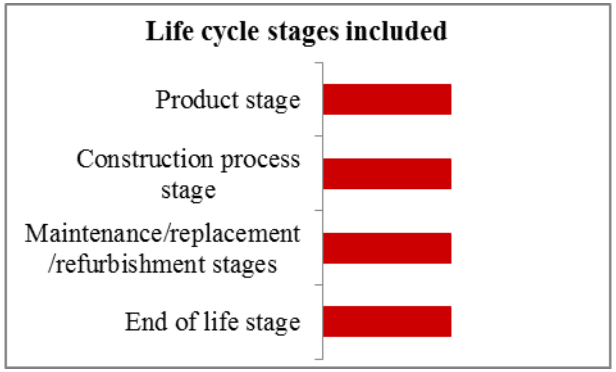
Residential building, Perugia (Italy)

Lifetime	50 years
Building description	The building is a detached house. The structure is realized with a reinforced concrete, the envelope is made of bricks with thermal insulating materials in the space, internal plaster and external plaster and bricks. The windows are composed with aluminium frame.
Energy reference area	443 m^2
Number of levels	3
eE	259 MJ/(m^2year)
eCO_{2eq}	21 $kgCO_{2eq}$/(m^2year)



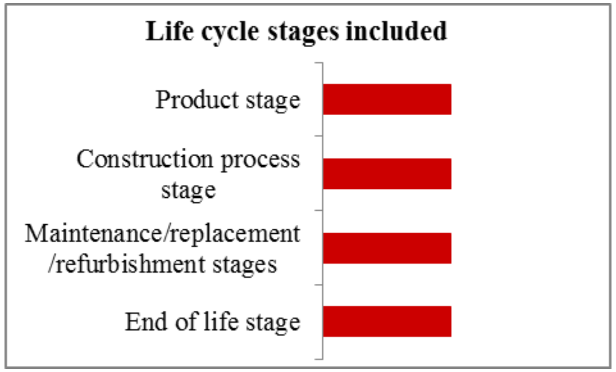
Residential building, Perugia (Italy)

Lifetime	50 years
Building description	The multi-dwelling residential building consists of 18 flat. The structure is realized with reinforced concrete, the envelope is made of bricks with thermal insulating materials in the space, internal plaster and external plaster and bricks. The windows are composed with aluminium frame.
Energy reference area	1,827 m^2
Number of levels	4
eE	173.4 MJ/(m^2year)
eCO_{2eq}	13.5 $kgCO_{2eq}$/(m^2year)

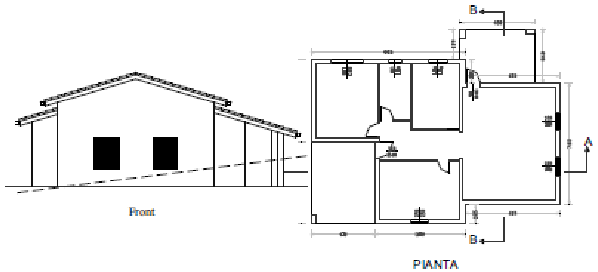


Office building, Perugia (Italy)

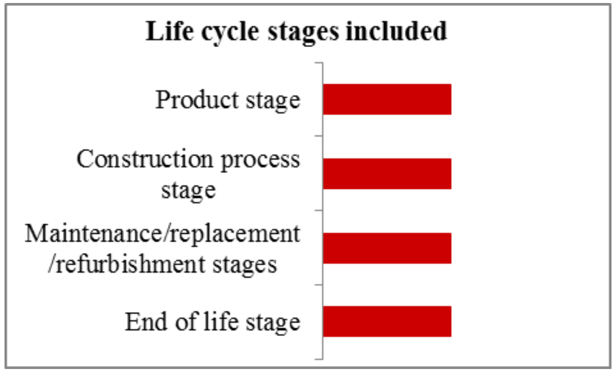
Lifetime	50 years
Building description	The multi-dwelling residential building consists of 18 flat. The structure is realized with reinforced concrete, the envelope is made of bricks with thermal insulating materials in the space, internal plaster and claddings (copper, aluminium, ceramic). The building presents a large-sized aluminium frame windows. Window/wall ratio = 0.11
Energy reference area	3,353 m^2
Number of levels	5
eE	147 MJ/(m^2year)
eCO_{2eq}	11.5 $kgCO_{2eq}$/(m^2year)



Residential building, Palermo (Italy)

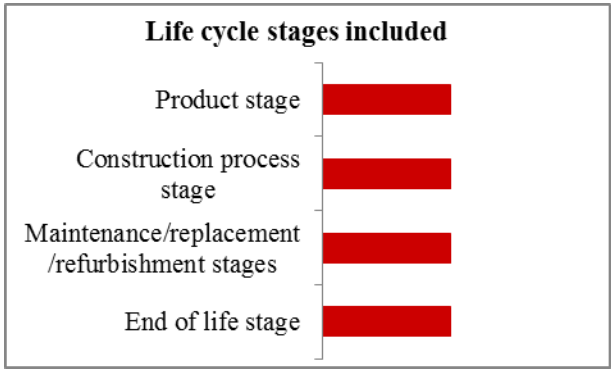


Lifetime	50 years
Building description	The building is a Mediterranean single-family house. The structural frame is made of reinforced concrete with masonry block walls. The external walls construction includes 20 cm bricks with a 9 cm of cavity filled with foam vermiculite. The floor is 20 cm thick, including perforated bricks and prefabricated reinforced concrete rafters. The roof has a wooden structure with composite materials and clay roof tiles cover. The ground floor lays on a structure made of reinforced concrete and cave crushed stones.
Energy reference area	110 m^2
Number of levels	1
eE	289.5 MJ/(m^2year)
eCO_{2eq}	22 $kgCO_{2eq}$/(m^2year)



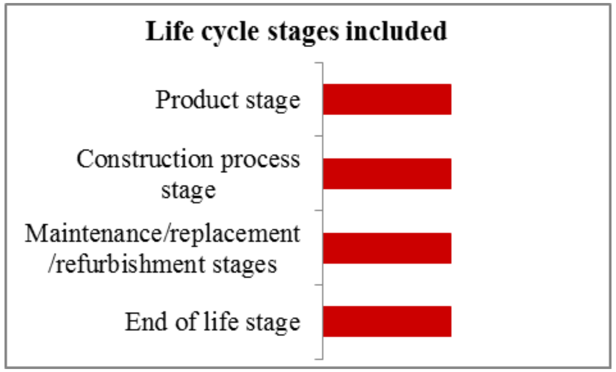
Residential building, Ancona (Italy)

Lifetime	70 years
Building description	The building envelope is composed of: walls realized in plaster (0.02m), light weight brick (0.3m), polystyrene (0.18m) and plaster (0.02m); roof made of plasterboard (0.03m), vapor barrier (0.001 mm), wood fiber (170 kg/m^3) (0.10m), rock wool (0.10m), sheathing (0.001m), air spaces, and pinewood (0.02m); floor: terracotta tiles (0.02m), concrete subfloor 0.05m) polyurethane foam (0.04m), lightweight concrete (0.05m), bitumen (0.005m), concrete (0.20m), air cavity (0.19m), gravel (0.115m). The south-facing window -to-wall ratio is about 24%, while the rest of orientations are kept below 10%. Windows are made of a double panel insulated glazing with 0.006m external glass, 0.14m gap filled with argon and 0.004m internal glass.
Energy reference area	481.76 m^2
Number of levels	3
eE	496.18 MJ/(m^{2}year)
eCO_{2eq}	-



Residential building, Brasília (Brasile)

Lifetime	50 years
Building description	The walls (both external and internal) are made of red ceramic blocks with a thickness of 14 cm and a layer of plaster (cement, lime and sand) of 2.5 cm on each side. The final upper row of ceramic blocks has a channel filled with reinforced concrete. All masonry surfaces have had a final treatment with a sealer and then painted. The roof is made of a wooden structure with a surface of ceramic tiles. The ceiling is a free–hanging structure of PVC-sheets. The floor is made of a concrete layer with 5 cm thickness, and all floors are covered with ceramic floor plates. The external doors and windows are metal framed and with a steel grating. The internal doors are made of wood.
Energy reference area	48 m^2
Number of levels	1
eE	158.3 MJ/(m^2year)
eCO_{2eq}	-



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