Energy in Buildings and Communities Programme

International Energy Agency

Strategies for Reducing Embodied Energy and Embodied GHG Emissions

Guideline for Designers and Consultants – Part 2

IEA EBC Annex 57

September 2016

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EBC

Energy in Buildings and Communities Programme

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IEA EBC Annex 57

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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
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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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Management Summary

This guideline is targeted specifically to design professionals and consultants with the aim to give them guidance in how to reduce embodied energy and GHG emissions in their design and decision making process. This guideline is a supplement to another guideline also targeted the group of design professional and consultants.

In this guideline, essential results of IEA EBC Annex 57 "Evaluation of Embodied Energy & CO2eq for Building Construction" are summarized and specific recommendations are presented, accompanied also by supporting information.

This publication is part of a series of guideline publications targeted to specific groups of actors working within the construction industry (construction product manufacturers, policy makers, procurers), and the education sector (educators).

Detailed information on the background for the recommendations in this report can be found in:

- A full report developed as part of the Subtask 4 (ST4) of IEA EBC Annex 57 describing the "Recommendations for the reduction of embodied greenhouse gasses and embodied energy from buildings".
- Case study collection report including the approximately 80 case studies that are used as background for analysis and examples in this guideline.

Both reports can be found here: www.iea-ebc.org.

Introduction

Life cycle assessment (LCA) is a method which is being increasingly used to evaluate the potential environmental impacts of products and services and their resource consumption. LCA is also being used in the building sector, where it is a crucial part of the assessment of buildings environmental sustainability. The life cycle approach moves focus from factors related to the completed building, to involving the entire life cycle of the building. LCA is included in International and European standards for sustainable construction, the European Construction Products Regulation (CPR) and in the certification schemes for sustainable building.

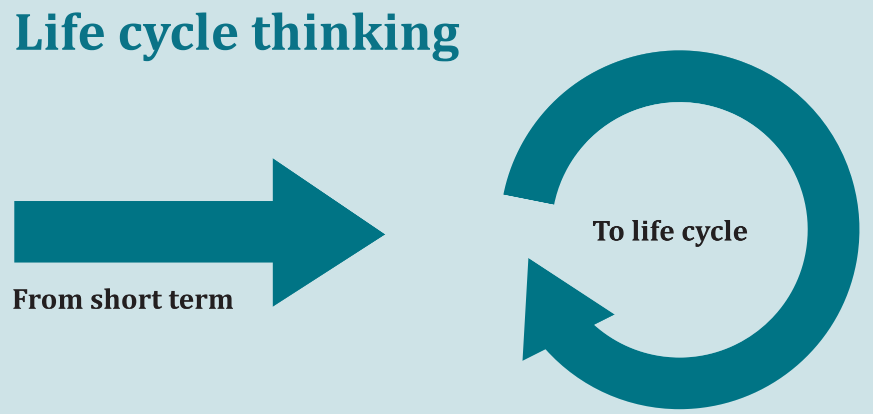
For the different players working in the assessment of the environmentally related part of sustainable building, LCA provides a basic knowledge of the parameters that contribute to resource use and the potential environmental impacts during a building's life cycle. Incorporating LCA as a tool in the building design stage, makes it possible to evaluate the environmental significance of building elements or of the different life cycle stages of the building. LCA can thus be used as part of the environmentally friendly design of buildings and in documenting the results.

The embodied impacts of buildings are limited to the building material related environmental impacts. Building LCA includes evaluation of several environmental impact categories. Evaluation of embodied energy and GHG emissions (EEG) are limited to two environmental impact categories evaluated in LCA.

This publication is intended for the group of design professional and consultants who wish to gain an insight into how evaluation of embodied energy and GHG emissions (EEG) can be used as a part of the development of sustainable building. Life Cycle Assessment (LCA) and evaluation of embodied energy and GHG emissions (EEG) is closely related, since evaluation of EEG is performed by using the LCA method. These two approaches are therefore both included in the publication.

This publication provides:

- Introduction to the concept of LCA on buildings to designers and consultants
- Introduction to the concept of embodied impacts
- Examples for selected Annex 57 case studies
- Ideas for reduction strategies in the building design



More sustainable solutions will be achieved by shifting the focus from optimising the building parts and products' life time, to considering their life cycles.

Figure 1. Life cycle thinking. Birgisdóttir and Rasmussen 2016

The Concept of LCA on buildings

The building life cycle

A life cycle assessment (LCA) and evaluation of embodied impacts (EEG) of a building normally involves evaluating its whole life cycle. This means including all of the stages in the assessment – raw material supply, manufacture of construction products, the construction process stage, use stage, demolition and when the materials are disposed of or recycled.

The building's life cycle is therefore divided into five stages which need to be dealt with: The product stage, construction process stage, use stage, the end-of -life stage and benefits and loads beyond the system boundary. Most often, the first two stages are the best known, even though in practice acquiring sufficient data for the calculations can be problematic. The next three stages are scenario-based, which means that assumptions have to be made about how the building will be used, maintained, and finally demolished. According to European standard EN 15978:2011, the final stage, which concerns the recycling of building waste, must be reported as a separate part of the calculations.

The guideline for designers – part 1 – gives detailed information on the subject of embodied impacts, presents the starting points for the integration of embodied impacts assessment into the design process and provides access to relevant information sources and tools.

A1-A3

1. Product stage

The product stage concerns the processes which involve the production of construction products used in the building: Raw material supply, transport to the production site as well as the final production of the construction products.

A4-A5

2. Construction process stage

The construction process stage involves the construction products' journey from production line to the point where they are installed as a part of the finished building: Transport from the manufacturer to the construction site as well as installation in the building.

B1-B7

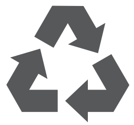
3. Use stage

The use stage involves the processes related to the construction products' continued performance as part of the building, e.g. maintenance, replacement, repair. Processes related to the building's ongoing operational energy and water use are also included. Most often, the processes will be based upon scenarios, i.e. perceptions about how the processes will take place.

C1-C4

4. End-of-life stage

The processes in this stage are also scenario-based. They concern what happens when the building reaches the end of its life, i.e. the building's demolition and the subsequent processes involved in reprocessing or handling the construction products/materials before further use of in other product systems.



D

5. Benefits and loads beyond the system boundary

This scenario-based stage contains the calculated gains and drawbacks from reusing and recycling construction products/materials. In accordance with the European standards, contributions from this stage must be considered outside the system boundary and be reported separately.

Figure 2. Description of the building life cycle and the five stages it is divided into. Birgisdóttir and Rasmussen, 2016.

What does a building's life cycle look like?

The figure illustrates the typical life cycle for a building and which stages and processes are involved. An LCA adds up all of the interactions with the environment which take place during the course of the included life cycle stages. Evaluation of embodied impacts (EEG) includes only building material related impacts.

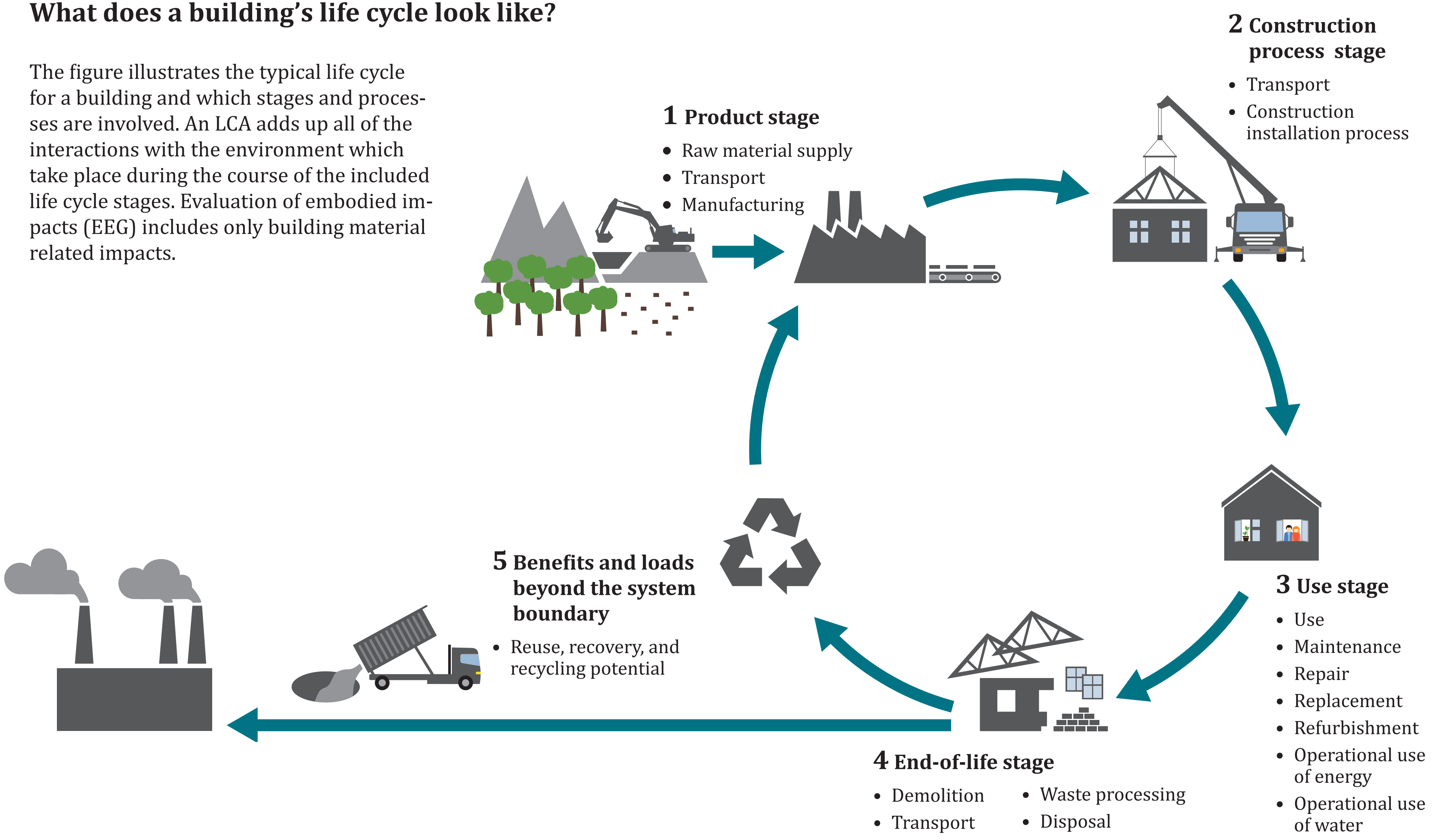


Figure 3: Typical stages of a building's life cycle: The product stage, construction process stage, use stage, the end-of -life stage and benefits and loads beyond the system boundary. Birgisdóttir and Rasmussen, 2016.

System boundaries

Definition of the system boundaries are an important parameter when evaluation of EEG and an LCA is to be carried out. The system boundary tells you which life cycle stages and which processes during each stage are included in your assessment. An understanding of the LCA system boundaries is also important when results from construction products need to be used in an assessment of a building in order to make decisions based on it. The system boundaries must be clearly defined for the results to be transparent.

The European standard EN 15978:2011 defines the building's life cycle stages as shown in the figure below. Note that LCAs of buildings rarely include all of the stages and processes that must be included in accordance with the standard. This may be due to insufficient underlying data or it may be because the aim of the LCA justifies simplification.

Irrespective of the grounds for simplification, it ought to be shown clearly which processes are included in an LCA.

The Annex 57 Guideline for designers and consultants – part 1 – gives detailed information on the system boundaries and how to ensure transparency in your assessment.

Module	A1-A3			A4-A5		B1-B7							C1-C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/ demolition	Transport	Waste processing	Disposal	Reuse, recovery, and recycling potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Table 1: Life cycle stages as defined in the European standard EN 15978:2011.

Introducing the concept of embodied impacts

Embodied energy and GHG emissions – definitions of indicators

As recommended in the Annex 57 Guideline for designers and consultants – part 1, the indicators used for the quantification of embodied impacts should primarily be:

- The consumption of primary energy total or non-renewable, accounted in MJ.
- The global warming potential, accounted in $kgCO_2eq$.

However, it should be noted that different sources of energy can be included in the recommended indicators which quantify embodied energy,as well as, different GHG emissions can be included in the $kgCO_2eq$. Therefore, the character and scope of each indicator should be clearly described in order to allow comparisons between data.

The table to the right is an example of the parameters that need to be given for describing the character of each of the recommended indicators in a transparent manner.

The exact description of the different indicators as recommended by Annex 57 is given in the detailed report "Basics, Actors and Concepts" that can be found here: http://www.iea-ebc.org.

The values of each of the recommended indicators should be calculated for each module and life cycle stage and be aggregated at the maximum level into cradle to handover impacts (module A1-A5) and cradle to grave impacts (module A, B and C).

	CORE LIST OF INDICATORS	ADDITIONAL INDICATORS
EMBODIED ENERGY (MJ)	Consumption of primary energy fossil [PE_1]	Consumption of fossil fuels as feedstock
	Consumption of primary energy non-renewable [PE_{nr}]	
	Consumption of primary energy total (renewable + non-renewable [PE_t]	Consumption of biomass as feedstock
EMBODIED GHG EMISSIONS ($kgCO_2eq.$)	Global Warming Potential [GWP 100]	F-gasses as identified in Montreal Protocol
		Stored Carbon

Table 2: Examples and description of indicators for embodied energy and GHG emissions. (ref. Guideline for designers and consultants – part 1)

What can an LCA and evaluation of EEG tell you?

LCA can provide you with an overview of the environmental impacts in the different stages of a building's life cycle, including both embodied impacts and impacts related to operational energy. The figure below illustrates how a building's LCA results for an impact category, in this case the global warming potential, can be divided among the different life cycle stages that are included. From there, it is possible to identify the most significant life cycle stages and try to minimise the negative effects.. An LCA helps you to prioritise your optimisation efforts on an informed basis and assess the individual processes against the larger perspective of the building's total life cycle . For example:

1. When in the building life cycle do the impacts occur? (Contributions from different life cycle stages)
2. Where in the building are the impacts located? (Contributions from building elements)
3. How do the different materials perform?

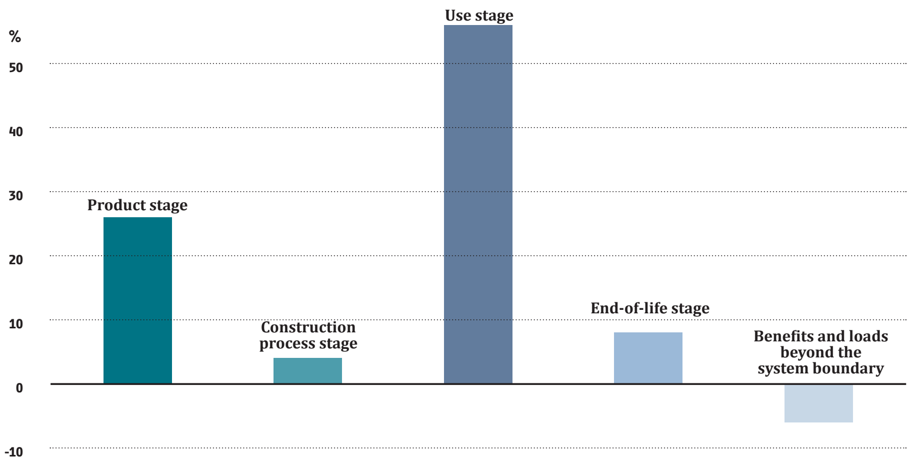


Figure 4. An example of the contribution distribution of environmental impact from different life cycle stages. In this case, the distribution of global warming potential (GWP) as a percentage. Birgisdóttir and Rasmussen 2016

1. Embodied impacts versus operational energy

As shown in the figure below, LCA allows you to divide the processes into those that are related to energy use during the building's use stage and those that are related to material use. The latter are described as embodied impacts.

Environmental impacts from energy use have traditionally been the greatest contributor to a building's LCA results. Since, it is expected in the future buildings will use less operational energy and this energy will come from renewable energy sources which means embodied impacts from construction products will become proportionally more significant in the total LCA for a building.

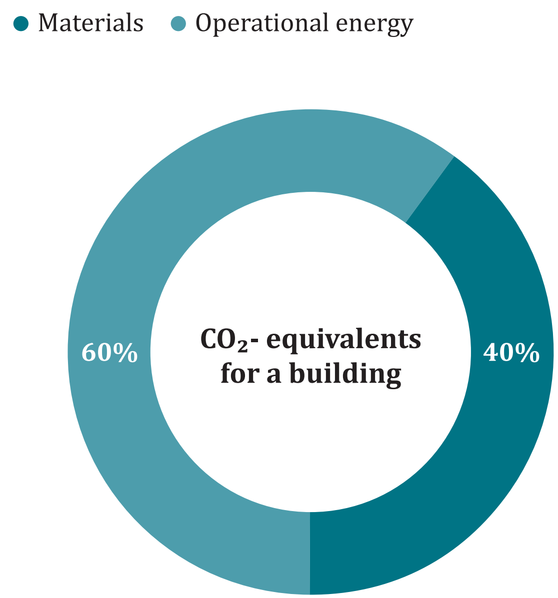


Figure 5. Embodied impacts versus operational energy. Birgisdóttir and Rasmussen, 2016.

2. The significance of building parts

LCA and evaluation of EEG gives you an overview of how the different building parts contribute to the overall environmental impacts. In this way, you can get help when deciding which building parts are responsible for driving high emissions or if you want to limit the potential environmental impacts from your building. Or, as shown in the figure below, you can test different building forms and see the impact on emissions results, as well as, the relative contribution from each building part.

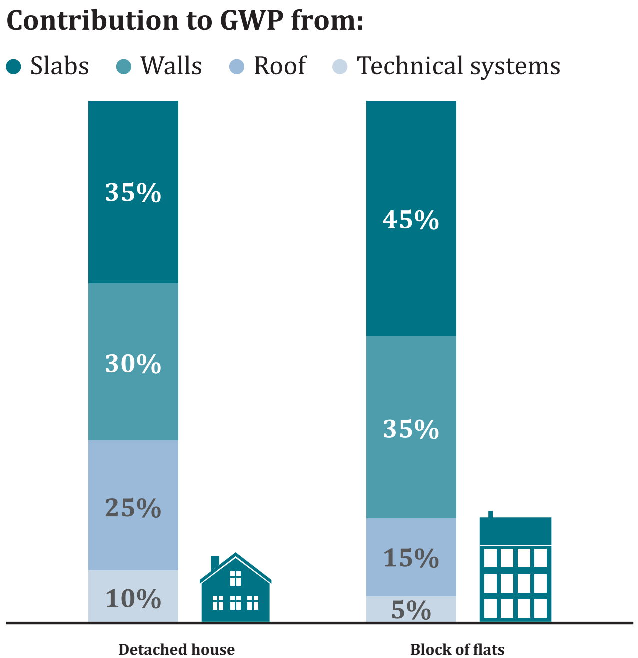


Figure 6. The significance of building parts. An example of the contribution of different building parts to EEG for two different building types. Birgisdóttir and Rasmussen 2016

3. Significance of materials

With LCA and evaluation of EEG, you can compare materials or construction products with the same properties in their environmental profile. In this way, you can get help in assessing the environmental profile of different solutions, for example, with the choice of materials for building parts.

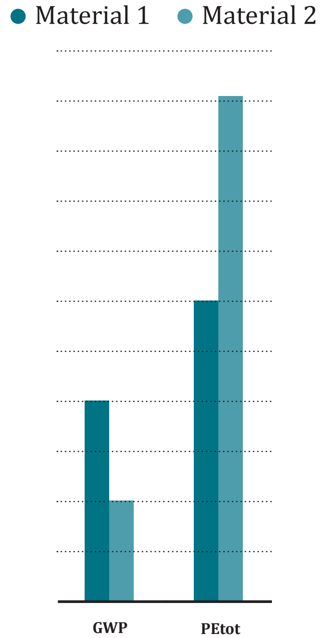


Figure 7. the Significance of materials. An example of the comparison of EG and EE for two different materials. Birgisdóttir and Rasmussen, 2016.

Case Studies

Annex 57 case studies

The purpose of Subtask 4 (ST4) is to develop measures to design and construct buildings with less Embodied Energy (EG) and Greenhouse gas Emissions (EG). In order to do so, Subtask 4 organized a call for case studies that resulted in approximately 80 case studies from 11 countries being received. The case studies are published in the Annex 57 publication Case study collection report. The collection includes 80 case studies presented in a standardized form. A template was developed in which the relevant information from the case study could be inserted. The template was designed for the widest diversity of studies – including qualitative studies – whilst at the same time ensuring transparency and completeness of quantitative data.

The purpose of the collection of case studies was to:

- Produce a body of different studies carried out in different countries and for different purposes, for which the relevant data is easily accessible and identifiable, as done in **Annex 57 publication Case study collection report**.
- Use the case studies to provide a comparison between studies for specific aspects, as done in the **ST4 report**.
- Use the case studies to develop guidelines for how to reduce embodied energy and greenhouse gases, as is done in this publication **Guideline for Designers and Consultants – Part 2**.

It is not the purpose of this guideline to go into details of the content nor the analysis of the respective case studies carried out within the ST4 task.

In order to get further information regarding the case studies and their indepth analysis, it is recommended to read the Case study collection report and the ST4 report.


Denmark

DK1: Novo Nordic HQ, new office building

	Ref.Building	Long life
Reference period (years)	50	100
EG (kg-CO2/m2 year)	7.9	4.8
EE (MJ/m2GFA/year)	89	60

Evaluation of the different building materials showed that for EG, concrete contributed with 42% , steel with 37% and aluminum with 8%.

DK2: Upcycle house, new residential building

	Upcycled	Ref. House
Reference period (years)	50	
EG (kg-CO2/m2 year)	1.04	5.5
EE (MJ/m2GFA/year)	55	175

Implementation of the upcycling strategy may face practical challenges, but it shows to reduce potential env. impacts (65-90% depending on the allocation factor).

DK3a: MiniCO2-house, Zero maintenance

	Zero maint.	Ref. House
Reference period (years)	150	120
EG (kg-CO2/m2 year)	2.0	3.7
EE (MJ/m2GFA/year)	31	71

Design strategy with durable building materials chosen for the main structure abd a large roof overhang protects windows and doors from weathering. Considerable reductions achieved compared to a reference building.

DK3b: MiniCO2-house, zero maintenance

	Zero maint.	Ref. House
Reference period (years)	150	120
EG (kg-CO2/m2 year)	1.6	3.7
EE (MJ/m2GFA/year)	46	71

Design strategy with glass cladding protects the wooden construction elements. Overhang furthermore protects weaker building components (like windows). Considerable reductions achieved compared to a reference building.

DK3c: MiniCO2-house, adaptable house

	Adaptable	Ref. House
Reference period (years)	50	50
EG (kg-CO2)	42000	57000
EE (MJ)	671000	964000

Outer wall elements of house can easily be reused in case of refurbishment. Inside wall systems are easily moved to change lay-out of rooms. Considerable reductions achieved compared to a reference building.

DK3d: MiniCO2-house, quota house

	Quota	Ref. House
Reference period (years)	50	50
EG (kg-CO2/m2 year)	6.1	5.6
EE (kWh/m2GFA/year)	120	96

An overall monitoring concept, "The Quota", helps the occupants manage and minimize the energy use throughout the year. Reductions achieved compared to a reference building.

DK4a: 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	5.1
EE (kWh/m2GFA/year)	161

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

DK4b: 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	5.1
EE (kWh/m2GFA/year)	69

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

DK4c: 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	7.2
EE (kWh/m2GFA/year)	76

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

DK4d: 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	7.5
EE (kWh/m2GFA/year)	91

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

DK4e 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	7.1
EE (kWh/m2GFA/year)	88

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

DK4f 7 Office buildings, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	6.0
EE (kWh/m2GFA/year)	82

The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions.

Figure 8. A page from the Case study collection report

Why are results of the case studies so different?

The uniqueness of constructed buildings makes direct comparisons of LCA results difficult. This is, among other things, the subject of the ST 4 report. The cradle-to-gate EG results from a selection of the Annex 57 case studies are shown in the figure to the right which clearly shows the wide diversity in results from all the case studies. This diversity can, to some degree, be explained by further examination of the background of the different case studies, where one finds that methodological choices and system set-up is performed differently from case study to case study and from country to country.

- Some illustrate a simplified inventory for early design choices (such as SE2a), whilst some are performed at a very detailed level of inventory when a building has been built (such as NO4).
- Some studies (such as AT5) account for carbon storage in wood, hence "neutralising" the greenhouse gas emissions from production of other building components.
- Some studies (such as DE4) show the relatively large impacts associated with technical equipment, but still manage to present the total results of the cradle to gate EG that are within the same range as studies with a limited inclusion of technical equipment (such as DK3c).
- Input-Output based LCA (as in JP5) is used in some studies, although most Annex 57 case studies are process based.
- A range of case studies present results for refurbished buildings (such as CH1).
- Few studies include different methodological aspects of recycled materials used in the construction of a new building (such as KR3).
- Even within the same country different system set-ups are used which produce results that are difficult to compare.

Furthermore, it should be noted that the performance indicator displayed in figure 9 is kgCO_2eq/m^2. Some of the case study calculations are based on gross floor area, whilst, others are based on net floor area which can make a difference of at least 10% of the area being used.

It is important to understand the differences mentioned here. The factors related to the methodological choices which impact emissions are thoroughly analysed and discussed in the ST4 report. Furthermore, considerations about the setup of evaluation of EEG are described in Guideline for designers and consultants – part 1.

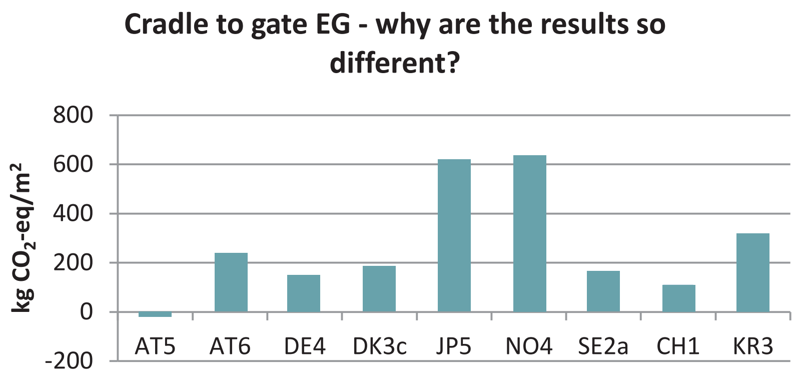


Figure 9. Embodied GHG emissions from the cradle to gate of different 57 case studies (ref. IEA EBC Annex 57, ST4 report).

In the following section four examples from the case studies (DK3, NO2, UK8 & JP4) are reviewed

DK3 - Design strategies to reduce EG

In the Danish project called the MiniCO2- houses, there are four test residential houses designed to reduce EG through different design measures. The test houses are compared to a typical Danish residential construction.

DK3a: Zero Maintenance I

DK3b: Zero Maintenance II

DK3c: Adaptable House

DK3d: Quota House

DK3e: Reference House

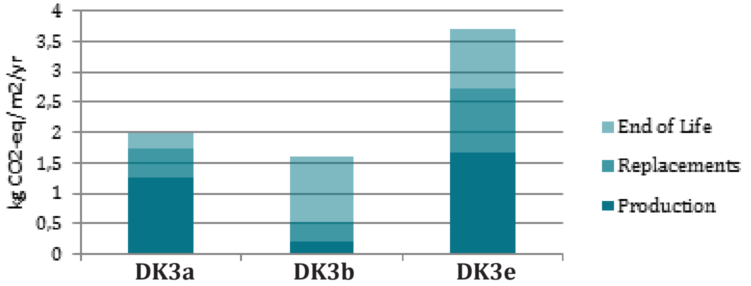
Figure 10 ©Realdania By og Byg: Jesper Ray (DK3a, DK3d) Helene Høyer (DK3b, DK3c) SBi (DK3e)

The Zero Maintenance Houses I (DK3a) and II (DK3b) are designed for low maintenance and long service life of the building. In the Zero Maintenance house I, durable building materials are chosen for the main structure. A large roof overhangs and protects the windows and doors from weathering. In the Zero Maintenance House II, glass cladding protects the wooden construction elements and an overhang protects weaker building components like windows. These initiatives are expected to extend the building's lifetime from 120 years to 150 years and extend the service life of windows from 25 years to 40 years.

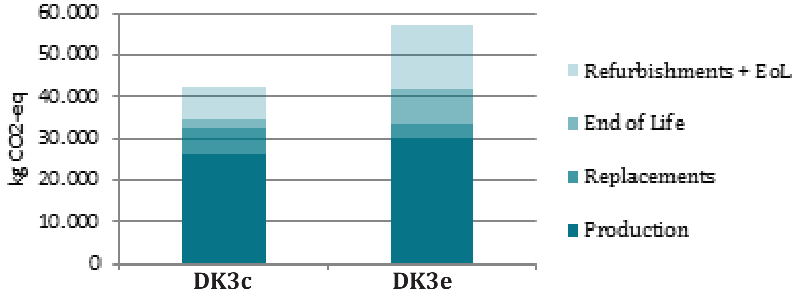
The Adaptable House (DK3c) is designed to enhance flexibility and adaptability in the use stage of the building. The outer wall elements of the house can be easily reused in the case of refurbishment and the inside wall systems can easily be moved to change the layout of the rooms.

The Quota House (DK3d) is designed to minimize energy consumption in the building's use stage. Technical and design solutions are made to encourage energy efficient behavior among occupants. Furthermore, an overall monitoring concept, "The Quota", helps the occupants manage the energy use throughout the year.

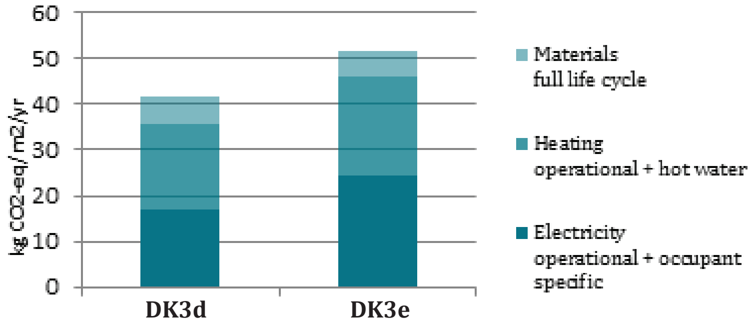
The results shown in the graphs below indicates the potential of the different strategies to reduce EG.



Emissions from Zero Maintenance houses compared to the Reference House



Emissions from Adaptable House compared to the Reference House



Emissions from Quota House compared to the Reference House

Figure 11. Comparison of emissions

NO2 - From concrete & steel to timber

In a Norwegian case, the ZEB office concept study has been optimised through a series of scenario studies, to consider a timber structure instead of the original steel and concrete frame. Although, it was not possible to completely eliminate steel and concrete as construction materials. However, as can be seen in the images below (in blue), the use of steel and concrete has been limited to just the foundations, the lift shaft and stairwell, as well as, a minimal amount used for cross-bracing on the top floor.

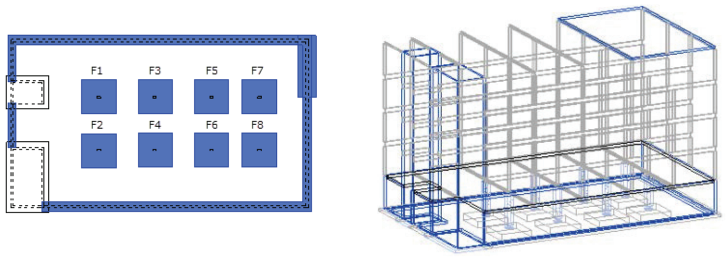


Figure 12. The use of steel an concrete are marked with blue. Illustrations © Tobias Hofmeister, Ingrid Thorkildsen and Hammersland P. (Source: ZEB/NTNU)

The aim of the study was to compare embodied material emissions between the original ZEB office concept study and a timber-framed alternative. The amount of concrete used was reduced by over half, however, additional material components were required for sound and fire-proofing of the lightweight timber structure.

Other advantages

Previous studies have shown timber structures typically have better indoor environments than concrete ones, providing better acoustics and better indoor air quality amongst other qualities.

The overall floor thickness in the ZEB office concept study can be almost halved by implementing glue laminated timber trussed floors. This is because building services may run between the trusses, instead of requiring a suspended ceiling, as seen in the concrete floor option.

System boundary

Originally, embodied material emissions were calculated from Cradle to Gate for both scenarios. However, this was later expanded to Cradle to Grave, with three alternate End of Life options:

Generic EcoInvent: This option follows the recommended End of Life treatment for building materials. It involves no energy recovery from waste materials treated with the process of municipal incineration.

EcoInvent with Energy Recovery: This option considers energy recovery from municipal incineration as a substitution for fossil fuels.

Norwegian Recycling Contractor: This option uses process data provided by Norwegian recycling contractor, modeled in SimaPro in order to obtain emission data. Emission savings were factored in when recovered energy substitutes fossil fuels. The results can be seen in the graph below.

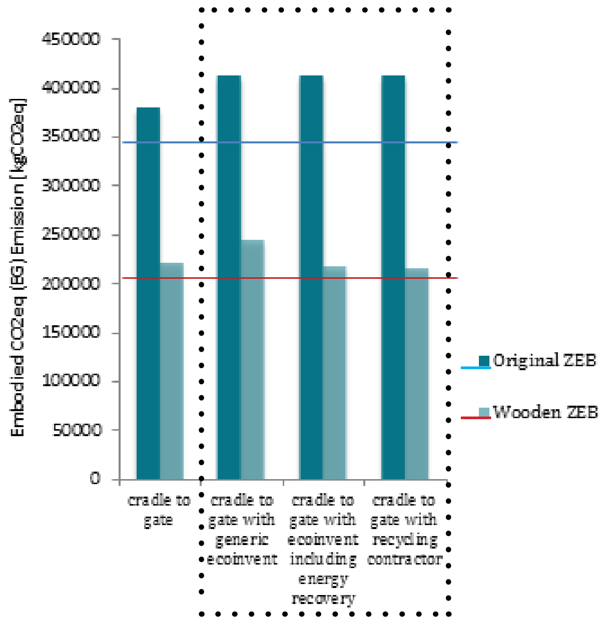


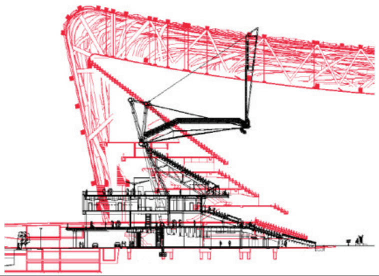
Figure 13 shows the embodied EG emissions for different scenarios.

UK8 - Strategies for the design of the Olympic park

In the design of the Olympic park in United Kingdom sustainability was set as a priority very early in the design process. The contractual system used allowed for an early engagement of the supply chain in the project, hence, facilitating integration of sustainability targets and collaborative work between the design team, contractors and suppliers from the early design stages. This resulted in some new alternative ideas to reduce the embodied energy and greenhouse gas emissions.

Velodrome: The construction of a light-weight cable net structure instead of a steel arch system, saved 1,500 tonnes of CO2 through the reduced steel and 1,100 tonnes CO2 through the reduced concrete-foundations. (© Rick Ligthelm)

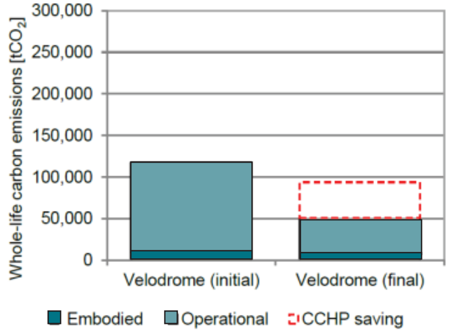
Aquatics Centre: The main contribution of value engineering in the embodied energy and greenhouse gas reduction in terms of materials was the change to reusable standard sized scaffolding for the temporary stands. (© George Rex)



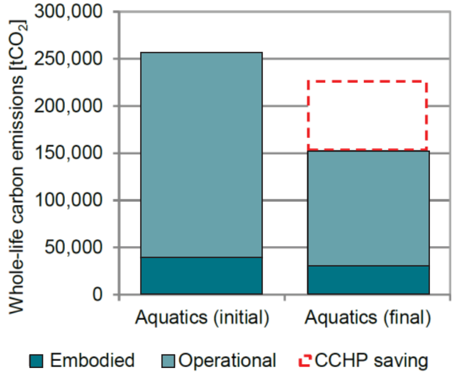
Olympic Stadium: The use of reclaimed steel (from gas pipes) for the compression truss structure saved 2,500 tonnes of new structural steel and hence significant amounts of greenhouse gases. (© Tryppick & Johnson, 2012)

The early collaboration of design teams, contractors and suppliers meant that targets were clarified early, when design changes were still possible. As an example, the use of reclaimed gas-pipes for the Stadium construction, was only possible thanks to the early collaboration between the design team and the supplier, giving the design team enough time to consider and make changes on the design according to the requirements of using this alternative material. This achieved a considerable reduction in the use of steel and hence embodied energy and greenhouse gas savings.

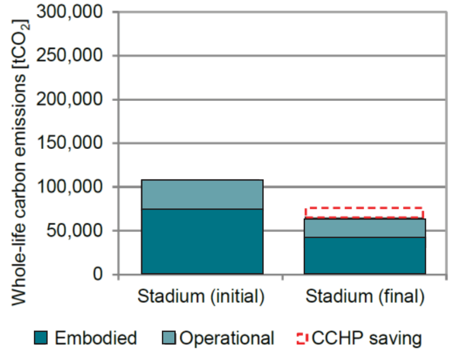
The difference in the results for the initial constructions ideas and the final is illustrated in the graphs to the right. The results illustrates the importance of the early collaboration between professionals and their involvement from early design stages.



Velodrome



Aquatics Centre



Olympic Stadium

Figure 14. (right) Lower emissions through design choices

JP4 - Prolongation of life time

In the Japanese case study, increased durability of the structure is used as one method to extend the life of a building.

To increase the life of building from 60 years to 100 years, in this case a library , the covering thickness of concrete for reinforcing rod is increased. The increased thickness gives an increase in earthquake resistant strength of 25% and 50 % respectively.

SYSTEM BOUNDARIES:
All impacts from the raw material extraction and the manufacturing of the building materials are included, because the calculation is based on intensity of 2005 I-O table in Japan.

A 1-3 Product stage			A 4-5 Construction process stage		B 1-7 Use stage							C 1-4 End-of-Life				D Next product system
Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential
x	x	x														

Table 3 shows the included stages

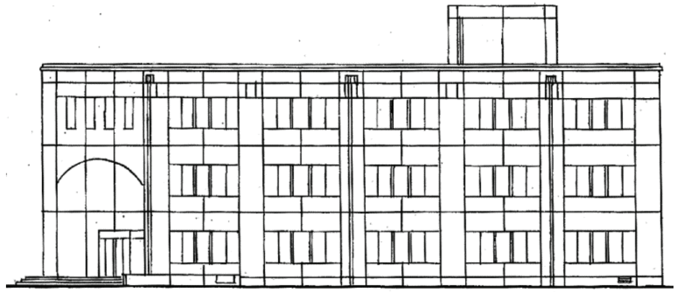


Figure 15

RESULTS
The embodied greenhouse gases (EG) and the Embodied Energy (EE) were calculated with a Reference Study Period (RFS) of 60 and 100 years respectively. The results can be seen in table 4 below. The results show that the extension in lifetime pays back even if the thickness of the concrete is increased to a level where the earthquake-resistant strength is 50 % higher.

Lifetime	60	100	years
EE	72	52(50) 48(25)	$MJ/m^2_{GFA}/year$
EG	6,6	5,2(50) 4,6(25)	kg CO_2 equiv. $/m^2_{GFA}/year$

Table 4 shows the results for embodied energy and embodied greenhouse gases for the different scenarios. (50):Earthquake-resistant strength +50%, (25):Earthquake-resistant strength +25%.

COST
The additional cost for prolongation of the building's life time is evaluated and is estimated to be 3% to 9% of the total construction cost of building.

Ideas for reduction strategies in the building design

Reduction strategies

The following pages provide an overview of the potential of different design and construction strategies for reducing embodied energy and emissions. This is a summary of the IEA Annex 57 ST4 report. Most case studies used to illustrate the strategies are Annex 57 case studies, but because not all strategies were addressed, other relevant case studies were used as well. It should be noted that as a result of the diversity of methodologies used in the case studies, the individual cases cannot be used to quantify reductions in general, but should be seen as a means to illustrate the potential of different reduction strategies in various contexts.

The following pages discuss and illustrate different design and construction strategies focusing on reducing the embodied energy and emissions. However, the relationship between operational energy and embodied energy also has to be taken into account. For example, a material with a low insulation value has low embodied energy, but can potentially result in high operational energy and vice versa. These relationships need to be taken into account at an early design stage, because decisions during this phase have the greatest potential for minimising the whole life cycle energy.

- **Substitution of materials**
  - Natural Materials for load bearing structures
  - Natural materials
  - Recycled & reused materials and components
  - Innovative materials
- **Reduction of resource use**
  - Light-weight constructions
  - Building form and design of layout plan
  - Design for flexibility and adaptibility
  - Low maintenance and service life extension
  - Reuse of building structures
- **Reduction of construction stage impacts**
- **Design for low end of life impacts**
  - Design for low impact of end-of-life stage

Each strategy is briefly explained, followed by several design considerations with illustrations. The green and the red arrows in the figures illustrate the potential positive and negative effect of the given impact. The relevant case studies are mentioned in a table on the bottom left of the page. The key points that should be taken into account are summarised in the “be aware” box on the bottom right.

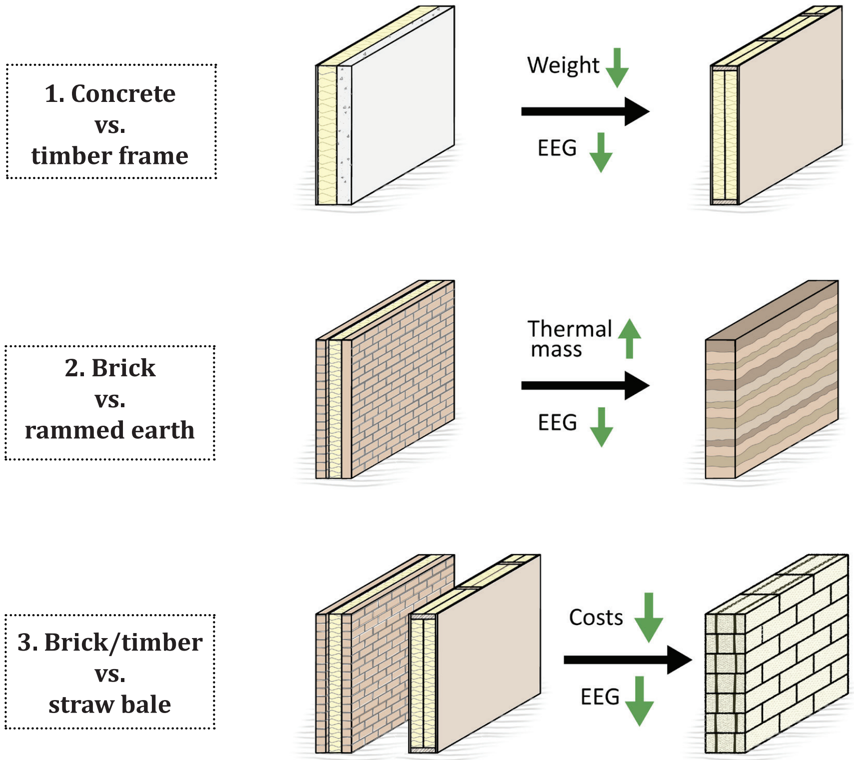
Substitution of materials

Natural Materials

Examples from the case studies show that the use of natural bio- based materials, which have a low or no processing energy during production, can reduce emissions. Natural materials can be sorted into 3 groups: inorganic, renewable plant-based, and animal-based products.

Design considerations for load bearing structures

1. Masonry, concrete and steel structures are frequently used as load bearing structures, but also have high embodied emissions, particularly in the production stage. The emissions can be reduced by replacing (a part of) the structure with timber elements.
2. Another alternative for masonry is to use unfired clay products, such as rammed earth which has less embodied emissions. This material has a higher thermal mass, but a lower thermal performance compared to a masonry wall.
3. Straw bales are cheap and have a low embodied emission. They can be used to build up walls instead of timber and masonry, but it requires special design and needs to be protected from moisture and pest.



Strategy	Case study references
Timber frame	UK5, SE2b, SE5, UK7
Unfired clay products	Růžička et al. (2013)
Straw bale	Sodagar et al. (2011)

- Some natural materials might require specific design and construction details
- Technical parameters in terms of thermal mass, thermal properties, fire safety, acoustics ect. which also should be taken into account, when choosing materials.
- When natural materials are used as found in nature, they may require extra protection against fire, moisture and pests.

Natural materials

Design considerations - Foundations

The use of high emission materials in the foundation accounts for a large share of the embodied emissions related to materials production. Alternative solutions for the foundations have been researched but so far the potential environmental benefits of these solutions have not been documented.

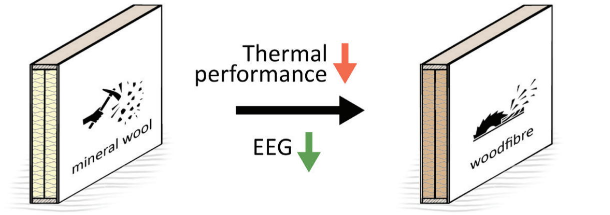
Design considerations - non-load bearing structures

1. For non-load bearing structures, the focus is mostly on the thermal envelope and façade of the building. A large part of the envelope consists of insulation which has a relative high impact and thus high potential for reduction. An example could be to replace with wood fibre or hemp-lime insulation. However, it should be noted that they are not pressure-resistant and hemp-lime has a weak thermal performance.

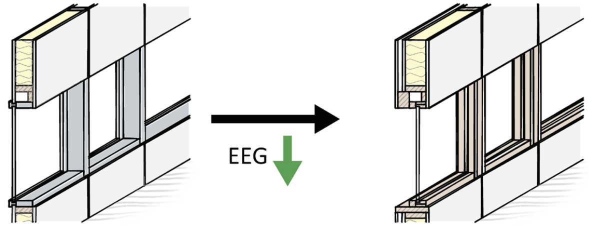
2. Curtain walls are often metal based and thus have a short life time which means that the environmental impact is oftn relative high. A wooden alternative can reduce embodied energy and emissions significantly.

3. Substituting cement with clay plaster is an simple way to achieve significant reductions. Other advantages are that it helps to balance indoor humidity, it can be locally sourced, and is simple to prepare. However, further research is needed to determine the durability and service life span.

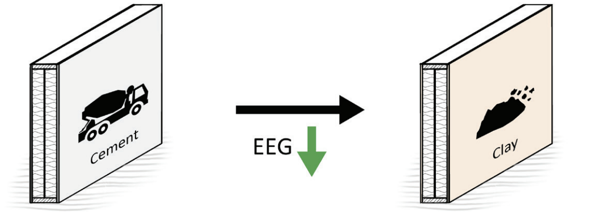
1. Mineral wool vs. woodfibre



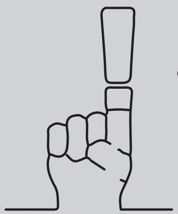
2. Aluminium vs. timber



3. Cement vs. clay



Strategy	Case study references
Foundation	UK4, UK5, KO5
Insulation	CZ03, Wright (2012)
Plaster	Melià et al. (2014),
Curtain walls	Tywoniak et al. (2014)



- Clay plaster is a local product with high potential for reduced emissions, but further research is needed to determine the life time and durabilty of the plaster.

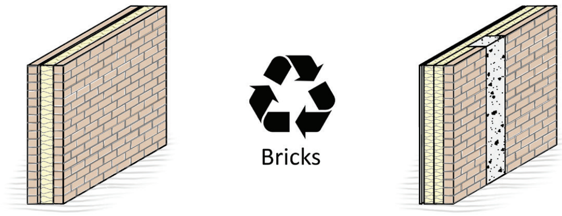
Recycled & reused materials and components

Recycled materials are materials that have undergone reprocessing or renewal and can be further used in construction as a replacement for new materials. Using recycled materials can reduce emissions when the process of recycling or making materials or components ready for reuse requires less energy than production of virgin materials. Recycling can reduce the consumption of primary raw material resources, but may require additional materials to strengthen the recycled material or element.

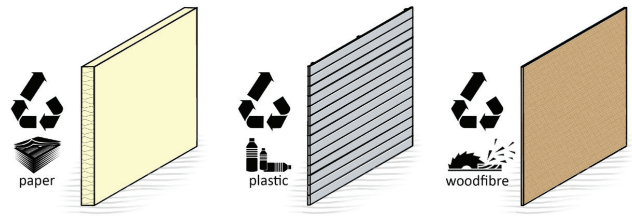
Design considerations

1. Reused bricks and parts of foundations can be integrated into the new construction. However, if additional structures (e.g. columns) are needed for extra support and increased lifetime the potential reductions can be reduced.
2. Creating building materials from waste products (upcycled materials) can lead to a reduction of emissions
3. Crushed concrete can be used as aggregates in new concrete, but the effect on the building embodied emissions is little.

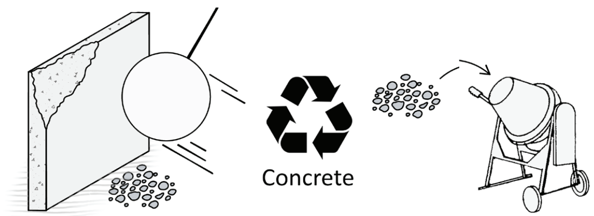
1. Recycling bricks



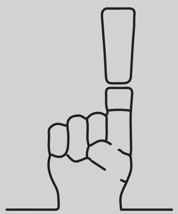
2. Upcycling waste



3. Recycling concrete



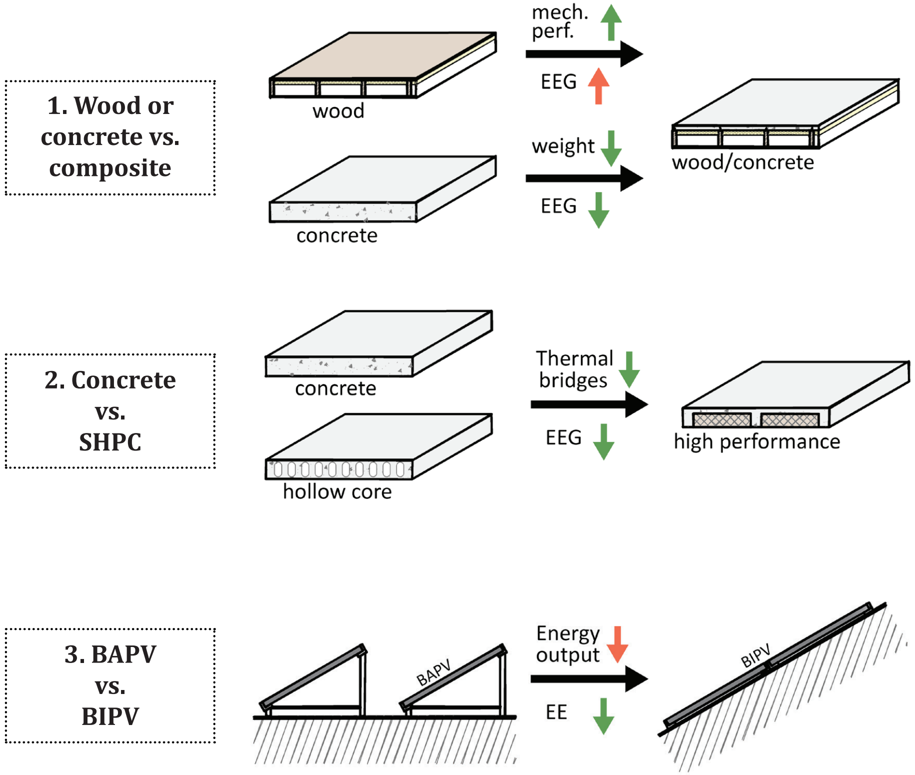
Strategy	Case study references
Recycling	UK11, CZ01, KO3, Yu & Shui (2014), Pavlů (2015)
Upcycling	DK2



- Whether upcycling leads to a reduction in emissions depends on the quality of the material and the accessibility of recycling facilities.
- Recycling can reduce the consumption of primary raw material resources, but sometimes it may require additional materials to strengthen the recycled material or element which can reduce the effect.
- Ensure that the reused materials do not contain any dangerous contaminants.

Innovative materials

Innovative materials are new to the construction sector and have a potential to surpass or match common materials in some key parameters. Improvements can be made regarding mechanical and thermal properties, surface treatment, and durability. The new materials can have higher environmental impacts per unit, but due to improved properties may reduce the total amount of units needed in the building, thus reducing the emissions at a whole building level. Despite significant developments in innovative materials, there are only few published cases that provide evidence for the potential of innovative materials to reduce emissions at a building level.



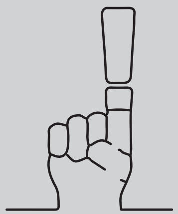
Design considerations

1. A wooden-concrete composite is a combination of wood and concrete floor. Compared to wood, this material has higher emissions but a better mechanical performance. Compared to concrete, the emissions and weight are decreased.

2. Ultra High Performance Concrete (UHPC) and Subtle High Performance Concrete (SHPC) with integrated wood shavings have lower emissions than standard concrete. The main advantage of SHPC over UHPC is that it helps to decrease thermal bridges.

3. Building integrated photovoltaics (BIPV) saves embodied emissions associated with the roofing materials, but has a lower energy output compared with Building Adapted photovoltaics (BAPV). However the effect of saving emissions is larger than the negative effect of the reduced energy generation.

Strategy	Case study references
Wooden-concrete composite	Petr Hájek (2014)
UHPC and SHPC	CZ02
BIPV	Ritzen, Rovers, Lupisek, & Republic (n.d.)



- The reduction of emissions should be evaluated at a whole building level, because the emissions might be higher per unit of material.
- Production methods of new materials may be in an early phase in relation to the efficiency potential.

Reduction of resource use

Light-weight constructions

The emissions related to the production of materials used in the building structure makes up a large part of the total emissions. The reduction of resource use as a strategy focuses on decreasing the volume and/or weight of the structure. Several case studies show reduced resource use as a large potential strategy for reducing emissions as long as basic solidity and functional requirements are fulfilled.

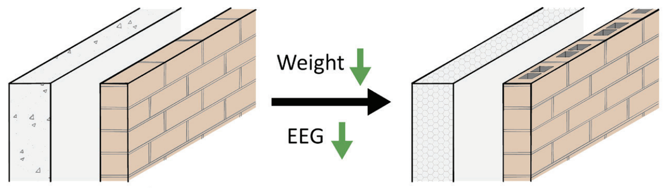
Design considerations

1. The use of cellular concrete, hollow core concrete, and multi-cell clay instead of solid concrete and clay can lead to a significant reduction in embodied energy and embodied emissions, as well as a reduction in weight.

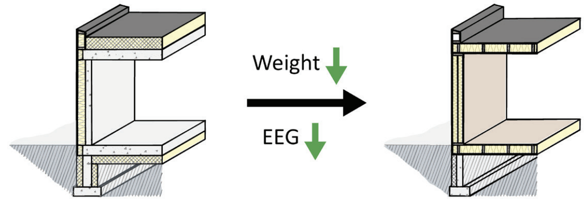
2. Substituting a concrete structure with a wooden structure reduces the weight of the building and therefore the amount of foundation materials that are needed.

3. Certain choices in foundation design can also reduce embodied energy and emissions. Choosing a strip foundation instead of a raft foundation can significantly reduce emissions. However, building materials may deteriorate faster in strip foundations if they are not protected from exposure and will thus have a shorter lifetime.

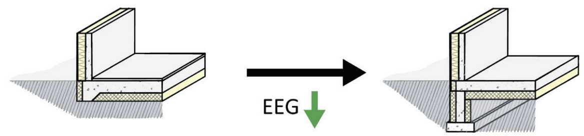
1. Replace with hollow core materials



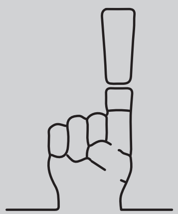
2. Replace concrete with timber frame



3. Choose strip foundation instead of slab



Strategy	Case study references
Solid vs. hollow-core	De Castro et al. (2014), CZ2
Concrete vs. timber	CZ2, NO2
Foundation	NO1, NO4



- The design of the foundation of a building can lead to a reduction in emissions of a building, but this also has consequences for the building structure.
- Building materials in a strip foundation may deteriorate faster in strip foundations if they are not protected from exposure and can therefore have a reduced service lifetime compared to materials in a raft foundation.
- Other technical parameters in terms of thermal mass, thermal properties, fire safety, acoustics ect. should be taken into consideration.

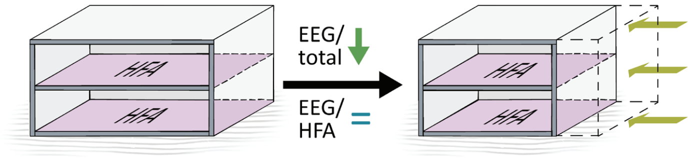
Building form and design of layout plan

A larger building results in higher emissions for construction and materials production due to increased material quantities and usually more operational energy for indoor climate regulation and lighting than a smaller similar building with the same function. For the same volume of building, the operational energy and emissions can be lowered by making its form more compact, but this is a limited reduction compared to, for example, material choice.

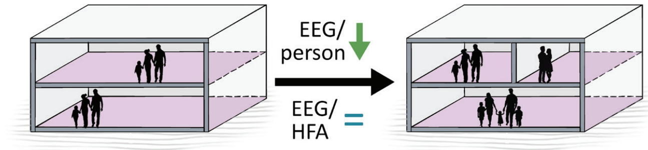
Design considerations

1. During the early design process the layout plan can be reduced to be more space efficient, yet still including the same functions and the total building emissions can be reduced. The emissions per heated floor area will however stay the same.
2. When the building layout in an existing building is rearranged to be more space efficient, the emissions per person are reduced, but the emissions per heated floor area stay the same.
3. A larger volume does not always result in higher emissions per heated floor area. In one case it was seen that a sloped roof offered a larger surface for (integrated) PV-panels , the possibility to add an extra floor, and a different architectural expression compared to a flat roof. In this case the extra emissions from adding more material and the increased energy output balanced each other out.

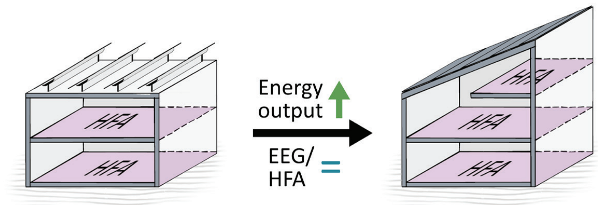
1. Reduce heated floor area (HFA)



2. Increase space efficiency



3. More energy generation



Strategy	Case study references
Building form	NO1, SE4
Building layout	NO1, SE3

- While compact buildings can reduce emissions, the reduction is limited compared to the choice of building materials.
- A more space efficient design can reduce emissions both if used in the design phase as well as in the retrofitting phase.
- When making a design more compact, the reduction of emissions is proportional to the reduction in floor space. Only the total building emissions are reduced.

Design for flexibility and adaptibility

The main driver behind flexible and adaptable buildings is to extend the service life time and at the same time reduce the need for material use during a refurbishment process. This is particularly important, since buildings always go through more retrofitting phases than expected.

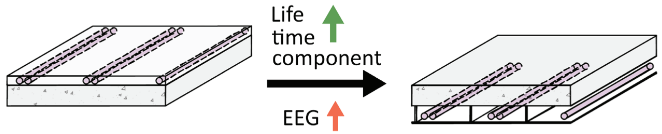
Design considerations

1. Physical separation of building services makes it easier to maintain and replace individual components. Since the life time of components varies, separation prevents that all services have to be upgraded at the same time. This is especially a good strategy when a building has high demands for indoor climate, such as hospitals and laboratories.

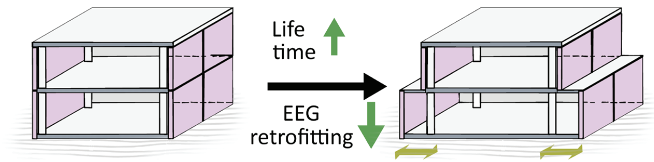
2. Prefabricated elements are easy to install and replace, and if the building is expanded they can be reused, thus lowering the embodied emissions during refurbishment.

3. Over dimensioning of the building structure can increase the flexibility by creating opportunities for changing the function to one with higher demands. However, it can also lead to an unnecessary increase in embodied emissions if this is not carefully done.

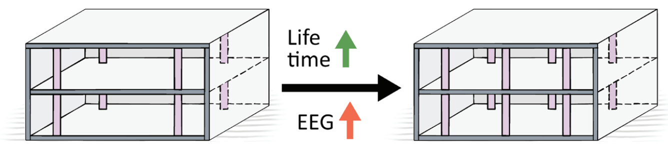
1. Separate building services



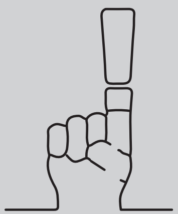
2. Prefab elements



3. Structural over dimension



Strategy	Case study references
Adaptable wall elements	DK3c
Adaptable structure	UK8 / UK11



- Due to a limited amount of case studies, there is limited evidence that adaptable design can improve the environmental performance.
- To be effective as a strategy for reducing emissions, adaptations should only be used for expected changes.
- Over dimensioning of the structure can lead to unnecessary material use and thus increased emissions if not carefully done.

Low maintenance and service life extension

Aesthetic qualities are very important to consider. It will be more likely that buildings and materials which patinates beautifully will be allowed to live longer. Design for low maintenance can include easy to maintain surfaces, choice of materials, and protection of materials to increase the durability. Increasing the service life may require increasing the durability of materials, replacement of components and renovation. It often implies an increase in embodied energy and emissions during the production stage to ensure an increased durability of the structure.

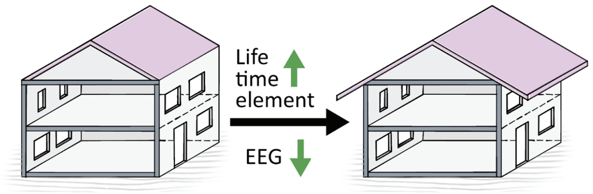
Design considerations

1. Durability can be increased by protecting the weaker elements (e.g. windows and doors). The life time of the element is increased so that less maintenance and replacement is needed during the complete life time of the building. The embodied impacts for the construction of the building can be higher, but when evaluating the complete life cycle of the building the embodied impacts are in many cases lower.

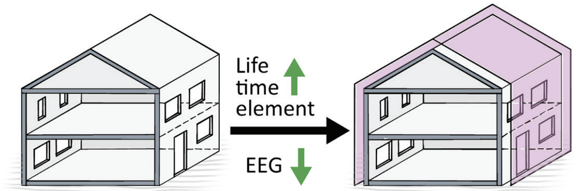
2. An extra layer does not only increase the durability, but also increases the thermal performance of the envelope. However, the designer should be aware that this design strategy can have a large impact on the architectural expression of the building.

3. In some situations it can be beneficial to over dimension the structure or add extra materials. This makes the building more resistant to natural phenomena, such as earthquakes, and can thus increase the total life time of the building.

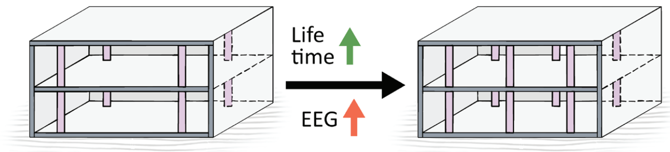
1. Increase life time of weaker elements



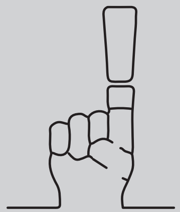
2. Increase life time of weaker elements



3. Increase life time of the structure



Strategy	Case study references
Life time structure	JP4, DK1, SE7,
Durability materials	DK3a, DK3b, NO8
Comparing service life time	Rauf and Crawford (2015), De Castro et al. (2014)



- Increasing the material use to make a building more durable should only be considered when the building is designed for a longer service life.
- A material that has a long service life may result in high emissions in the production stage, but can be balanced when the whole life cycle is evaluated.

Reuse of building structures

Reusing parts of the existing building structure is a strategy that reduces resource use and the embodied energy and emissions that are associated with the product and construction process stage of the material.

However, there are no case studies in the Annex 57 that have done an LCA comparison between the embodied energy and emissions of a major refurbishment versus new-built.

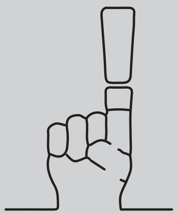
Therefore, the reduction potentials of this strategy cannot be discussed with examples.

Some of the case studies do highlight the benefits of replacing building parts to provide a longer service life instead of replacing the whole building. This is already discussed in the previous section.

A further opportunity is the use of smart facade technologies in the refurbishment phase. An example is the use of double skin facades as an alternative to single skin refurbishments. When embodied costs are compared to the operational savings, the emissions are easily paid back within the service life time of the facade component.

Power House Kjørbo, Norway. Copyright: Snøhetta

Strategy	Case study references
Service life extension	DK1, SE7
Smart facade technology	UK13

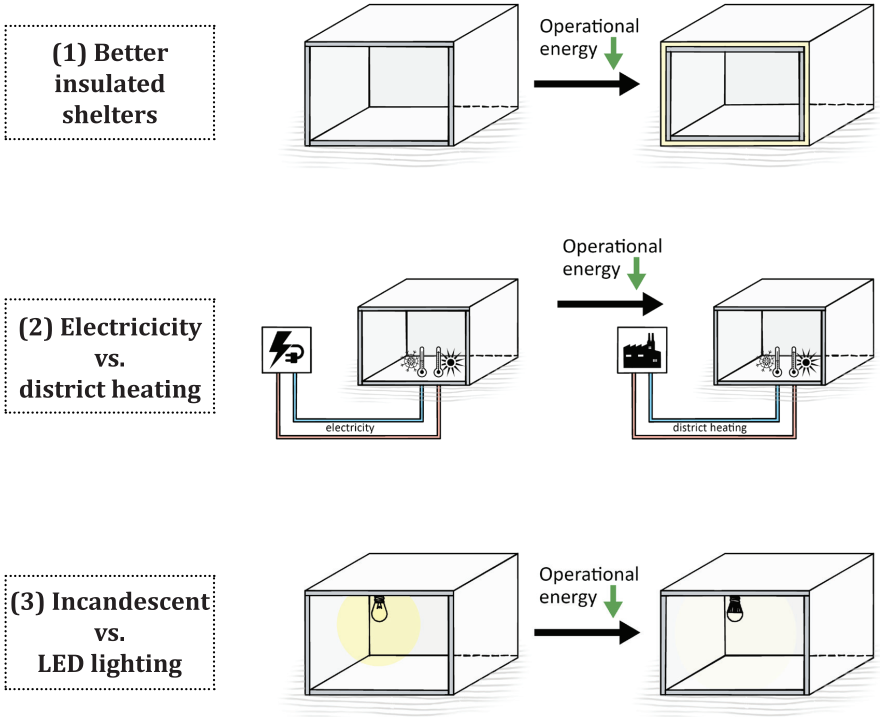


- This strategy cannot be discussed with examples because there is a lack of evidence comparing the embodied energy and emissions of major refurbishments versus new-built.
- Some case studies highlight the benefits of replacing building parts to provide a longer service life instead of replacing the whole building.
- Another opportunity is double skin façades as an alternative to single skin refurbishments, which results in operational savings.

Reduction of construction stage impacts

Reduction of construction stage impacts

The construction stage impacts are divided in impacts related to on-site processes and impacts related to transportation to the site. An important variable that affects the embodied emissions during the construction stage is what type of energy is used, and whether construction takes place during the heating season or not. Project valuation and the duration of the construction are not significantly correlated with the embodied emissions.



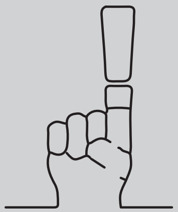
Design considerations

1. Improvement of construction sheds offers potential to reduce the energy used during the construction stage. Sheds of higher quality and with better insulation allow for reduced heat loss and thus reduced heating demand.

2. Another strategy in addition, is to heat the sheds with district heating instead of electricity. District heating is more energy efficient than individual heating systems, thus resulting in lower emissions.

3. The last improvement regarding construction sheds is to use LED lighting instead of conventional lighting. Compared to incandescent lighting, LED lights have a longer life time and are energy efficient.

Strategy	Case study references
Construction sheds	SE7, Hatami (2007), Kellner and Sandberg (2013)
Reduction potential	UK3



- The type of energy that is used and whether the construction takes place during the heating season or not, affects the operational energy.
- A significant share of the total electricity used on site is associated with the heating and lighting of construction sheds, thus improving the sheds offers a great potential for reducing embodied energy.

Reduction of construction stage impacts - continued

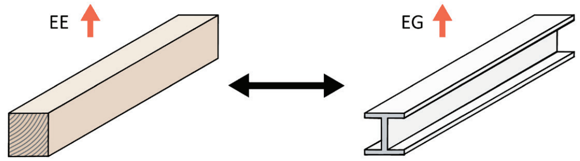
4. Different structural materials have different impacts on the embodied energy and emissions during the construction phase. For instance if wood and steel are compared, wood has lower embodied emissions, but requires more energy during the construction stage.

5. Waste material makes up a significant share of the total embodied energy of the building, of which most happen during the construction stage. An increase of prefabricated components decreases the waste generation on site.

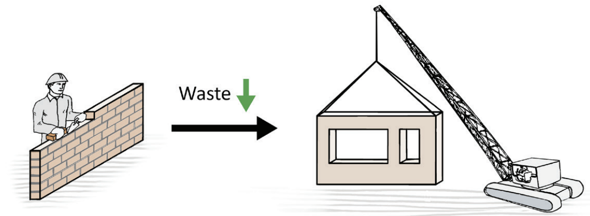
6. Transportation of materials to the site typically accounts for a low share of the total energy and emissions. However, a prefabricated construction system implies a higher share of the operational energy associated with the transportation.

The modules do have an advantage on on-site energy use. Therefore, a trade-off needs to be considered between transportation to the site and on-site energy use. Since the production stage normally dominates the total embodied energy and emissions, the construction stage is often neglected. Therefore there is a limited amount of relevant case studies that provide insight in the processes that contribute to the impacts during the construction stage, as well as in the potential of reduction strategies.

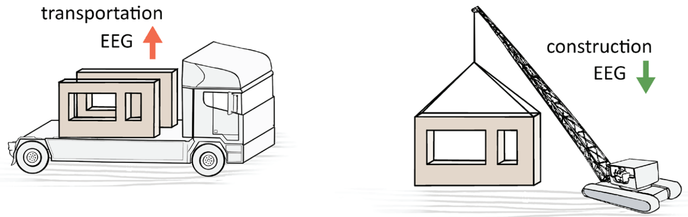
(4) Timber vs. steel



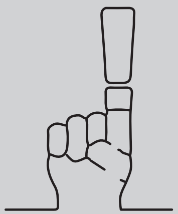
(5) On site vs. prefabrication



(6) Emissions related to prefabrication



Strategy	Case study references
Structural materials	UK7
Waste generation	UK5
Transportation	Quale et al (2012)



- Prefabricated modules compared to on-site building have the advantage that they generate less waste and use less energy on-site. However, the emmissions related to transportation are higher thus a trade-off needs to be made between the different factors.

Design for low end of life impacts

Design for low impact of end-of-life stage

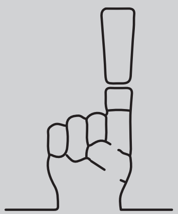
There are two approaches to design for a low impact end-of-life stage: design for disassembly and design for recyclability. These approaches mostly influence emissions in the product stage of future buildings, which lies beyond the system boundaries. Therefore no case studies were found that focused on the reduction potentials of design for disassembly and reuse of components. It can however positively influence the disposal stage of buildings in the cases where recycling or reuse of materials causes less impact than landfilling or incineration. For example, recycling of steel has high environmental impacts, but is still better than landfilling. The reuse of steel components could therefore significantly increase the recovery potential of steel.

When only a small ratio of recycling is considered, there is no benefit and the impact is higher than in a scenario with no recycling. This is because transportation to the recycling facility has a higher impact than landfilling or incineration. However, in scenarios with a higher potential for recycling and reuse there is a significant decrease of impacts of the whole life cycle.

In conclusion it can be said that this strategy is difficult for reducing emissions of a building's end-of-life stage. It is difficult to predict further development of recycling technologies and building practice and even the future use of buildings is unsure. However, we can assume that at least technologies that are known today shall be developed and increasingly used.


Disassembly of industrial complex. Copyright: Colorbox

Strategy	Case study references
Recycling of structure	UK7
Recycling scenarios	Junnila (2004)



- When recycling is used on a small scale, it might have higher impacts than a scenario without recycling due to the impacts or transportation to recycling facilities.
- Trying to reduce environmental impacts of a building's end-of-life stage during the design stage is difficult because recycling and reuse often have effects on the product stage of future buildings.

Final reflections

These guidelines aim to provide a preliminary overview of the key design strategies and illustrate their potentials for reducing embodied energy and emissions through the use of case study examples. At the moment, operational energy dominates the life cycle energy use and greenhouse gas emissions of buildings, but as the energy use decreases, the influence of embodied energy and emissions in the life cycle assessment increases.

Therefore, any design or construction measures to reduce emissions should avoid increasing, and preferably rather decrease operational energy use. On the other hand, minimising operational energy use should of course neither lead to an increase of emissions.

A wide range of strategies to reduce emissions has been discussed in this document. It should be noted that these strategies are interconnected and can sometimes be considered both positive and negative. Interconnections between strategies may seem obvious but are supported by incidental case studies. There was no available literature in the field, so the findings are as a result of consistently evaluating design strategies in relation to each other. In addition, the feasibility and emission reduction potential of each individual design strategy is heavily influenced by a number of factors such as climate, topography, national building requirements and cultural preferences.

It is not so easy to draw conclusions from combining findings of individual case studies, whereas the limited number of case studies which illustrate most design and construction strategies actually also presents a challenge in drawing robust conclusions. Recent initiatives to standardise building assessments, as seen in EN 15978 and EN 15804, as well as recommended minimum documentation requirements, may enhance comparability of future assessments.

Design choices made early in the design process are influential in constraining possibilities for reducing embodied energy and emissions, as well as operational energy use and greenhouse gas emissions later on. It is therefore important to involve these reduction considerations as early as possible in the design (and construction) process.

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