EBC

Energy in Buildings and Communities Programme

International Energy Agency

Evaluation of Embodied Energy and GHG Emissions for Building Construction (Annex 57)

Case studies demonstrating Embodied Energy and Embodied Greenhouse gas Emissions in buildings

November 2016

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

iea Energy Technology Network

International Energy Agency

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Case studies demonstrating Embodied Energy and Embodied Greenhouse gas Emissions in buildings

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Editors

Harpa Birgisdóttir, hbi@sbi.aau.dk
Danish Building Research Institute, Aalborg University Copenhagen

Authors

Harpa Birgisdóttir[1], Aoife Houlihan-Wiberg[2], Tove Malmqvist[3], Alice Moncaster[4] and Freja Nygaard Rasmussen[1]

Case study authors

Alexander Passer, Beate Lubitz-Prohaska, Gernot Fischer, Helmuth Kreiner, David Venus, Rolf Frischknecht, Guillaume Habert, Marie Nehasilová, Ctislav Fiala, Holger König, Harpa Birgisdottir, Freja Nygaard Rasmussen, Marina Mistretta, Keizo Yokoyama, Noriyoshi Yokoo, Sung-Hee Kim, Suhyun Cho and Chang-U Chae, Aoife Houlihan Wiberg, Torhildur Fjola Kristjansdottir, Marianne Rose Inman, Tove Malmqvist and Eleni Soulti.

[1] Danish Building Research Institute, Aalborg University Copenhagen
[2] Norwegian University of Science & Technology, NTNU
[3] KTH Royal Institute of Technology, Stockholm
[4] University of Cambridge

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United Kingdom
www.iea-ebc.org
essu@iea-ebc.org

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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Introduction

Annex 57 is an international expert team within the International Energy Agency's Energy in Buildings and Communities Programme (IEA EBC). The purpose of the team is to produce an 'Evaluation of Embodied Energy and Greenhouse gas Emissions for Building Construction'.

The purpose of Subtask 4 (ST4) is 'To develop measures to design and construct buildings with less Embodied Energy and Greenhouse gas Emissions'. This report is a collection of around 80 case studies that have been used for analysis and discussions of approaches to reducing embodied energy (EE) and embodied greenhouse gas emissions (EG) from buildings. A common abbreviation for both embodied energy (EE) and embodied greenhouse gas emissions (EG) is EEG.

This report is a collection of case studies within Annex 57 partner countries focusing on embodied energy (EE) and embodied greenhouse gasses (EG) for building construction. The call for case studies was organised by ST4 so that all Annex 57 participants were sent an invitation by email to submit case studies in 2013, again in 2014, and finally in 2015. Majority of the studies are based on detailed reports or published academic literature. ST4 asked that the studies be submitted using the prepared template, thus ensuring that comparable data was provided where possible.

The collection includes around 80 case studies presented in a standardised form. Template was developed through which case studies could be submitted. The template was designed to allow the widest variety of studies – including qualitative studies – while encouraging transparency and completeness of quantitative data.

The purpose of the collection of case studies is 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.
- Use the case studies to compare between studies for specific aspects, as done in the **IEA EBC Annex 57, ST4 report**.
- Use the case studies to develop guidelines for how to reduce embodied energy and greenhouse gasses, as is done in **Guideline for Designers and Consultants – Part 2**.

This collection of case studies is a product of inputs from various experts within embodied energy and greenhouse gasses in buildings around the world. The editor would like to thank the all authors of the filled case study templates for their contribution. The authors of the case study templates are responsible for the correctness of the results presented. Authors and contact persons for all case studies are listed in Appendix 1 of this report.

Characteristics of case studies

In order to structure the case studies and the content presented in the templates, the call for case studies included specified wishes for how to report in the templates. This included:

- Original objective of the case study.
- Identification of the potential stakeholders who might find the case studies of interest – the Annex 57 team identified a number of these:
  - National government/policy
  - Local government/planning
  - Designers/consultants
  - Developers/contractors
  - Clients/owners
  - Manufacturers.
- Identification of the 'theme' of the case study - these too were developed through discussions with the Annex 57 participants, and were initially intended to be the divisions for the analysis. The following 6 themes were identified:

1) Strategies for building design

The aim of this theme was to collect case studies to analyse the effects of different design choices (or strategies) in building design on EEG, such as:

1.1 Selection of materials, for ex.
  - Light weight vs. heavier
  - Insitu or prefabricated components
  - Traditional materials vs. emerging state of the art material
  - Type of material
  - Using recycled material
  - Use of local materials
  - Using materials that can be easily deconstructed, e.g. mortar which allows re-use of masonry products
  - Using technologies such as RFID (radio frequency identification) tags on steel beams to support future reuse.

1.2 Flexibility and space efficiency in design/layout

1.3 Prolongation of building life time

1.4 Design choices, building form, space efficiency

1.5 Design for Recyclability

1.6 Impact of construction practices, such as site waste management and site energy management.

2) Significance of different factors

In order to understand which strategies to take to reduce the EEG, it is important to understand how significant different factors may be in relation to the environmental impact caused by buildings over the entire life cycle. The aim of this theme was to collect case studies to analyse:

2.1 Which stages in the life cycle of the building are most important?

2.2 Which elements in the building?

2.3 Impact of off-site manufacture v. in situ?

2.4 Impact of location (including rural v. brownfield v. urban high density, plus also which country)?

3) How the EEG is calculated and effected by the choice of method/system boundaries

There are still many methodological issues to be aware about when calculating building Life Cycle Assessment (LCA) or embodied energy and greenhouse gas emissions (EEG). It is useful to understand the impact of specific methods in order to understand the potential extent of under-estimates of EEG being published. The aim of this theme was to collect case studies that illustrate the effects on the results of different methodological choices as well as illustrating difficulties and uncertainties in calculations. This includes:

3.1 Length of the reference study time

3.2 Life cycle stages included

3.3 Completeness of building data

3.4 Use of forecasting (future energy, efficiency of PVs, dynamic LCA, predicted reduction in carbon intensity of national grid, etc.)

3.5 Carbon sequestration of wooden buildings (or use of wood in buildings)

3.6 Source of data: Generic, product specific, quality of data

3.7 Life cycle analysis method (process based, input-output, hybrid).

4) Reduction strategies/Significant factors and calculation of EEG for building components and construction materials

The aim of this theme is to collect case studies with building components and construction materials as object of study and that either illustrates methodological issues in calculations, significant factors for the EEG calculation results or that highlight strategies for reducing EEG in construction products or materials.

4.1 Traditional materials vs. emerging state of the art material

4.2 Improved processes for concrete products, etc.

4.3 Carbon sequestration in concrete, wood

4.4 Handling credits for recycling of metals

5) Reduction strategies/Significant factors and calculation of EEG for building sector at national level

The aim of this theme was to collect case studies with the national building and construction sectors as object of study and that either illustrates methodological issues in calculations, significant factors for the EEG calculation results or that highlight strategies for reducing EEG at a national level.

5.1 National strategies for reduction of EEG

5.2 National level calculations of EEG

5.3 Which are the dominant activities of the building sector contributing to energy use, CO_2e emissions?

5.4 Methodological issues regarding national level calculations of EEG.

6) Processes, how focus on EEG is integrated into decision making process

The aim of this theme was to collect case studies that illustrate how LCA or EEG has been integrated into the design process.

6.1 LCA/EEG integrated into the design process, different steps and different decisions

6.2 Development work to facilitate the consideration of LC thinking/EEG in the design process

6.3 Which life cycle stages have the highest potential for reduction, and whose responsibility each stage is – for example, contractors, designers, clients, planning authorities, cement producers, etc.

Case studies

The case study collection includes around 80 case studies from 11 countries. The case studies are reported in a standardised case study template, typically 6-10 pages for each case study. Consequently the collection of the case study template consists of almost 600 pages in total. The full version of the case study templates for all case studies is found in Appendix 2 of this report.

This chapter includes four sections which give an introducing overview to all Annex 57 case studies, and is thought as a preview for the collection found in Appendix 2. The sections are:

- **Geographical location,** which gives an overview of the amount of case studies and building according to their geographical location.
- **Embodied impacts (EEG) of Annex 57 case studies**, which gives a short overview of the results of the case studies which are presented in more details in the **IEA EBC Annex 57, ST4 report**.
- **Summary of case studies,** which gives a short introduction to the main results of each case study, reference study period and the exact results of embodied energy and embodied greenhouse gas emissions.
- **Details of case studies**, which as an example give an overview of the database used, reference study period and modules included. This information is essential for the analysis of methodological choices that are substantial for both the results of the study and the following analysis of the case studies carried out in the **IEA EBC Annex 57, 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.

Geographical location of case studies

The case study collection includes around 80 case studies from 11 countries. Figure 1 shows the geographical location of the case studies.

Figure 1. Geographical location of the case studies.

Figure 2 shows the different building types included in the collection of case studies. The size of the circles illustrates the amount of case studies for the different building types from each country.

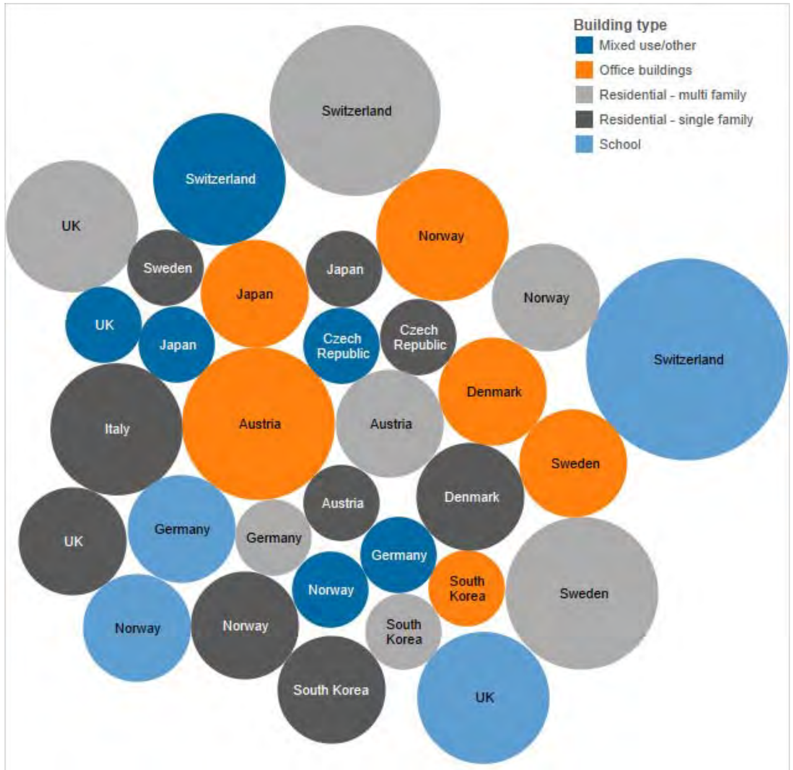


Figure 2. Amount and origin of case studies per building type.

Embodied impacts (EEG) of Annex 57 case studies

The uniqueness of constructed buildings makes direct comparisons of LCA results difficult. In figure 3, cradle-to-gate EG results from a selection of the IEA EBC Annex 57 case studies are shown which represents the wide diversity of the 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 applied differently from case study to case study and from country to country. For instance, the goal, scope and methodology of the case studies are different, some are simplified inventory for early design choices (such as **SE2a**) while some are performed at a very detailed level of inventory when a building has been built (such as **NO4**). Some studies (such as **AT5**) accounts 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**) and a 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-up is used (for instance seen in **AT5** and **AT6**) and thus produces results that are difficult to compare. Furthermore, it should be noted that the performance indicator displayed in figure 3 is kg CO_{2eq}/m^2. Furthermore, some of the case study calculations are based on gross floor area whilst others are on net floor area which can make a difference of at least 10% of the area being used. These aspects are explained in details in chapter 2 of the **IEA EBC Annex 57, ST4 report.**

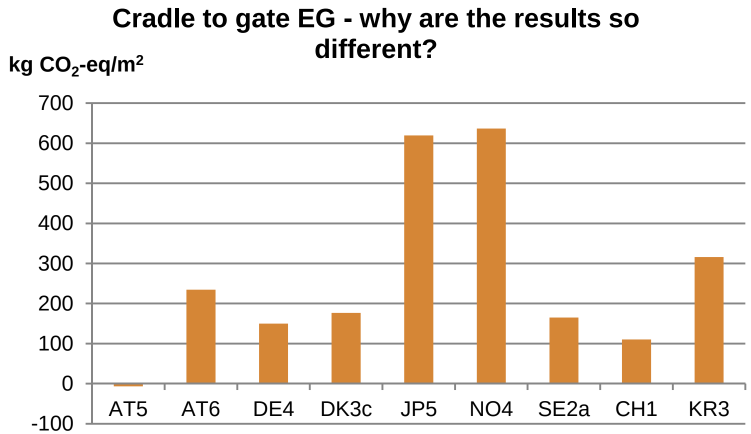


Figure 3. Embodied GHG emissions from the cradle to gate stage of different Annex 57 case studies. See appendix I for the list of case studies included in the IEA EBC Annex 57 work.

In the following section, aggregated results of EE and EG from case studies are presented for:

- cradle-to-gate results (modules A1-A3)
- cradle-to gate + replacement results (modules A1-A3 + B4)
- cradle-to-gate + replacements + EoL results (modules A1-A3 + B4 + C3-C4).

The **IEA EBC Annex 57, ST4 report** (chapter 3) explains more details behind the embodied impacts of the case studies and therefore it is recommended to read this chapter in order to get deeper understanding of the following figures.

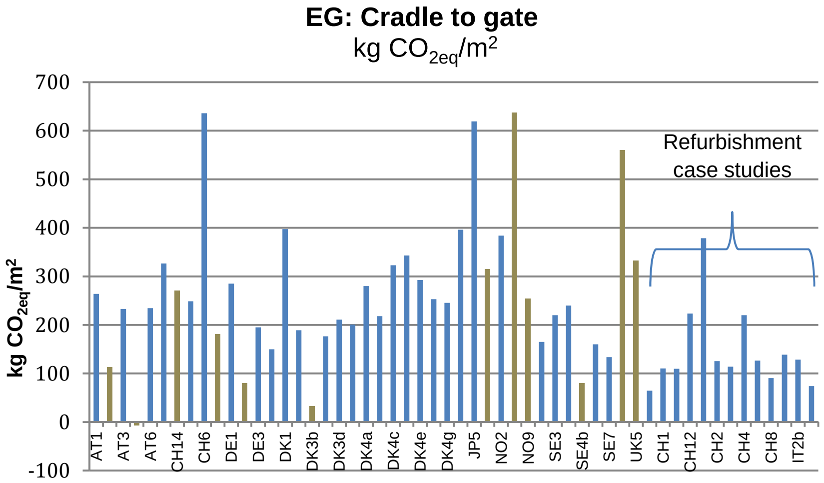


Figure 4. Cradle-to-gate EG from available Annex 57 case studies. Brown bars indicate constructions with wooden or hybrid wooden/concrete structures. Blue bars indicate constructions with concrete, steel or bricks as main materials for load bearing structures.

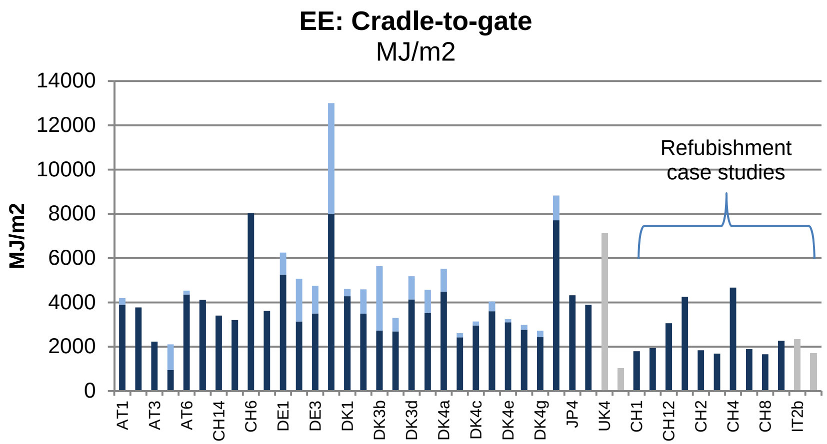


Figure 5. Cradle-to-gate EE from available Annex 57 case studies. Light blue bars indicate the additional amount of renewable primary energy for the buildings. Grey bars indicate case studies where the EE numbers are reported as a sum of renewable and non-renewable primary energy.

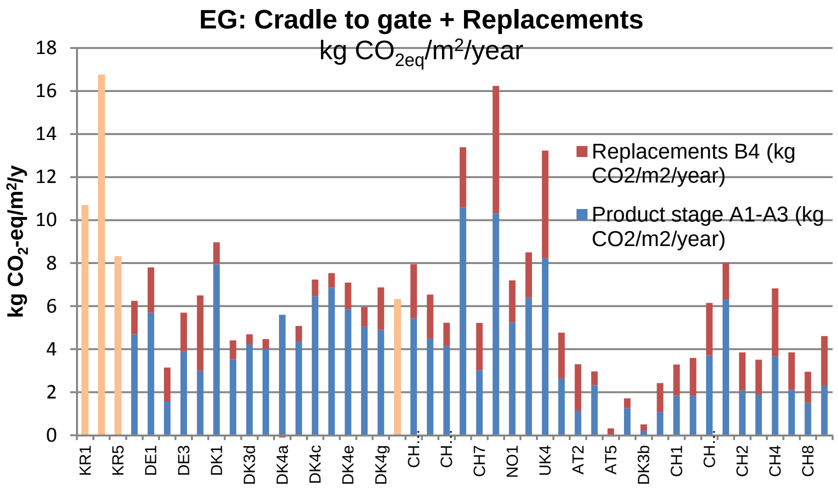


Figure 6. Cradle-to-gate + replacement EG from available Annex 57 case studies. Orange bars indicate case studies where reported results is a sum of production and replacement impacts.

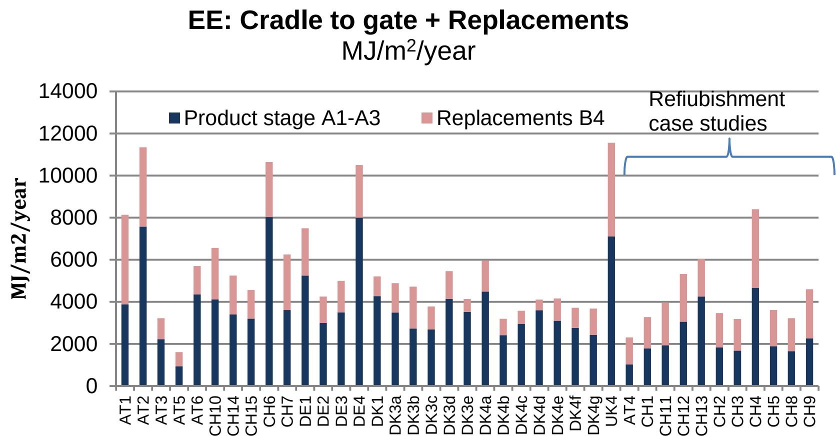


Figure 7. Cradle to gate + replacement EE from available Annex 57 case studies.

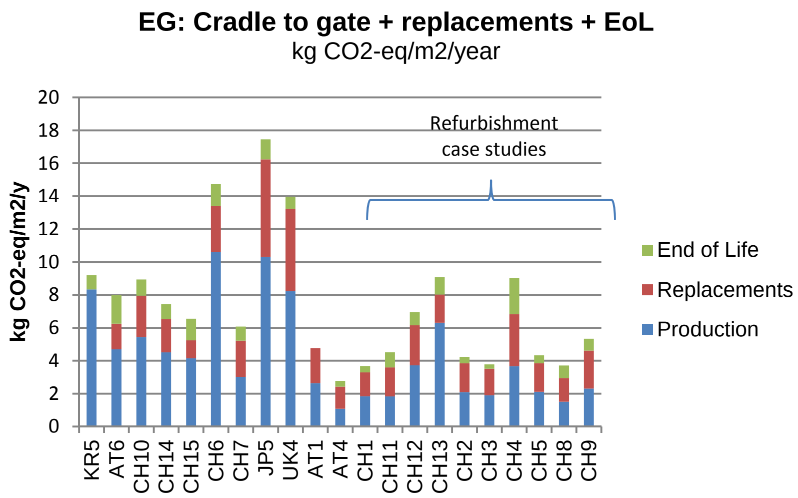


Figure 8. Cradle to gate + replacements + EoL EG from available Annex 57 case studie

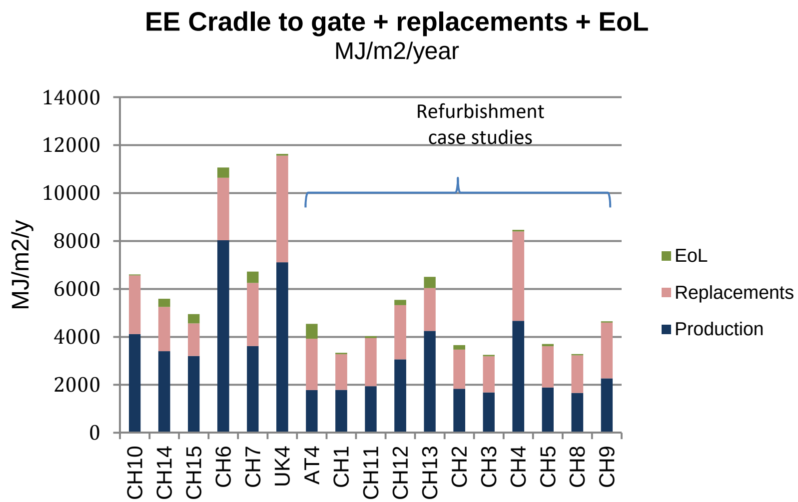


Figure 9. Cradle-to-gate + replacement + EoL EE from available Annex 57 case studies.

Summary of case studies

Note: The copyright of the pictures in the summaries are found in the templates

Austria

AT1: Aspern IQ, new office building

Reference period (years)	100
EG (kg-CO2/m2 year)	4.77
EE (kWh/m2GFA/year)	22.6

The study showed that the building materials contributed with 34% of Primary Energy

AT2: LCT ONE, new office building

Reference period (years)	100
EG (kg-CO2/m2 year)	3.29
EE (kWh/m2GFA/year)	21.03

The study showed that the LCT One building materials contributed with 20**%** of Primary Energy.

AT3: TU Vienna, new office building

Reference period (years)	100
EG (kg-CO2/m2 year)	2.97
EE (kWh/m2GFA/year)	8.97

The study showed that the TU Vienna building materials contributed with 10**%** of Primary Energy

AT4: Plus energy residential building, renovation

Reference period (years)	60
EG (kg-CO2/m2 year)	2.77
EE (kWh/m2GFA/year)	10.9

The aim of this research project is to develop a prefabricated construction for the refurbishment of houses, which were build in Austria between the 1950 and 1980's.

AT5: Energy City Graz, new residential building

Reference period (years)	100
EG (kg-CO2/m2 year)	0.91
EE (kWh/m2GFA/year)	11.84

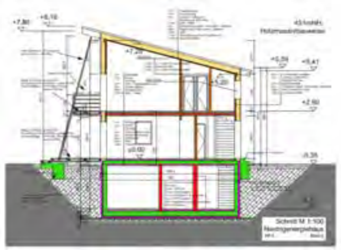
The main objective of the research project Energy City Graz-Reininghaus (ECR) focuses on the development of an energy self-sufficient and CO_2-neutral city district in the City of Graz (Austria).

AT6: Karmeliterhof, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	7.99
EE (kWh/m2GFA/year)	96.18

In this research project an assessment based on the criteria from the DGNB and a critical examination of the ecological performance from the Office Building Karmeliterhof was done.

AT7: Ökovergleiche



Reference period (years)	100
EG (kg-CO2/m2 year)	7.08 – 9.40
EE (kWh/m2GFA/year)	27.37 – 33.57

The aim of this research project is to subject a number of building concept models to a comprehensive comparative analysis and evaluation in terms of ecological and economic keyfigures.

Switzerland

CH1: School A, school renovation

Reference period (years)	60
EG (kg-CO2/m2 year)	3.68
EE (MJ/m2GFA/year)	55.6

This assessment is performed in the context of the discussion about reference and target values for env. impacts of different building types. The assesment show that the roof, windows, flooring and the infrastructure cause the main impact within the construction stage.

CH2: School B, school renovation

Reference period (years)	60
EG (kg-CO2/m2 year)	4.24
EE (MJ/m2GFA/year)	60.9

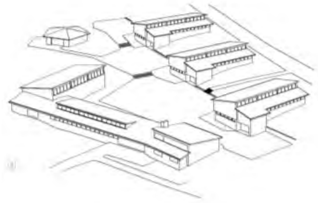
The context of case CH2 is similar to CH1.

CH3: School C, school renovation

Reference period (years)	60
EG (kg-CO2/m2 year)	3.77
EE (MJ/m2GFA/year)	54.2

The context of case CH3 is similar to CH1.

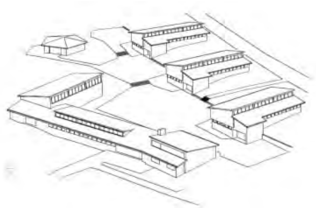
CH4: School D, renovation school



Reference period (years)	60
EG (kg-CO2/m2 year)	9.04
EE (MJ/m2GFA/year)	141.1

The context of case CH4 is similar to CH1. The assesment show that roof, windows and the infrastructure cause the main impact within the construction stage.

CH5: School E, school renovation



Reference period (years)	60
EG (kg-CO2/m2 year)	4.34
EE (MJ/m2GFA/year)	61.7

The context of case CH5 is similar to CH1. The assesment showed that the roof, windows, flooring and the infrastructure cause the main impact within the construction stage.

CH6: School F, new school

Reference period (years)	60
EG (kg-CO2/m2 year)	14.70
EE (MJ/m2GFA/year)	186,4

The context of case CH6 is similar to CH1.The assesment show that the ceilings, pillars, flooring and infrastructure cause the main impact within the construction stage

CH7: School G, new school

Reference period (years)	60
EG (kg-CO2/m2 year)	6.07
EE (MJ/m2GFA/year)	106.4

The context of case CH7 is similar to CH1.

CH8: Residential building A, refurbishment

Reference period (years)	60
EG (kg-CO2/m2 year)	3.71
EE (MJ/m2GFA/year)	54.7

The context of case CH8 is similar to CH1.

Switzerland

CH9: Residential building B, new residential building

Reference period (years)	60
EG (kg-CO2/m2 year)	5.33
EE (MJ/m2GFA/year)	77.5

The context of case CH9 is similar to CH1.

CH10: Residential building B, new residential building

Reference period (years)	60
EG (kg-CO2/m2 year)	8.93
EE (MJ/m2GFA/year)	115.2

The context of case CH10 is similar to CH1.

CH11: Retirement home A, refurbishment

Reference period (years)	60
EG (kg-CO2/m2 year)	4.51
EE (MJ/m2GFA/year)	67.2

The context of case CH11 is similar to CH1.

CH12: Retirement home B, refurbishment

Reference period (years)	60
EG (kg-CO2/m2 year)	6.96
EE (MJ/m2GFA/year)	92.4

The context of case CH12 is similar to CH1.

CH13: Retirement home C, refurbishment

Reference period (years)	60
EG (kg-CO2/m2 year)	9.08
EE (MJ/m2GFA/year)	108.4

The context of case CH13 is similar to CH1.

CH14: LCA of apartment buildings, new

mfh08

Reference period (years)	60
EG (kg-CO2/m2 year)	87.31
EE (MJ/m2GFA/year)	107.8

The assesment show that the most relevant building elements are external walls (wall coverings included), ceilings (floorings included) and windows.

CH15: LCA of apartment building mfh11, new

mfh11

Reference period (years)	60
EG (kg-CO2/m2 year)	7.78
EE (MJ/m2GFA/year)	104.8

The assesment show that the relevant building elements are ceilings, external walls (wall coverings included) and baseplate (floorings included).

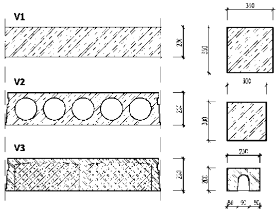
Czech Republic

CZ1: Reused versus new materials, residential building

Scenario	Reuse	new mat.
Reference period (years)	60	60
EG (kg-CO2/m2 year)	-	-
EE (MJ/m2GFA/year)	-	-

The case showed that reuse of materials does not necessary mean reduction of the total environmental impact of a house. Although a big part of the structure is from reused materials in scenario 1, the reduction of environmental impact in the product stage is not very significant.

CZ2: UHPC versus standard concrete frame, material



Scenario	v1	v2	v3
Reference period (years)	100	100	100
EG (kg-CO2/m2 year)	-	-	-
EE (MJ/m2GFA/year)	-	-	-

Use of new composite silicate material for building frame – ultra high performance concrete (UHPC) can bring significant reduction of environmental impacts. It is possible to reduce environmental impact in the range 10 to 54% in comparison to common solutions.

Germany

DE1: Elementary school, new school

Reference period (years)	50
EG (kg-CO2/m2 year)	8.4
EE (MJ/m2GFA/year)	135

The evaluation of the different building materials showed the following contributions: Concrete 83.5%, floorings 5.9%, metal 3.3% , walling 2%, insulation 1.6%, sealings 1.4%, wood 1.1%, glass 0.5% and technical equipment 0.2%.

DE2: Gymnasium Diedorf , new school

Reference period (years)	50
EG (kg-CO2/m2 year)	4.71
EE (MJ/m2GFA/year)	93

The evaluation of the different building materials showed the following contributions: Concrete 70.3% , floorings with 10.4%, wood and wood based products 7.2%, metal 3.9%, insulation 3.2%, walling 2.9%, sealings 0.7%, glass 0.7% and technical equipment 0.4%.

DE3: Residential building, new residential building

Reference period (years)	50
EG (kg-CO2/m2 year)	5.7
EE (MJ/m2GFA/year)	97.3

The evaluation of the different building materials showed the following contributions: Concrete 78.6% , floorings with 6.9%, metal 4.4%, walling 3%, insulation 2%, wood based products 1.4%, glass 0.9% and technical equipment 0.7%.

DE4: Administration Building, new office building

Reference period (years)	50
EG (kg-CO2/m2 year)	9.36
EE (MJ/m2GFA/year)	2017

This evaluation of the different building materials showed following contributions: Concrete 51.6 %, wood and wood based products 10.7%, floorings 10.5%, walling 8.8%, insulation 8.3%, metal 4.7%, sealings 2.8%, plastic 1.1%, and technical equipment 1.0%, glass 0.3% and paintings 0.2%.

Denmark

DK1: Novo Nordic HQ, new office building

Senario	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

Senario	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 the strategy to reduce environmental damage shows a big potential for the future.

DK3a: MiniCO2-house, new residential house

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

Durable building materials chosen for the main structure. A large roof overhang protects windows and doors from weathering.

DK3b: MiniCO2-house, new residential house

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

Glass cladding protects the wooden construction elements. Overhang furthermore protects weaker building components (like windows).

DK3c: MiniCO2-house, new residential house

Senario	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.

DK3d: MiniCO2-house, new residential house

Senario	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.

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

Denmark

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

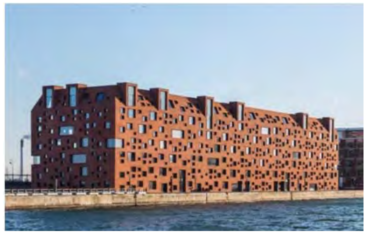
The building was a pilot project in the adaptation process of the DGNB certification system to meet Danish conditions

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

DK4g 7 Office buildings, new office building



Reference period (years)	50
EG (kg-CO2/m2 year)	6.9
EE (kWh/m2GFA/year)	88

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

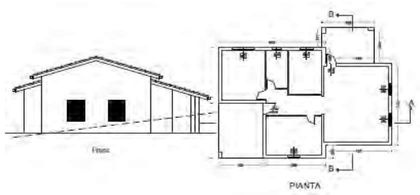
Italy

IT1: Kenaf-fibre insulation board, material

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The study presents a LCA of a kenaf-fibre insulation board. The results show that the use of natural fibres involves a significant reduction of the environmental impacts and that the overall energy impact of the building could be more easily evaluated with a life cycle analysis approach.

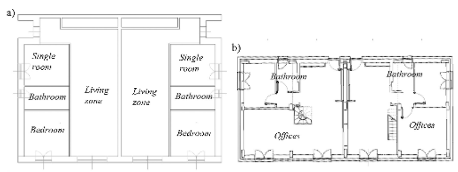
IT2: Single family house, retrofit residential building



Reference period (years)	50
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The study assess the energy and environmental impacts of the retrofit actions.

IT3: Net ZEB, new residential building



Reference period (years)	70
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	0

The study assess the life-cycle energy balance of an Italian nearly Net ZEB.

IT4: Sicilian Tiles, materialer

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The study presents a LCA of the “Sicilian tiles”, which are a typical roof tiles used in the past and recently employed in restoring old buildings in the Mediterranean area. The assesment highlight the most significant energy and environmental issues of the tile.

Japan

JP1: Zero LCCO2 Model , new residential building

Reference period (years)	90
EG (kg-CO2/m2 year)	5
EE (MJ/m2GFA/year)	-

This house was built to demonstrate ultimate energy effective measures including operational and embodied energy.

JP2: Low Energy house, new residential building

1st Floor Plan

Energy efficiency	Standard	Low energy
Reference period (years)	-	-
EG (ton-CO2)	40.6	43.8
EE (MJ/m2GFA/year)	-	-

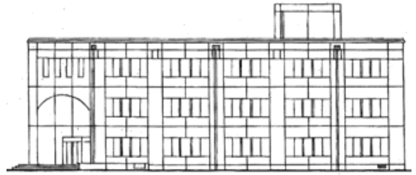
LCA of a standard house and a low energy house is studied. The assesment show that the increase of EG in the construction of the low-energy house can be recovered in terms of operation CO2 in about two years.

JP3: Waste recycle, residential building

Case study	1	2	3
Reference period (years)	60	60	60
EG (kg-CO2/m2 year)	12.5	11.2	10.3
EE (MJ/m2GFA/year)	-	-	-

When comparing with Case1, Case2 shows an EG decrease of 10.7%. When comparing with Case2, Case3 shows an EG decrease of 7.9%.
With regard to wooden houses, recycling promotion and expanded utilization of woodchip energy can contribute to reduction in CO2 emissions.

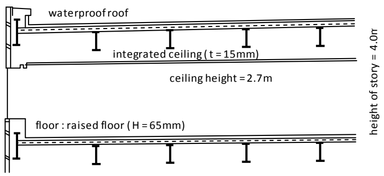
JP4: Prolongation of life time, design of a Library



Extra earthquakeresistant	0%	50%	25%
Reference period (years)	60	100	100
EG (kg-CO2/m2 year)	6.6	5.2	4.6
EE (MJ/m2GFA/year)	72	52	48

The length of RFS is an important factor for the results. Evaluation of additional cost for prolongation of life time, the additional cost is 3 to 9% of total construction cost of building.

JP5: Freon, new office building



Reference period (years)	60
EG (kg-CO2/m2)	1.093
EE (MJ/m2GFA/year)	-

EG due to Freon gases contained in insulators is 26 (kg-CO_2/m^2), 2% of the building's EG.
EG due to Freon gases contained in refrigerants is 107 (kg-CO_2/m^2), 10% of the building's EG.

JP6: Long life and low carbon, new office building

Lifetime	Short	Long
Reference period (years)	50	100
EG (kg-CO2/m2 year)	22	12
EE (MJ/m2GFA/year)	240	125

To increase the building life time from 50 years to 100 years, the covering thickness of concrete, the steel frames, oil dumpers are considered. The length of RFS is an important factor for the results.

JP7: Renovation of an office building

Reference period (years)	50	50
EG (kg-CO2/m2)	306	966
EE (GJ/m2GFA)	3.8	11.2

The evaluation og the case clearly illustrates a large differences of energy use and energy intensity between renovation and reconstruction project.

South Korea

KR1: Han-ok, refurbisment of residential building

Reference period (years)	30
EG (kg-CO2/m2 year)	10.7
EE (MJ/m2GFA/year)	-

Evaluation of building components showed that the major ity of EG are covered by few materials like Korean roof tiles(39.1%), cement (32%) and lumber (27%) during production stage, while riprap, sand, mud and granite stone are used by a large amount by weight.

KR2: Multi-family building, new residential building

Reference period (years)	30
EG (kg-CO2/m2 year)	16.8
EE (MJ/m2GFA/year)	-

Evaluation of the different building materials showe that for EG, concrete contributed with 72.3% and cement(brick) with 8.6%.

KR3: Posco Green Bulding. New office

Reference period (years)	50
EG (kg-CO2/m2 year)	6.32
EE (MJ/m2GFA/year)	-

The study shows that the building materials contributed with 12.9% of EG with RFS of 50 years, and in the case of 100years it is decreased to 6.9%. This means reused building products decrease the EG compared to conventional buildings.

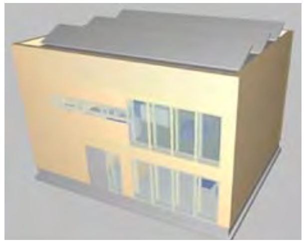
KR4: Timber framed house, residential building

Reference period (years)	30
EG (kg-CO2/m2 year)	8.33
EE (MJ/m2GFA/year)	-

Evaluation of the different building materials showed that concrete contributed with 67.5%, timbers with 8.8% and rebar with 4.0 % of the embodied carbon. In relation to this there were used 82.% concrete and 9.2% timber in the construction.

Norway

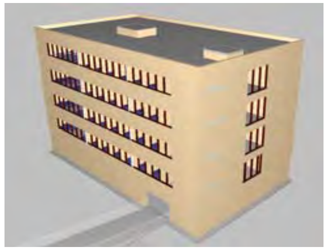
NO1: ZEB Single Family House, new residential building



Reference period (years)	60
EG (kg-CO2/m2 year)	7.2
EE (kWh/m2GFA/year)	-

The study showed that the emissions from building materials contributed 44% to total emissions. The photovoltaic panels (32%), the concrete (13%) and the EPS insulation (12%) were the building parts that contribute the most.

NO2: ZEB Office Concept, new office building



Reference period (years)	60
EG (kg-CO2/m2 year)	8.5
EE (kWh/m2GFA/year)	-

The study showed that the emissions from building materials contributed 66% to emmisions. The photovoltaic panels (25%), concrete (22%) and steel (15%) were the building materials that contributed the most.

NO4: ZEB Living Lab, new residential house

Reference period (years)	60
EG (kg-CO2/m2 year)	12,3-13,9
EE (kWh/m2GFA/year)	-

The evaluation showed a difference between generic and specific datasets and that the outer roof (30%), solar collectors (16%) and the outer walls (14%) were the largest contributors to total embodied emissions.

NO8: Powerhouse Kjørbo, renovated office building

Reference period (years)	60
EG (kg-CO2/m2 year)	6.6
EE (kWh/m2GFA/year)	-

The study showed that emissions from building materials contributed 36% to total emissions. Energy production from photovoltaic panels covers over 100% of total embodied emissions

NO9: Multikomforthus, new residential building

Reference period (years)	60
EG (kg-CO2/m2 year)	5.96
EE (kWh/m2GFA/year)	-

The evaluation of different building parts, showed that emissions from photovoltaic panels (30%), low carbon concrete (11%) and windows (9%) were the largest contributors to total embodied emissions.

Sweden

SE1:The swedish building sector

Reference period (years)	1
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The study concludes that strategies to reduce climate change should not only prioritize heating of buildings but also include increased recycling, well-informed selection of building materials and choice of building methods that extend building life.

SE2a: Terrinen, new residential building

Reference period (years)	50
EG (kg-CO2e/m2HFA year)	3.3
EE (MJ/m2GFA/year)	-

The study showed that the building materials contributed with 47% of Global Warming Potential (GWP). Evaluation of the different building materials showed that for EG, concrete contributed with 77% and steel with nearly 6%.

SE2b: Terrinen early design, new residential building

Construction	Wood	Concrete
Reference period (years)	50	50
EG (kg-CO2e/m2HFA year)	0.6	2.6
EE (MJ/m2GFA/year)	-	-

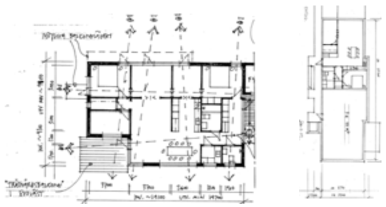
In the early design stage a calculation tool was used to identify key improvements of the building. The low figure for EG can be assumed to be a result of the simplifications – only main building elements are considered and no replacements of materials was undertaken during the life cycle.

SE3: ZEB single family home, residential building

Scenario	Org.	wooden walls	less insul.
Reference period (years)	50	50	50
EG (kg-CO2e/m2HFA year)	4.4	3.2	4.15
EE (MJ/m2GFA/year)	-	-	-

The results demonstrate that in the case of zero energy buildings, material choice affects the GWP significantly. In the original design concrete is responsible for the majority of the EG. It should be noted that EG for solar panels and photovoltaics was not part of the calculation.

SE4: Load bearing and form, new res. building



Reference period (years)	50/100
EG (kg-CO2e/m2HFA year)	-
EE (MJ/m2GFA/year)	-

In terms of EG the study show that the timber alternatives for load-bearing construction material are favorable to the concrete. Further more the study show that the square building form consistently had an EG 5 % lower than the rectangular building form.

SE5: Uppfinnaren Office, new office building

Senario	ref.	Energy reduc.	wood floors
Reference period (years)	50	50	50
EG (kg-CO2e/m2HFA year)	3.2	3.3	2.3
EE (MJ/m2GFA/year)	-	-	-

The case shows that for buildings with low operational energy demand supplied by low-GWP energy carriers, lifetime GWP can be most effectively mitigated with reducing embodied GWP. In this case the replacement of re-inforced concrete internal floors with timber alternatives.

SE6: Office fit-out, refurbisment of an office building

Reference period (years)	1
EG (kg-CO2e/m2 retrofitted	74
EE (MJ/m2 retrofitted area)	1.7

Considering that office fit-outs may be undertaken several times during the life-time of an office building, GWP and CED of fit-outs could contribute more to life-cycle impacts than new construction, and other activities undertaken in the use phase of office buildings.

SE7: New multifamily building, new residential building

Reference period (years)	50	100
EG (kg-CO2e/m2HFA year)	8.7	5.1
EE (MJ/m2HFA/year)	80	40

For EG, concrete contributed with more than 50%. A 15% reduction in EG was potentially possible by changing external walls to wood.

United Kingdom

UK1: Greater London Authority, Policy

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

It is estimated that planning policies and decisions made within the GLA and London Boroughs can give significant GWP savings. In terms of more strict standards regarding sustainable materials it can potential save 5.07 Mt CO_2 per year,.

UK2: Rampton Drift, Retrofit of a res. building

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

One of the outcomes of this research was the calculation of the retrofit payback times, in terms of energy and carbon payback times, rather than monetary cost. Hence, the carbon payback times were calculated and found to be between 6 and 33

UK3: Housing developments, new res. building

Reference period (years)	-
EG (kg-CO2/m2 year)	2.38 to 12.88
EE (MJ/m2GFA/year)	-

Data regarding energy, water use and waste production during the construction stage has been collected for 11 developments. The duration of the construction stage and the project valuation do not seem to have a significant influence on the resulting carbon emissions.

UK4: St Faith's, new school building

Reference period (years)	68
EG (kg-CO2/m2 year)	16,4
EE (MJ/m2GFA/year)	204,6

The study show that superstructure consume a considerable amount of energy in all life stages. While fittings, fixtures and furni- ture are the highest contributor to the ener- gy consumption at the replacement stage.

UK5: Lingwood development, residential building

Scenario	1	2	3
Reference period (years)	20	20	20
EG (kg-CO2/m2)	405	535	612
EE (MJ/m2GFA)	-	-	-

A house constructed using a panellised timber frame construction, had 26% lower EE and 34% reduction in EC than the equivalent traditional masonry house.

UK6: Four school buildings, new/refurbishment

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

Through analyses of four UK school building projects, procured at the same time through different processes, the case study offers insight into why EG and energy was taken into account for two of the schools and excluded from the others.

UK7: School sports hall, new School

Sceniario	Steel	Timber
Reference period (years)	60	60
EG (kg-CO2/m2)	2.5	2.47
EE (MJ/m2GFA)	178.5	254.8

Material sources, selection and waste management, at the end of the building life are the most important stages within the lifecycle of the structural elements of a building

UK8: Olympic Park and the ODA, sporting venues

Reference period (years)	50
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

Considerable reduction in embodied energy and carbon emmision from the construction of sporting venues for the London 2012 Olympic Park were achieved though early collaboration of design teams, contractors and suppliers

United Kingdom

UK9: Bridport House, new residential building

Reference period (years)	-
EG (ton-CO2)	-
EE (MJ/m2GFA/year)	-

The EG of the Cross Laminated Timber (CLT) option is almost 61% lower compared to the reinforced concrete structural option for the specific case study.

UK10: Residential building B, new residential building

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

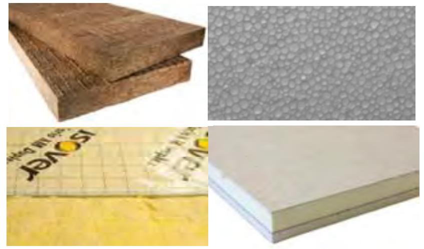
The case demonstrates some of the available options for LCA and embodied energy and carbon calculations, focusing on the construction sector and differentiating between different types of tools used for various purposes.

UK11: Olympic Park, sporting venue

Reference period (years)	-
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The Olympic Delivery Authority (ODA) collaborated with the concrete supply chain to develop sustain-able concrete mixes. This resulted in saving approxi-mately 24% (30,000 tonnes) of EG and eliminating more than 70,000 of road vehicle movements.

UK12: Retrofit solid wall buildings, residential building



Reference period (years)	60
EG (kg-CO2/m2 year)	-
EE (MJ/m2GFA/year)	-

The outcome of the study is that the embodied carbon spent in excess to achieve a product with better thermal conductivity, is very low compared to the operational carbon that will be saved during the building’s lifetime. The carbon payback time varies from 9 to 13 months.

Details of case studies

Case study	Database	RSP	Product stage			Construction process stage		Use stage					End-of-Life				Next product system	Main concept	Type
			Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential		
Austria																			
AT1	baubook eco2soft	100	x	x	x						x	x						New	Office
AT2	baubook eco2soft	100	x	x	x						x	x						New	Residential
AT3	baubook eco2soft	100	x	x	x						x	x						New	Office
AT4	EcoBat	60	x	x	x						x		x			x		Refurbishment	Residential
AT5	Baubook eco2soft	100	x	x	x						x	x						New	Residential
AT6	Ökobau 2009	50	x	x	x						x				x	x		New	Office
AT7	baubook eco2soft	100	x	x	x						x				x	x		New	Residential
Switzerland																			
CH1	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	School
CH2	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	School
CH3	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	School
CH4	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	School
CH5	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	School
CH6	EcoInvent 2.2	60	x	x	x						x				x	x	x	New	School
CH7	EcoInvent 2.2	60	x	x	x						x				x	x	x	New	School
CH8	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	Residential
CH9	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	Residential
CH10	EcoInvent 2.2	60	x	x	x						x				x	x	x	New	Residential
CH11	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	Residential
CH12	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	Residential
CH13	EcoInvent 2.2	60	x	x	x						x				x	x	x	Refurbishment	Residential
CH14	EcoInvent 2.2	60	x	x	x						x			x		x		New	Residential

Case study	Database	RSP	Product stage			Construction process stage		Use stage					End-of-Life				Next product system	Main concept	Type
			Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential		
CH15	EcoInvent 2.2	60	x	x	x						x			x		x		New	Residential
Czech republic																			
CZ1	Envimat	60	x	x	x													New	Residential
CZ2	Ecoinvent 2.2	100	x	x	x	x	x						x	x	x	x		-	Material
Germany																			
DE1	Ökobau 2011	50	x	x	x						x				x	x	x	New	School
DE2	Ökobau 2011	50	x	x	x						x				x	x	x	New	School
DE3	Ökobau 2011	50	x	x	x						x				x	x	x	New	Residential
DE4	Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
Denmark																			
DK1	PE int	50	x	x	x						x				x	x	x	New	Office
DK2	PE int	50	x	x	x													New	Residential
DK3a	ESUCO/Ökobau 2011	150	x	x	x						x				x	x	x	New	Residential
DK3b	ESUCO/Ökobau 2011	150	x	x	x						x				x	x	x	New	Residential
DK3c	ESUCO/Ökobau 2011	50	x	x	x						x	x			x	x	x	New	Residential
DK3d	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Residential
DK3e	ESUCO/Ökobau 2011	50	x	x	x						x	x			x	x	x	New	Residential
DK4a	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4b	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4c	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4d	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4e	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4f	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office
DK4g	ESUCO/Ökobau 2011	50	x	x	x						x				x	x	x	New	Office

Case study	Database	RSP	Product stage			Construction process stage		Use stage					End-of-Life				Next product system	Main concept	Type
			Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential		
Italy																			
IT1	Various	-	x	x	x	x	x		x					x		x		-	Material
IT2	EcoInvent	50	x	x	x				x		x		x	x	x	x	x	New	Residential
IT2	EcoInvent	50	x	x	x				x		x		x	x	x	x	x	Refurbishment	Residential
IT3	EcoInvent	70	x	x	x	x	x		x			x	x	x			x	New	Residential
IT4	(Not specified)	-	x	x	x	x												-	Material
Japan																			
JP1	IO table Japan	90	x	x	x	x	x		x		x							New	Residential
JP2	(Not specified)	-	x	x	x													New	Residential
JP3	Various	60	x	x	x	x	x				x	x	x	x	x	x		New	Residential
JP4	IO table Japan	60/100	x	x	x													New	Office
JP5	IO table Japan	60	x	x	x	x	x	x		x	x	x	x					New	Office
JP6	IO table Japan	50/100	x	x	x	x												New	Office
JP7a		-	x	x	x	x	x				x	x	x	x				Refurbishment	Office
JP7b	IO table Japan	-	x	x	x	x	x				x	x	x	x				New	Office
South Korea																			
KR1	KOR LCI	30	x	x	x	x					x				x	x		New	Residential
KR2	KOR LCI	30	x	x	x						x				x	x		New	Residential
KR3	KOR LCI	50	x	x	x	x	x									x		New	Office
KR4	KOR LCI	30	x	x	x						x				x	x		New	Residential

Case study	Database	RSP	Product stage			Construction process stage		Use stage					End-of-Life				Next product system	Main concept	Type
			Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential		
Norway																			
N01	EcoInvent	60	x	x	x						x							New	Residential
NO2	EcoInvent	60	x	x	x						x							New	Office
NO4	EPD	60	x	x	x	x												New	Residential
NO8	EcoInvent	60	x	x	x						x							Refurbishment	Office
NO9	EcoInvent	60	x	x	x						x							New	Residential
Sweden																			
SE1	Swedish IO data	1	x	x	x	x	x		x	x	x	x	x					-	Sector
SE2a	EcoInvent, BECE	50	x	x	x													New	Residential
SE2b	EcoInvent, BECE	50	x	x	x													New	Residential
SE3	EcoEffect, BEAT, EcoInvent	50	x	x	x													New	Residential
SE4	EcoEffect, BEAT, EcoInvent	50	x	x	x													New	Residential
SE4	EcoEffect, BEAT, EcoInvent	50	x	x	x													New	Residential
SE5	EcoEffect, BEAT, EcoInvent	50	x	x	x													New	Office
SE6	EPD, Ökobau 2013, EcoInvent, KBOB	1									x							Refurbishment	Office
SE7	IVL Miljödata, EPDs, EcoInvent, KBOB, ICE	50	x	x	x	x	x			x		x	x	x	x	x		New	Residential
United Kingdom																			
UK1	-	-																-	Policy
UK2	BATH ICE, ECEB	N/A	x	x	x	x	x							x				Refurbishment	Residential
UK3	(Not specified)	N/A					x											New	Residential
UK4	BATH ICE, ECEB	68	x	x	x	x	x			x	x	x	x	x	x	x		New	School
UK5	ICE, EcoInvent, USLCI	20	x	x	x	x	x											New	Residential
UK6	-	-																-	Policy

Case study	Database	RSP	Product stage			Construction process stage		Use stage					End-of-Life				Next product system	Main concept	Type
			Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential		
UK7	Bath ICE	60	x	x	x	x	x		x	x			x	x	x	x	x	New	Sports hall
UK8	-	-																-	Policy
UK9	EPD, ELCD, Industry data	-	x	x	x	x	x						x	x	x	x	x	New	Residential
UK10	-	-																-	Tools
UK11	-	-																-	Policy
UK12	BATH ICE, Green guide to specification, ECEB	60	x	x	x	x	x		x	x	x	x	x	x	x	x		Refurbishment	Residential

Appendix 1: Authors and contacts for case studies

Case study	Contact
AT1	**Beate Lubitz-Prohaska** Austrian Institute of Ecology **Alexander Passer, Gernot Fischer** Graz University of Technology- Institute of Technology and Testing of Building Materials
AT2	**Beate Lubitz-Prohaska** Austrian Institute of Ecology **Alexander Passer, Gernot Fischer** Graz University of Technology- Institute of Technology and Testing of Building Materials
AT3	**Beate Lubitz-Prohaska** Austrian Institute of Ecology **Alexander Passer, Gernot Fischer, Helmuth Kreiner** Graz University of Technology- Institute of Technology and Testing of Building Materials
AT4	**Alexander Passer, Gernot Fischer** Graz University of Technology- Institute of Technology and Testing of Building Materials **Beate Lubitz-Prohaska** Austrian Institute of Ecology **David Venus** AEE INTEC
AT5	**Alexander Passer , Gernot Fischer, Helmuth Kreiner** Graz University of Technology- Institute of Technology and Testing of Building Materials **Beate Lubitz-Prohaska** Austrian Institute of Ecology
AT6	**Alexander Passer, Helmuth Kreiner** Graz University of Technology- Institute of Technology and Testing of Building Materials
AT7	**Alexander Passer, Gernot Fischer** Graz University of Technology- Institute of Technology and Testing of Building Materials
CH1	**Rolf Frischknecht** Treeze Ltd
CH2	**Rolf Frischknecht** Treeze Ltd
CH3	**Rolf Frischknecht** Treeze Ltd

Case study	Contact
CH4	**Rolf Frischknecht** Treeze Ltd
CH5	**Rolf Frischknecht** Treeze Ltd
CH6	**Rolf Frischknecht** Treeze Ltd
CH7	**Rolf Frischknecht** Treeze Ltd
CH8	**Rolf Frischknecht** Treeze Ltd
CH9	**Rolf Frischknecht** Treeze Ltd
CH10	**Rolf Frischknecht** Treeze Ltd
CH11	**Rolf Frischknecht** Treeze Ltd
CH12	**Rolf Frischknecht** Treeze Ltd
CH13	**Rolf Frischknecht** Treeze Ltd
CH14	**Guillaume Habert** ETHZ
CH15	**Guillaume Habert** ETHZ
CZ1	**Marie Nehasilová** CTU in Prague
CZ2	**Ctislav Fiala** CTU in Prague
DE1	**Holger König** ASCONA
DE2	**Holger König** ASCONA

Case study	Contact
DE3	**Holger König** ASCONA
DE4	**Holger König** ASCONA
DK1	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK2	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK3	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK4	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK5	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK6	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK7	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK8	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK9	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK10	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK11	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK12	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK13	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute
DK14	**Harpa Birgisdottir and Freja Nygaard Rasmussen** Danish Building Research Institute

Case study	Contact
IT1	**Marina Mistretta** Università degli Studi Mediterranea Reggio Calabria
IT2	**Marina Mistretta** Università degli Studi Mediterranea Reggio Calabria
IT3	**Marina Mistretta** Università degli Studi Mediterranea Reggio Calabria
IT4	**Marina Mistretta** Università degli Studi Mediterranea Reggio Calabria
JP1	**Keizo Yokoyama** Kogakuin University
JP2	**Keizo Yokoyama** Kogakuin University
JP3	**Keizo Yokoyama** Kogakuin University
JP4	**Keizo Yokoyama** Kogakuin University
JP5	**Keizo Yokoyama** Kogakuin University
JP6	**Noriyoshi Yokoo** Utsunomiya University
JP7	**Keizo Yokoyama** Kogakuin University
JP7	**Keizo Yokoyama** Kogakuin University
KR1	**Sung-Hee Kim/ Suhyun Cho and Chang-U Chae** Hannyang University/ Korea Institute of Civil Engineering and Building Technology
KR2	**Sung-Hee Kim/ Suhyun Cho and Chang-U Chae** Hannyang University/ Korea Institute of Civil Engineering and Building Technology
KR3	**Sung-Hee Kim/ Suhyun Cho and Chang-U Chae** Hannyang University/ Korea Institute of Civil Engineering and Building Technology
KR4	**Sung-Hee Kim/ Suhyun Cho and Chang-U Chae** Hannyang University/ Korea Institute of Civil Engineering and Building Technology

Case study	Contact
N01	**Aoife Houlihan Wiberg** The Research Centre on Zero Emissions Buildings (ZEB), Norwegian University of Science & Technology (NTNU)
NO2	**Torhildur Fjola Kristjansdottir (Contact: Aoife Houlihan Wiberg)** The Research Centre on Zero Emissions Buildings (ZEB), Norwegian University of Science & Technology (NTNU)
NO4	**Marianne Rose Inman and Aoife Houlihan Wiberg** The Research Centre on Zero Emissions Buildings (ZEB), Norwegian University of Science & Technology (NTNU)
NO8	**Torhildur Fjola Kristjansdottir (Contact: Aoife Houlihan Wiberg) ,** The Research Centre on Zero Emissions Buildings (ZEB), Norwegian University of Science & Technology (NTNU)
NO9	**Torhildur Fjola Kristjansdottir (Contact: Aoife Houlihan Wiberg) ,** The Research Centre on Zero Emissions Buildings (ZEB), Norwegian University of Science & Technology (NTNU)
SE1	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE2a	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE2b	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE3	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE4	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE4	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE5	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE6	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
SE7	**Tove Malmqvist** KTH Royal Institute of Technology, Stockholm
UK1	**Eleni Soulti** University of Cambridge
UK2	**Eleni Soulti** University of Cambridge

Case study	Contact
UK3	**Eleni Soulti** University of Cambridge
UK4	**Eleni Soulti** University of Cambridge
UK5	**Eleni Soulti** University of Cambridge
UK6	**Eleni Soulti** University of Cambridge
UK7	**Eleni Soulti** University of Cambridge
UK8	**Eleni Soulti** University of Cambridge
UK9	**Eleni Soulti** University of Cambridge
UK10	**Eleni Soulti** University of Cambridge
UK11	**Eleni Soulti** University of Cambridge
UK12	**Eleni Soulti** University of Cambridge

Appendix 2: All case study templates

Austria

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Reduction of the EE and EG vs. OE and OG
3.5 Reduction of EG by the use of wood

Case study AT1
Aspern IQ - Austria

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The quality criteria for the eco-efficiency of the complete building within the life cycle (or the materials used in the building) are calculated by using the OI3 indicator (here: $OI3_{BG3,BZF}$). Within a life cycle analysis of 100 years it includes all superstructures available in a given building as well as all materials used.

The study showed that the aspern IQ building materials contributed with **34%** of (PE) Primary Energy**.**

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_3	53,23	[kWh/m^2_{GFA}*year]
EE_2	22,6	[kWh/m^2_{GFA}*year]
OG_1	7,76	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	4,77	[kg CO_2-eq/m^2_{GFA}*year]

The study evaluates:

- The significance of the Embodied Energy (EE) compared to the Operational Energy (OE)
- The impacts related to different building materials
- The percentile contribution of each material
- The materials contribution to the impacts compared to the total impacts

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) , Global Warming Potential (GWP) and acidification (AP), related to the life cycle of a new office building in Austria.

BUILDING KEY FACTS

Intended use: Office building

Size: 12.682 m² GFA

Location: Vienna, Austria

Architect: ATP architects and engineers, Vienna

Building year: Completed 2012

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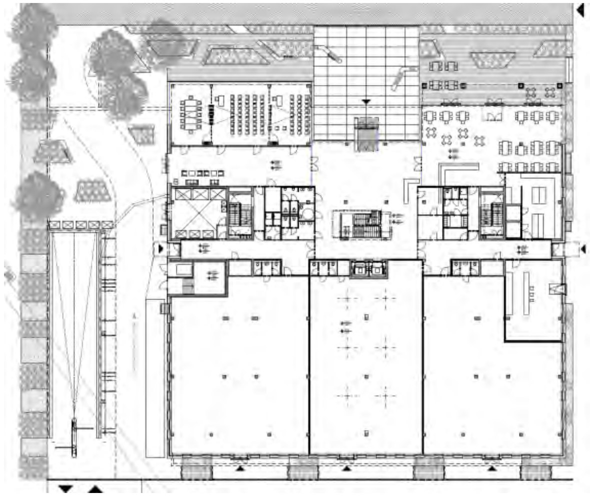
THE BUILDING

With 240 hectares and a projected population of 20,000 residents and workers, the Seestadt Aspern is not only Vienna's largest current urban development project but also one of the largest in Europe. At the end of August 2012, phase one of the "aspern IQ" Technology Centre was completed by the Vienna Business Agency on the development area's first building plot. The first finished building of the Seestadt Aspern was designed by ATP Architects and Engineers to Plus Energy standards and should act as a flagship project, showing how a Plus Energy building which is adapted to local resources can offer the highest possible levels of user comfort while fulfilling all sustainability requirements.

The building offers companies and others involved in the development of sustainable technology multifunctional spaces at ground level and office areas on the upper floors.
The rental units are heated and cooled by concrete core activation alone. Here, hot or cold water is fed, as required, into plastic piping laid in the reinforced concrete slabs. Zone valves permit different areas of the same rental unit to be differently treated in such a way that, theoretically, one zone can be heated while the other is being cooled.

A highly efficient central ventilation plant ensures a constant mechanical air input and output and the required level of air humidity. Air in the rental units is supplied via swelling air diffusers and centrally extracted. A CO_2 sensor which measures air quality and hence the number of people present determines the rate of air changes and facilitates needs-related control.
In addition to the energy-efficiency and the intelligent regulation and control of the technical plant, the energy requirements of aspern IQ are further reduced by the recovery of heat and energy and the remaining energy needs are met by the use of renewable energy sources.



Source: ATP architects and engineers

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OI3 Calculation as leading indicator for the eco efficiency of the building

The quality criteria for the eco-efficiency of the complete building within the life cycle (or the materials used in the building) are calculated by using the OI3 indicator (here: $OI3_{BG3,BZF}$). Within a life cycle analysis of 100 years it includes all superstructures available in a given building as well as all materials used.

Out of the wealth of environmental categories or properties, the OI3 index uses the following three:

- Greenhouse potential (for 100 years, as of 1994)
- Acidification potential
- Consumption of non-renewable energetic resources

The ecological production effort for a building with the current building standard is about the same as the ecological effort for heating a passive house for 100 years. Therefore the ecological optimisation of the production effort forms an essential part of ecological building activities. Ecological optimisation in this context refers to minimising the flow of material, the energy input and the amount of emissions during the production of the building and the building material used. Nowadays not only the date of construction is taken into account but also the maintenance cycles during the entire life of a building which are necessary depending on the useful life of the construction used are considered.

Previously, the OI3 index of a building was mainly calculated for the thermal building envelope at the time of construction ($OI3_{TGH,BGF}$). In the context of the life cycle evaluations this boundary was expanded deliberately:

BG0 (former thermal building envelope boundary): Construction of thermal building envelope + subceilings – roofing – moisture proofing – rear-ventilated parts of the front

BG1: thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety)

BG2: BG1 + interior walls relevant from a building physics point of view + buffer rooms without interior components

BG3: BG2 + interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)

The TQB evaluation uses system boundary BG3. For system boundary BG3 not only the first construction is taken into account but also the useful life and the necessary renovation and maintenance cycles of the component layers during the entire life cycle of a building are considered. According to ÖN EN 15804, the standardised evaluation period is assumed to be 100 years.

Source: ÖGNB

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X						

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

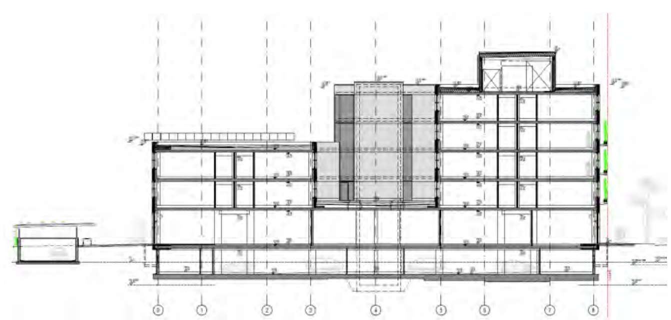
Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings were calculated according to EN 15978.

LCA BACKGROUND

Reference study period: 100 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: According to baubook eco2soft (LCA for buildings)

REFERENCES

Project: MonitorPLUS
Project Number: FFG Proj. Nr. 827 141
Project management: Austrian Institute of Ecology
Project partner: Austrian Institute for Healthy and Ecological Building
Funding Program: Federal Ministry for Transport, Innovation and Technology, Haus der Zukunft
Website: http://www.hausderzukunft.at/results.html/id6385
Assessor: Austrian Institute of Ecology



Source: ATP architects and engineers

DETAILED RESULTS OF THE OFFICE BUILDING aspern IQ : Product stage (A1 – A3)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Product stage (A1-A3)	**m² construction area**		**Total**		
global warming (GWP100)	77,04	kg CO_2 / m²	2327109	kg CO_2	
acidification	0,29	kg SO_4 / m²	8689	Kg SO_4	
PEI nicht erneuerbar	1134,40	MJ / m²	34266417	MJ	
GWP C-Speicher	-4,67	kg CO_2 / m²		kg CO_2	
CO2 Prozess	81,71	kg CO_2 / m²	2468081	kg CO_2	
PEI erneuerbar	88,47	MJ / m²	2672409	MJ	
photochemical oxidation	0,05	kg C_2H_2 / m²	1481	kg C_2H_2	
eutrophication	0,11	kg PO_4--- / m²	3205	kg PO_4---	
ozone layer depletion (ODI	5,79E-06	kg CFC-11 / m²	1,75E-01	kg CFC-11	
OI3 BG3,BZF			**265**		Points

Source: Austrian Institute for Healthy and Ecological Building– OI3 Index calculation

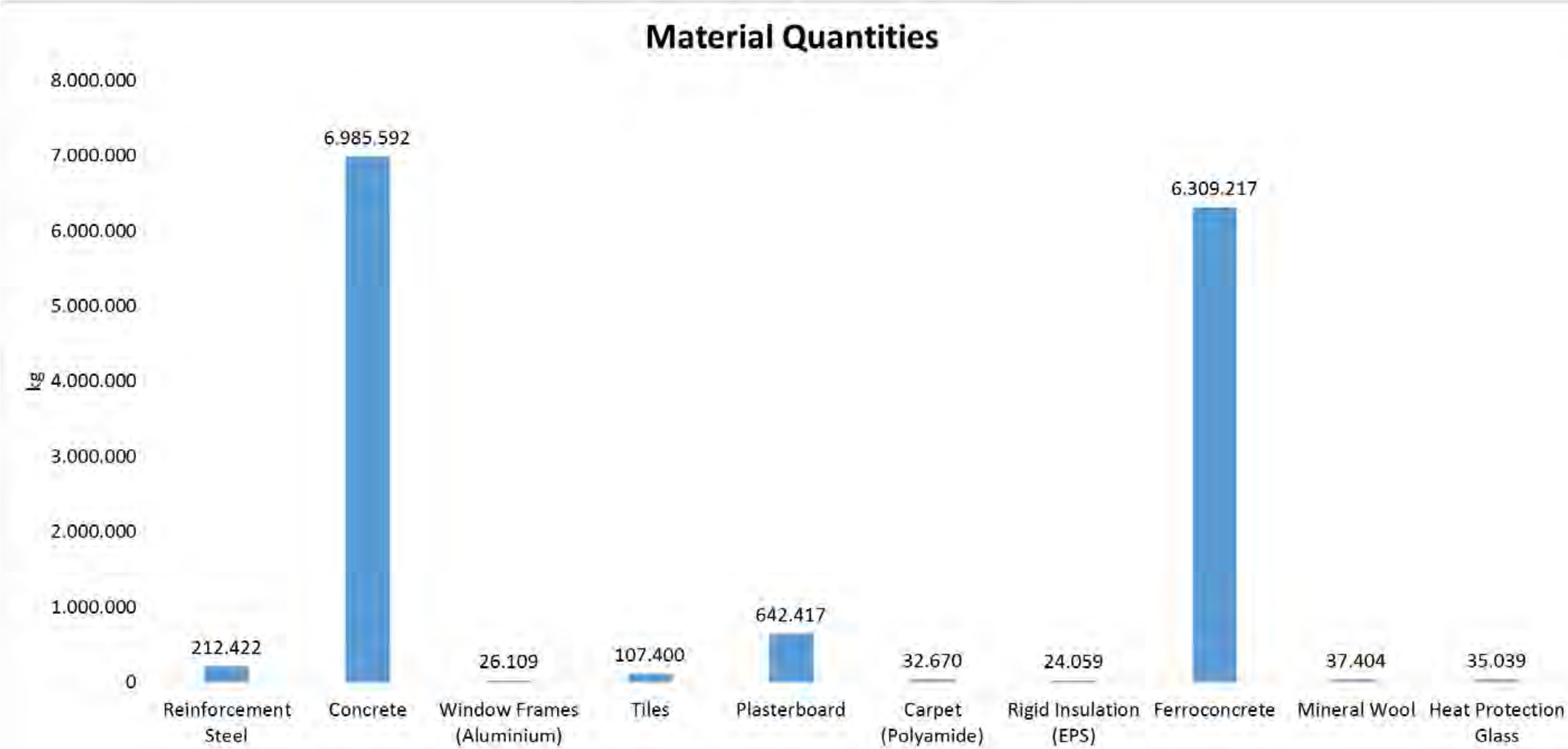
DETAILED RESULTS OF THE OFFICE BUILDING aspern IQ: Use stage (B4)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Operation stage (B4)	m² construction area		Total	
global warming (GWP100)	62,08	kg CO_2 / m²	1875268	kg CO_2
acidification	0,29	kg SO_4 / m²	8733	Kg SO_4
PEI nicht erneuerbar	1239,94	MJ / m²	37454304	MJ
GWP C-Speicher		kg CO_2 / m²		kg CO_2
CO2 Prozess	62,08	kg CO_2 / m²	1875268	kg CO_2
PEI erneuerbar	99,60	MJ / m²	3008561	MJ
photochemical oxidation	0,05	kg C_2H_2 / m²	1435	kg C_2H_2
eutrophication	0,09	kg PO_4--- / m²	2597	kg PO_4---
ozone layer depletion (ODP)	6,98E-06	kg CFC-11 / m²	2,11E-01	kg CFC-11
OI3 BG3,BZF			**533**	Points

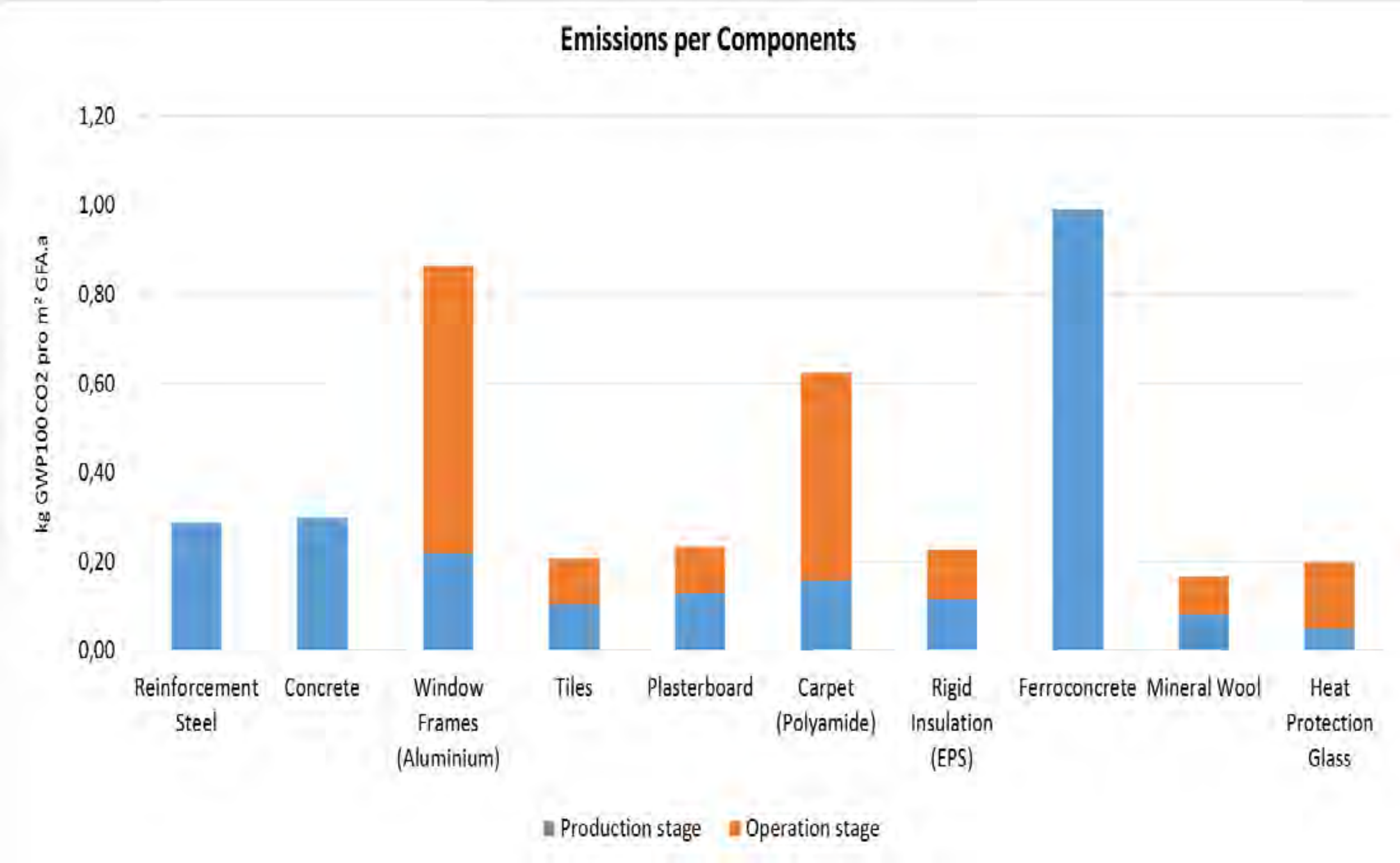
Source: Austrian Institute for Healthy and Ecological Building – OI3 Index calculation

Materials Use and Quantities
The total consumption of building materials is estimated to approximately 15.608.413 kg or 1.770 kg/m² GFA.



The illustration shows an assortment of the components.

RESULTS OF STUDY PERIOD = 100 YEARS



Components	Lifetime in years
Reinforcement Steel	100
Concrete	100
Window Frames (Aluminium)	25
Tiles	50
Plasterboard	50
Carpet (Polyamide)	25
Rigid Insulation (EPS)	50
Ferroconcrete	100
Mineral Wool	50
Heat Protection Glass	25

The illustration shows an assortment of the Components.

RESULTS OF STUDY PERIOD = 100 YEARS

Total Primary Energy consumption:
75,83 kWh/m^2_{GFA}*year
- Production and Operation stage: 30%
- Operational energy: 70%

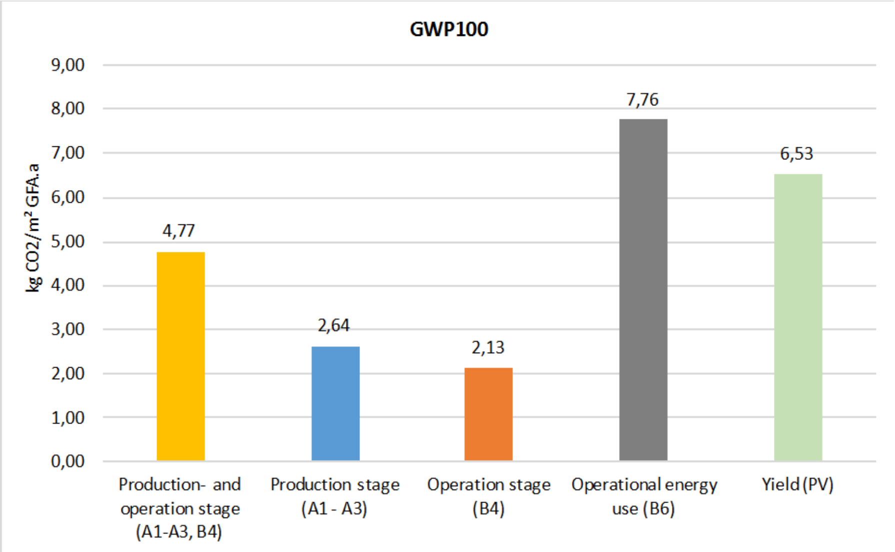
Total Primary Energy production:
- -51,82 kWh/m^2_{GFA}*year

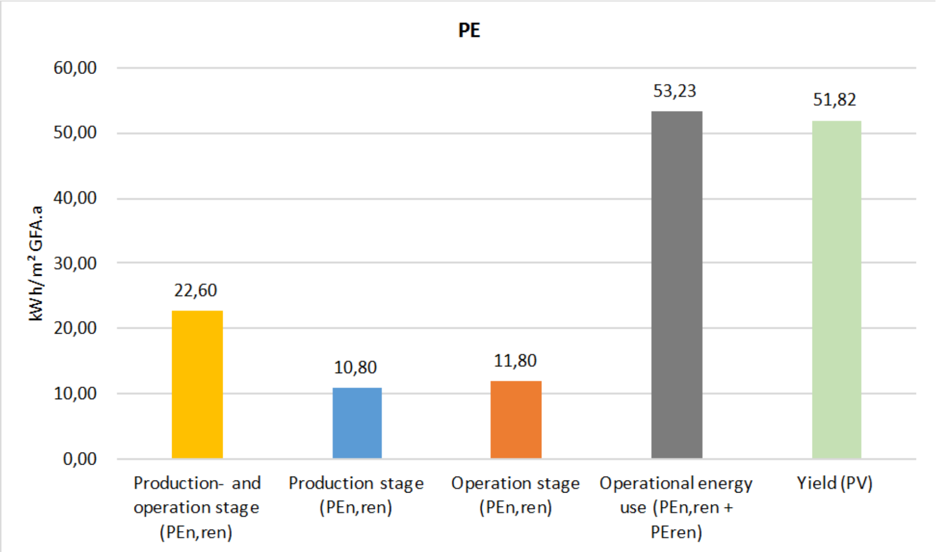
Embodied Energy:
22,6 kWh/m^2_{GFA}*year

Total Global Warming Potential :
12,53 kg CO_2 equiv. $/m^2_{GFA}$*year
- Production and Operation stage: 38 %
- operational energy: 62 %

Total Global Warming Potential production:
6,53 kg CO_2 equiv. $/m^2_{GFA}$*year

Embodied Global Warming Potential:
4,77 kg CO_2 equiv. $/m^2_{GFA}$*year





GWP: Global warming potential
PEn,ren: Primary Energy, non-renewable = EE_2
PEn, ren + PEren: Primary Energy, total = EE_3

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	aspern IQ – office building, new construction
Energy-standard	Plus - energy
Gross floor area/ Net floor area	12.682 m^2
Gross volume/ Net volume	50.254 m^3 / n/a
Reference area for EE/EG	8.816,84 m^2
Surface/Volume ratio (m-1)	n/a / 0,29 m-1
Construction method	Masonry construction
Thermal insulation	Optimized passive house envelope (http://www.passivhausprojekte.de/index.php?lang=en#d_4106)
Ventilation system	Highly efficient central ventilation
Heating and cooling system	Heating: The rental units are heated and cooled by concrete core activation alone. Here, hot or cold water is fed into plastic piping laid in the reinforced concrete slabs. Zone valves permit different areas of the same rental unit to be differently treated in such a way that, theoretically, one zone can be heated while the other is being cooled. Cooling: The rental units are cooled with the use of groundwater and - free cooling from a roof-mounted heat exchanger. In addition to this, the groundwater is also used for the pre-warming of the input air.
Final energy demand electricity	n/a
Final energy demand for heating and hot water	According to OIB-RL 6 (2007): Annual heating demand (HWB*): 2.06 kWh/m^3a // Annual heating demand (HWB): 8.07 kWh/m^2a According to Passive House Planning Tool (PHPP): Heating: 10.25 kWh/m^2a // Sanitary hot water: 2.09 kWh/m^2a
Final energy demand for cooling	According to OIB-RL 6 (2007): Annual cooling demand (KB*): 0.70 kWh/m^3a According to Passive House Planning Tool (PHPP) Cooling: 4.37 kWh/m^2a
Benchmark	-
Purpose of assessment	To determine GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	Calculation of the $OI3_{BG3,BZF}$ indicators using EcoSoft by IBO (Austrian Institute for Healthy and Ecological Building) see for more information: http://www.ibo.at/de/ecosoft.htm
Reference Study Period	100 years
Included life cycle stages	From cradle to grave Construction stage // Use stage // End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety) interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)
Scenarios and assumptions used	According to EcoSoft by IBO (LCA for buildings)
Accounting of electricity mix	According to EcoSoft by IBO (LCA for buildings)
Databases used	According to EcoSoft by IBO (LCA for buildings)
LCA Software used	According to EcoSoft by IBO (LCA for buildings)
Method of materials quantification	According to EcoSoft by IBO (LCA for buildings)
Values and sources of primary energy and emission factors	According to EcoSoft by IBO (LCA for buildings)
Character of the indicator used	According to EcoSoft by IBO (LCA for buildings)
Indicators assessed	GWP 100a (EcoSoft by IBO) Acidification (EcoSoft by IBO) CED non renewable (EcoSoft by IBO)

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

TU Graz in cooperation with Austrian Institute of Ecology:

Data based on IBO:

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Reduction of the EE and EG vs. OE and OG
3.5 Reduction of EG by the use of wood

Case study AT2
LCT ONE - Austria

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated by using the OI3 indicator (here: OI3BG3,BZF) 100 years respectively. The study showed that the LCT One building materials contributed with 20**%** of Primary Energy (PE) with RFS of **100 years.**

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas(OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_3	95,93	[kWh/m^2_{GFA}*year]
EE_2	21,03	[kWh/m^2_{GFA}*year]
OG_1	30,27	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	3,29	[kg CO_2-eq/m^2_{GFA}*year]

The study evaluates:

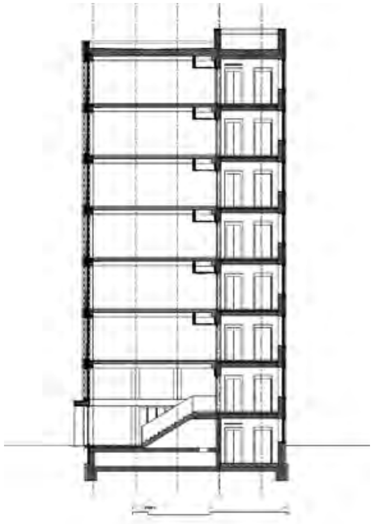
- The significance of the Embodied Energy (EE) compared to the Operational Energy (OE)
- The impacts related to different building materials
- The percentile contribution of each material
- The materials contribution to the impacts compared to the total impacts

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) , Global Warming Potential (GWP) and acidification (AP), related to the life cycle of a new office building in Austria.

BUILDING KEY FACTS

Intended use: Office building
Size: 2.355 m² GFA
Location: Vienna, Austria
Architect: Hermann Kaufmann ZT GmbH, Schwarzach
Building year: Completed 2012



Source: Hermann Kaufmann ZT GmbH

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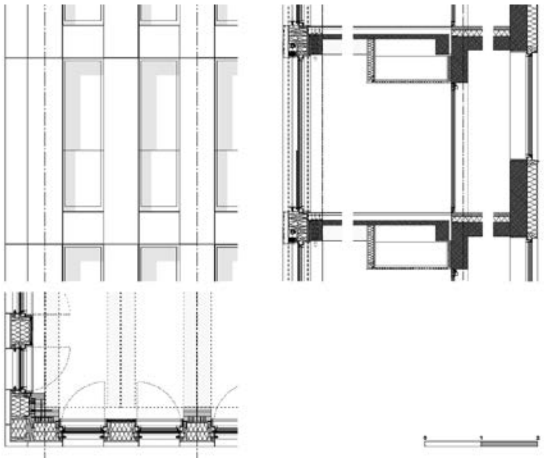
THE BUILDING

At the initiative of the Vorarlberg-based Rhomberg Group, a team of leading experts from all disciplines of sustainable construction (architecture, timber construction, building physics, structural engineering etc.) has developed a market-ready hybrid construction system for high-rise buildings of up to 30 storeys. The prototype demonstrates the versatility of this modular construction system.
Cree GmbH, the Rhomberg Group subsidiary specifically established to create the LifeCycle Tower, demonstrates the feasibility of the system for sustainable urban design projects and presents the advantages of this building concept (resource and energy efficiency, 90% improvement in CO_2 emissions, 50% reduction in construction time, industrial production of components, etc.) to the public at large.

The building approval, which allows Cree to construct an eight-storey timber hybrid building, represents a milestone and is the result of intensive preparations. Because in contrast to conventional timber buildings, the loadbearing elements of the LCT ONE are not lined. This represents a new departure, which has been possible as a result of close cooperation with the fire safety authorities and extensive fire testing. The unencapsulated, i.e. open and unlined, timber structure provides a direct experience of wood as a construction material in the interior, it preserves resources and is also an important part of the fire safety concept. For example, the voids between beams are used to accommodate services installations and sprinkler systems. In the event of a fire, the open timber deck design resists the spread of the fire because the timber beams are not directly connected to each other.



Source: Hermann Kaufmann ZT GmbH

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THE CONSTRUCTION

As the name suggests, the LifeCycle Tower aims to optimise the life cycle value of this building – from its construction through to its service life and ultimately its demolition/disposal. The modular system and industrial production already reduce life cycle costs at the construction stage, as it is possible to considerably reduce design and construction costs. As the construction time is significantly shorter, the building is available at an earlier date, which increases the return on investment. A sophisticated and highly energy-efficient services concept – available options include Plus-energy, low energy or PassivHaus standards – ensures that energy consumption is as low as possible and can be covered by different renewable energy sources, depending on the location, and keeps running costs down. Not only that, but the LifeCycle Tower will still be profitable for the grandchildren of the owner, because it is fully recyclable.

The prototype demonstrates how universally applicable the system is. LCT ONE is primarily used as an office building. In addition, it accommodates an exhibition space for sustainable ideas, products and concepts.

Since the system does not require loadbearing partition walls, it is very flexible in terms of size of rooms and layouts. It will be easy to change the layout to accommodate changing uses in all areas of the building. The LCT ONE was not conceived as an individual project but as a modular system for a variety of projects, all of which are based on the same fully designed and tested system. Owing to its modularity, the structural elements can be arranged and rearranged to suit changing needs.

OI3 Calculation as leading indicator for the eco efficiency of the building

The quality criteria for the eco-efficiency of the complete building within the life cycle (or the materials used in the building) are calculated by using the OI3 indicator (here: $OI3_{BG3,BZF}$). Within a life cycle analysis of 100 years it includes all superstructures available in a given building as well as all materials used.

Out of the wealth of environmental categories or properties, the OI3 index uses the following three:

- Greenhouse potential (for 100 years, as of 1994)
- Acidification potential
- Consumption of non-renewable energetic resources

The ecological production effort for a building with the current building standard is about the same as the ecological effort for heating a passive house for 100 years. Therefore the ecological optimisation of the production effort forms an essential part of ecological building activities. Ecological optimisation in this context refers to minimising the flow of material, the energy input and the amount of emissions during the production of the building and the building material used. Nowadays not only the date of construction is taken into account but also the maintenance cycles during the entire life of a building which are necessary depending on the useful life of the construction used are considered.

Previously, the OI3 index of a building was mainly calculated for the thermal building envelope at the time of construction ($OI3_{TGH,BGF}$). In the context of the life cycle evaluations this boundary was expanded deliberately:

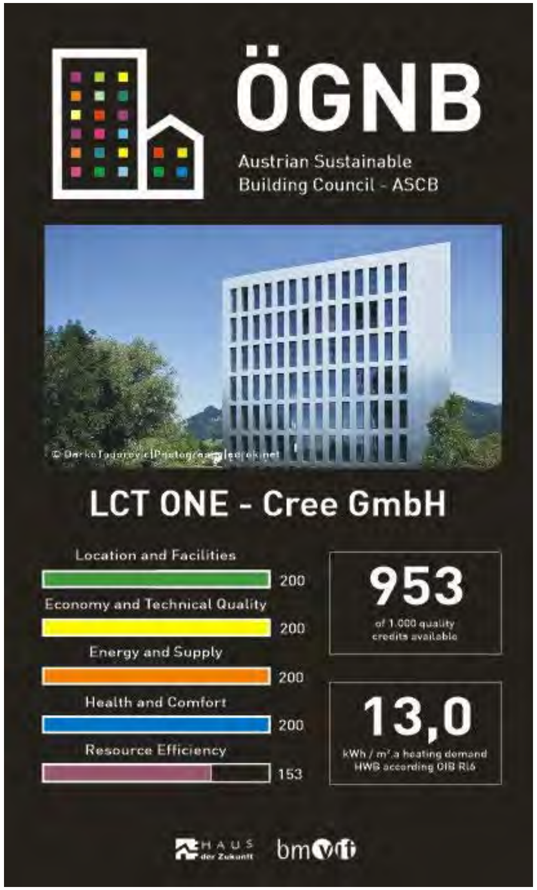
BG0 (former thermal building envelope boundary): Construction of thermal building envelope + subceilings – roofing – moisture proofing – rear-ventilated parts of the front

BG1: thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety)

BG2: BG1 + interior walls relevant from a building physics point of view + buffer rooms without interior components

BG3: BG2 + interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)

The TQB evaluation uses system boundary BG3. For system boundary BG3 not only the first construction is taken into account but also the useful life and the necessary renovation and maintenance cycles of the component layers during the entire life cycle of a building are considered. According to ÖN EN 15804, the standardised evaluation period is assumed to be 100 years.



Source: ÖGNB

Building life cycle stages included in the study, according to EN15978

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						X		X						

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according EN 15978.

LCA BACKGROUND

Reference study period: 100 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: according to baubook eco2soft (LCA for buildings)

REFERENCES

Project: monitorPLUS

Project Number: FFG Proj. Nr. 827 141

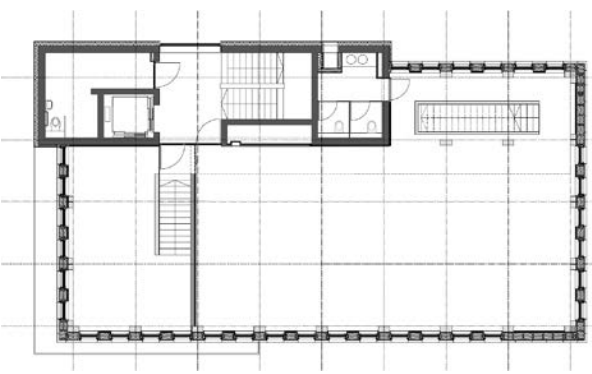
Project management: Austrian Institute of Ecology

Project partners: Austrian Institute for Healthy and Ecological Building

Funding Program: Federal Ministry for Transport, Innovation and Technology, Haus der Zukunft

Website: http://www.hausderzukunft.at/results.html/id6385

Assessor: Austrian Institute of Ecology



Source: Hermann Kaufmann ZT GmbH

DETAILED RESULTS OF THE OFFICE BUILDING LCT ONE: Product stage (A1 – A3)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Production stage (A1-A3)	m² construction area		Total	
global warming (GWP100)	16,76	kg CO_2 / m²	233472	kg CO_2
acidification	0,16	kg SO_4 / m²	2220	Kg SO_4
PEI nicht erneuerbar	561,98	MJ / m²	7826647	MJ
GWP C-Speicher	-25,99	kg CO_2 / m²		kg CO_2
CO2 Prozess	42,75	kg CO_2 / m²	595424	kg CO_2
PEI erneuerbar	407,96	MJ / m²	5681651	MJ
photochemical oxidation	0,03	kg C_2H_2 / m²	416	kg C_2H_2
eutrophication	0,06	kg PO_4--- / m²	877	kg PO_4---
ozone layer depletion (ODP)	2,36E-06	kg CFC-11 / m²	3,28E-02	kg CFC-11
OI3 BG3,BZF			**271**	Points

Source: CREE, Rhomberg GmbH – OI3 Index calculation

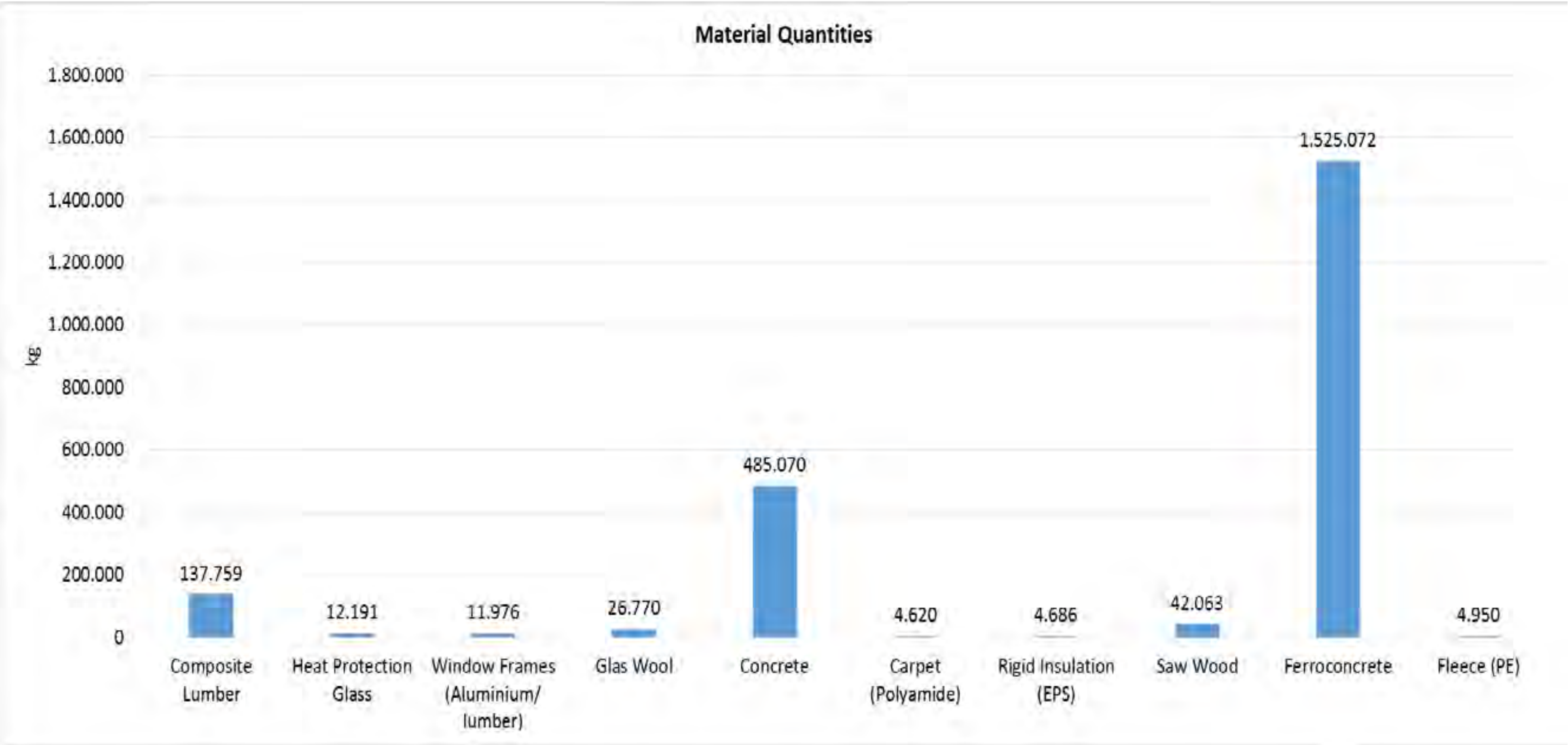
DETAILED RESULTS OF THE OFFICE BUILDING LCT ONE: Use stage (B4)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Operation stage (B4)	m² construction area	Total	
global warming (GWP100)	32,29 kg CO_2 / m²	449686 kg CO_2	
acidification	0,16 kg SO_4 / m²	2293 Kg SO_4	
PEI nicht erneuerbar	566,06 MJ / m²	7883526 MJ	
GWP C-Speicher	kg CO_2 / m²	kg CO_2	
CO2 Prozess	32,29 kg CO_2 / m²	449686 kg CO_2	
PEI erneuerbar	442,12 MJ / m²	6157411 MJ	
photochemical oxidation	0,03 kg C_2H_2 / m²	408 kg C_2H_2	
eutrophication	0,06 kg PO_4--- / m²	790 kg PO_4---	
ozone layer depletion (ODP)	2,46E-06 kg CFC-11 / m²	3,42E-02 kg CFC-11	
OI3 BG3,BZF		**563**	Points

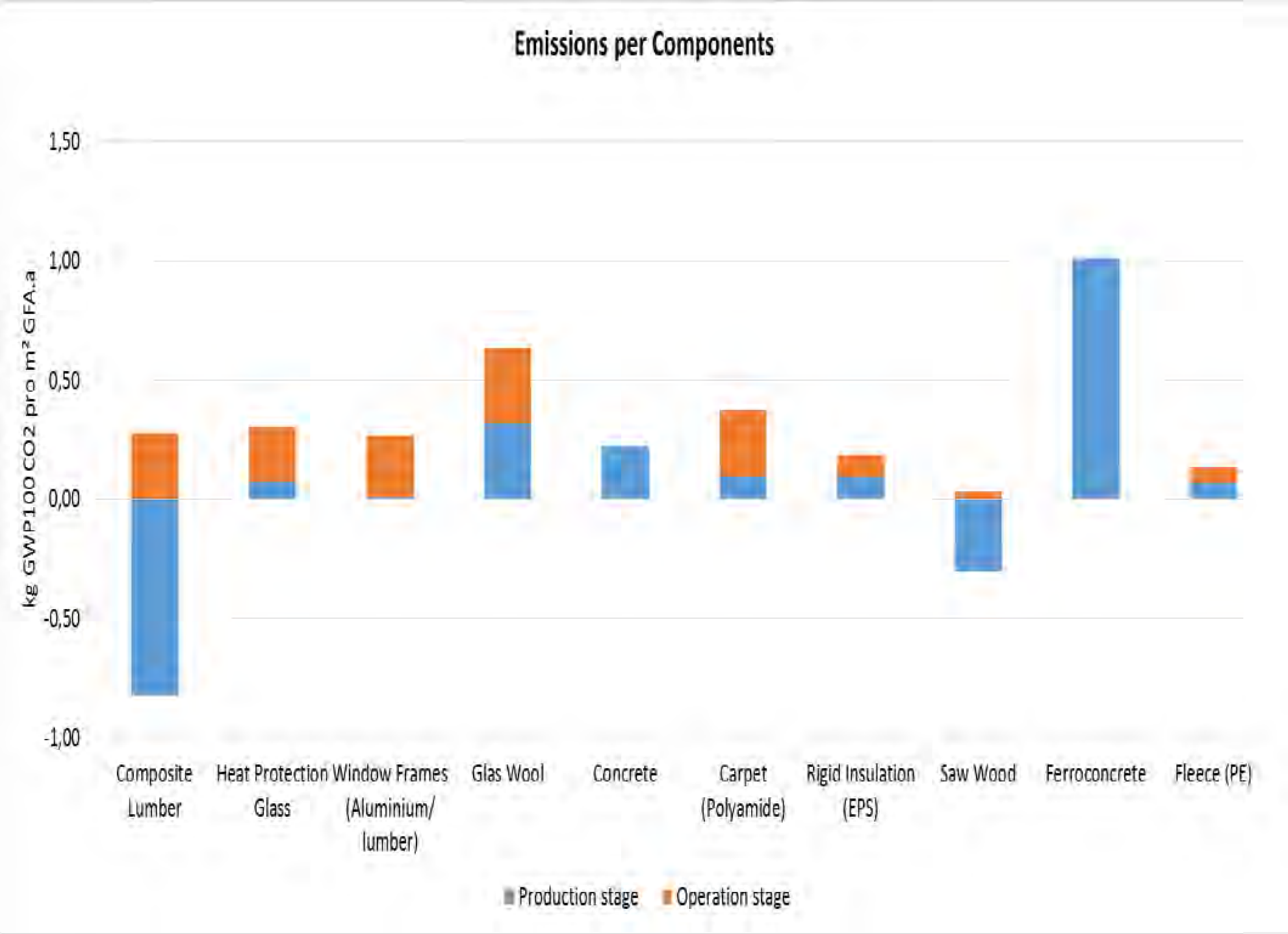
Source: CREE, Rhomberg GmbH – OI3 Index calculation

Materials Use and Quantities
The total consumption of building materials is estimated to approximately 2801402 kg or 1.350 kg/m² GFA.



The illustration shows an assortment of the components.

RESULTS OF STUDY PERIOD = 100 YEARS



Components	Lifetime in years
Composite Lumber	50
Heat Protection Glass	33
Window Frames (Aluminium/ lumber)	33
Glas Wool	50
Concrete	100
Carpet (Polyamide)	25
Rigid Insulation (EPS)	50
Saw Wood	50
Ferroconcrete	100
Fleec (PE)	50

The illustration shows an assortment of the Components.

RESULTS OF STUDY PERIOD = 100 YEARS

Total Primary Energy consumption:

116,96 kWh/m^2_{GFA}*year

- Production and Operation stage: 18%
- Operational energy: 82%

Embodied Energy:

21,03 kWh/m^2_{GFA}*year

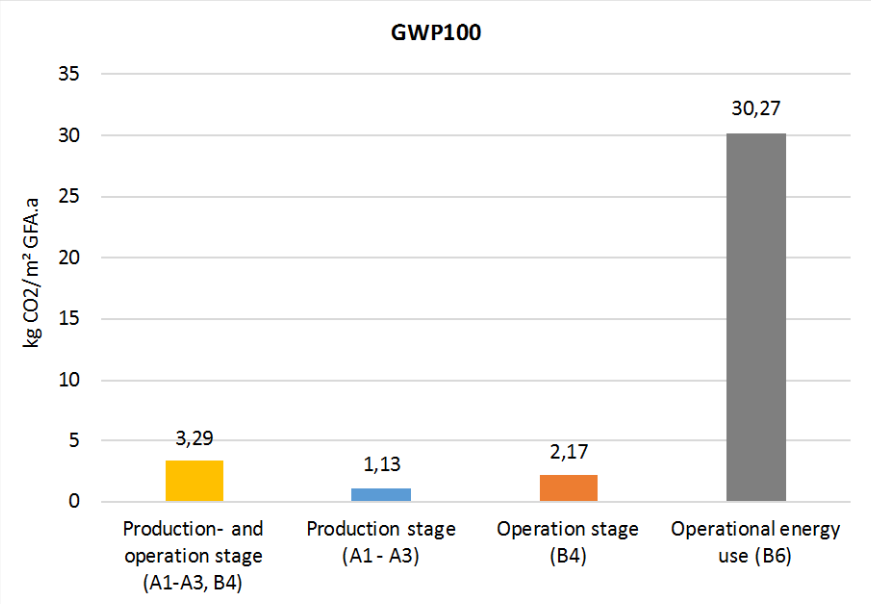
Total Global Warming Potential :

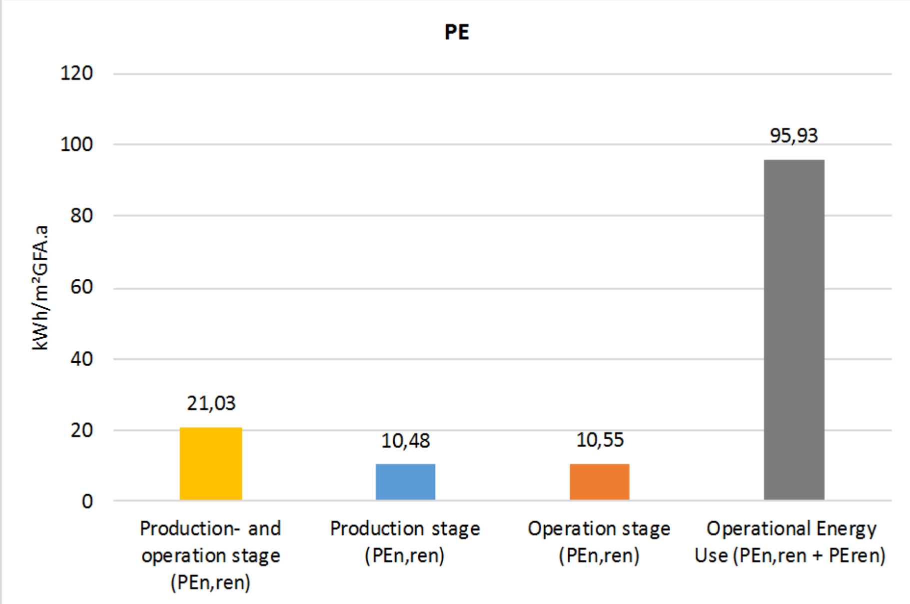
33,56 kg CO_2 equiv. /m^2_{GFA}*year

- Production and Operation stage: 11 %
- operational energy: 89 %

Embodied Global Warming Potential:

3,29 kg CO_2 equiv. /m^2_{GFA}*year





GWP: Global warming potential

PEn,ren: Primary Energy, non-renewable = EE_2

PEn, ren + PEren: Primary Energy, total = EE_3

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	LCT ONE – office buildung, new construction
Energy-standard	Certified Passive house
Gross floor area/ Net floor area	2.355 m^2
Gross volume/ Net volume	7.996 m^3 / n/a
Reference area for EE/EG	2.355,19 m2
Surface/Volume ratio (m-1)	n/a / 0,32 m-1
Construction method	Timber hybrid construction
Thermal insulation	Optimized passive house envelope - Certified Passive house by Dr. Wolfgang Feist (http://www.passivhausprojekte.de/index.php?lang=en#d_3855)
Ventilation system	Highly efficient central ventilation
Heating and cooling system	Heating and cooling panels on the ceeling
Final energy demand electricity	n/a
Final energy demand for heating and hot water	According to OIB-RL 6 (2007): Annual heating demand (HWB*): 3.92 kWh/m^3a // Annual heating demand (HWB): 13.00 kWh/m^2a
Final energy demand for cooling	According to OIB-RL 6 (2007): Annual cooling demand (KB*): 0,8 kWh/m^3a According to Passive House Planning Tool (PHPP) Cooling: 2 kWh/m^2a
Benchmark	-
Purpose of assessment	To determine GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	Calculation of the $OI3_{BG3,BZF}$ indicators using EcoSoft by IBO (Austrian Institute for Healthy and Ecological Building) See for more information: http://www.ibo.at/de/ecosoft.htm
Reference Study Period	100 years
Included life cycle stages	From cradle to grave Construction stage // Use stage // End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety) interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)
Scenarios and assumptions used	According to EcoSoft by IBO (LCA for buildings)
Accounting of electricity mix	According to EcoSoft by IBO (LCA for buildings)
Databases used	According to EcoSoft by IBO (LCA for buildings)
LCA Software used	According to EcoSoft by IBO (LCA for buildings)
Method of materials quantification	According to EcoSoft by IBO (LCA for buildings)
Values and sources of primary energy and emission factors	According to EcoSoft by IBO (LCA for buildings)
Character of the indicator used	According to EcoSoft by IBO (LCA for buildings)
Indicators assessed	GWP 100a (EcoSoft by IBO) Acidification (EcoSoft by IBO) CED non renewable (EcoSoft by IBO)

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

TU Graz in cooperation with Austrian Institute of Ecology:

Data based on:

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Reduction of the EE and EG vs. OE and OG
3.4 Use of new technologies to reduce the EG/EE

Case study AT3
TU Vienna - Austria

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated by using the OI3 indicator (here: OI3BG3,BZF) 100 years respectively. The study showed that the TU Vienna building materials contributed with 10% of Primary Energy (PE) with RFS of **100 years.**

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_3	78,6	[kWh/m^2_{GFA}*year]
EE_2	8,97	[kWh/m^2_{GFA}*year]
OG_1	15,10	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	2,97	[kg CO_2-eq/m^2_{GFA}*year]

The study evaluates:

- The significance of the Embodied Energy (EE) compared to the Operational Energy (OE)
- The impacts related to different building materials
- The percentile contribution of each material
- The materials contribution to the impacts compared to the total impacts

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) , Global Warming Potential (GWP) and acidification (AP), related to the life cycle of a new office building in Austria.

BUILDING KEY FACTS

Intended use: Office building
Size: 10.556 m² GFA
Location: Vienna, Austria
Architect: ARGE architects Kratowil-Waldbauer-Zeinitzer
Building year: Completed 2014

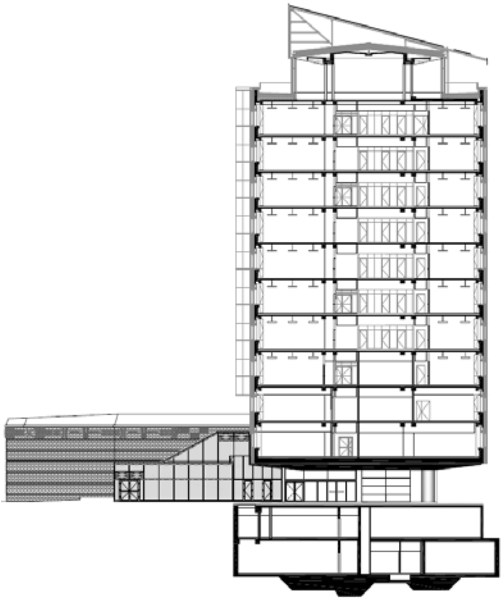
© Renate Schrattenecker-Fischer

THE BUILDING

Austria's largest plus-energy-office building situated on Getreidemarkt is now in completion and the relocation of the staff is going to take place in August 2014. The building offers 700 working spaces. The entire building has a net floor area of 13.500 m² and 11 storages.

Goal of the project was to accomplish the plus-energy-standard on a primary energy level on the site of the building including office computers and servers. The coverage of the primary energy demand is accomplished with the photovoltaic system, the usage of thermal discharge from the servers and the energy recovery from the elevators.

The central point for reaching the plus-energy-standard of the office building was the extreme reduction of the energy demand for all sections and components in the building, from heating to cooling and also for the office computers and smaller electric components. 9.300 components out of 280 categories in the project were registered, optimized and approved by the science team.



Source: ARGE architects Kratowil-Waldbauer-Zeinitzer

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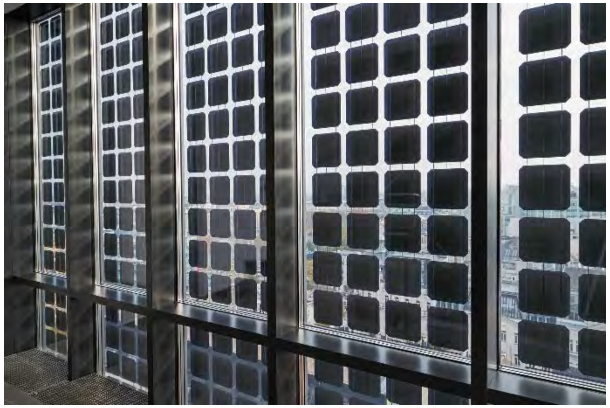
PLUS-ENERGY-STANDARD

To accomplish the plus-energy-standard for the office building the following points were realised in the project.

- optimized passive house envelope
- core ventilation for automatized night ventilation and lower cooling demand
- highly energy efficient building services
    - double rotary heat exchangers for more efficient recovery of moisture and to prevent humidification and dehumidification
    - high insulated distribution pipes (heating 6/3, cooling 3/3)
    - thermal activation of building structures (activated screed for heating and cooling)
    - cooling machine with SEER > 9
    - ventilation system and air ducts with minimal pressure drops, no heating and cooling coils
    - demand-actuated ventilation system
- LED-lighting with 110 lm/W
- 24 V grid for higher energy efficiency and centralization of power adapters
- energy efficient office computers, kitchen appliances and servers
    - stepwise exchange concept for existing computers of the institutes
    - transfer of the simulation computers from the working space to the server room for centralized and efficient cooling
- energy production: photovoltaic system on the roof and in the facade
    - total power: 328,4 kWp
    - roof: 97,8 kWp
    - facade: 230,6 kWp, largest building integrated photovoltaic system in Austria
- energy production: usage of thermal discharge from the servers and usage in the thermal activation system, coverage of the greater part of the building's heating energy demand
- energy production: elevator better then energy demand class A with energy recovery and weight reduction

Source: ARGE architects Kratowil-Waldbauer-Zeinitzer



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OI3 Calculation as leading indicator for the eco efficiency of the building

The quality criteria for the eco-efficiency of the complete building within the life cycle (or the materials used in the building) are calculated by using the OI3 indicator (here: $OI3_{BG3,BZF}$). Within a life cycle analysis of 100 years it includes all superstructures available in a given building as well as all materials used.

Out of the wealth of environmental categories or properties, the OI3 index uses the following three:

- Greenhouse potential (for 100 years, as of 1994)
- Acidification potential
- Consumption of non-renewable energetic resources

The ecological production effort for a building with the current building standard is about the same as the ecological effort for heating a passive house for 100 years. Therefore the ecological optimisation of the production effort forms an essential part of ecological building activities. Ecological optimisation in this context refers to minimising the flow of material, the energy input and the amount of emissions during the production of the building and the building material used. Nowadays not only the date of construction is taken into account but also the maintenance cycles during the entire life of a building which are necessary depending on the useful life of the construction used are considered.

Previously, the OI3 index of a building was mainly calculated for the thermal building envelope at the time of construction ($OI3_{TGH,BGF}$). In the context of the life cycle evaluations this boundary was expanded deliberately:

BG0 (former thermal building envelope boundary): Construction of thermal building envelope + subceilings – roofing – moisture proofing – rear-ventilated parts of the front

BG1: thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety)

BG2: BG1 + interior walls relevant from a building physics point of view + buffer rooms without interior components

BG3: BG2 + interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)

The TQB evaluation uses system boundary BG3. For system boundary BG3 not only the first construction is taken into account but also the useful life and the necessary renovation and maintenance cycles of the component layers during the entire life cycle of a building are considered. According to ÖN EN 15804, the standardised evaluation period is assumed to be 100 years.

Source: ÖGNB

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X	X	X						

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building skin. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according EN 15978. Their estimated service life was taken assuming the values by the ESL-Catalogue in Austria.

LCA BACKGROUND

Reference study period: 100 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: according to baubook eco2soft (LCA for buildings)

REFERENCES

Project: monitorPLUS

Project Number: FFG Proj. Nr. 827 141

Project management: Austrian Institute of Ecology

Project partners: Austrian Institute for Healthy and Ecological Building

Funding Program: Federal Ministry for Transport, Innovation and Technology, Haus der Zukunft

Website: http://www.hausderzukunft.at/results.html/id6385

Assessor: Austrian Institute of Ecology

DETAILED RESULTS OF THE OFFICE BUILDING TU Vienna: Product stage (A1 – A3)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Production stage (A1-A3)	m² construction area	Total	
global warming (GWP100)	112,97 kg CO_2 / m²	3492782 kg CO_2	
acidification	0,37 kg SO_4 / m²	11364 Kg SO_4	
PEI nicht erneuerbar	1080,67 MJ / m²	33412171 MJ	
GWP C-Speicher	-9,37 kg CO_2 / m²	kg CO_2	
CO2 Prozess	122,63 kg CO_2 / m²	3791343 kg CO_2	
PEI erneuerbar	195,44 MJ / m²	6042559 MJ	
photochemical oxidation	0,06 kg C_2H_2 / m²	1774 kg C_2H_2	
eutrophication	0,19 kg PO_4--- / m²	5982 kg PO_4---	
ozone layer depletion (ODP)	5,70E-06 kg CFC-11 / m²	1,76E-01 kg CFC-11	
		247	Points

Source: Austrian Institute of Ecology – OI3 Index calculation

DETAILED RESULTS OF THE OFFICE BUILDING TU Vienna : Use stage (B4, B5)

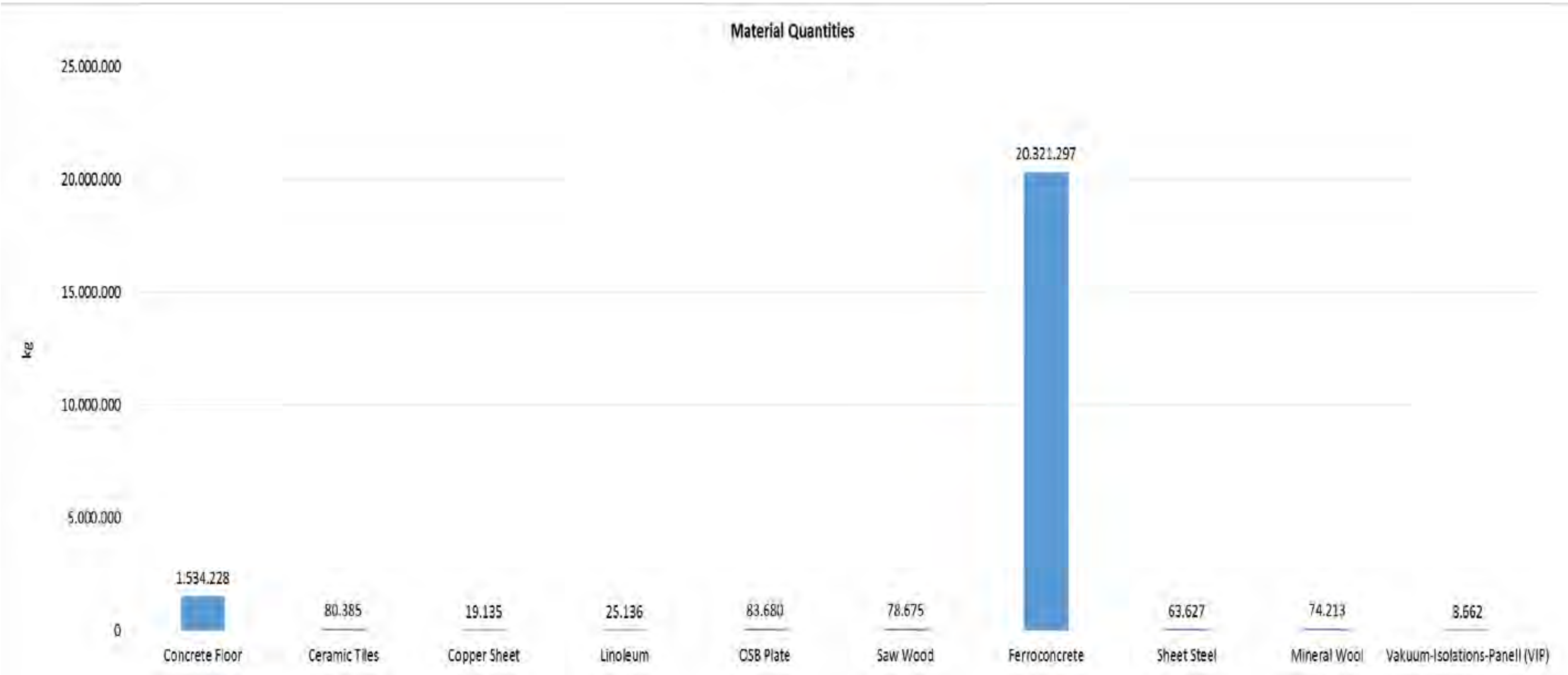
Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m² reference area.

Operation stage (B4)	m² construction area	Total	
global warming (GWP100)	30,99 kg CO_2 / m²	958168 kg CO_2	
acidification	0,19 kg SO_4 / m²	5757 Kg SO_4	
PEI nicht erneuerbar	485,90 MJ / m²	15022984 MJ	
GWP C-Speicher	kg CO_2 / m²	kg CO_2	
CO2 Prozess	30,99 kg CO_2 / m²	958168 kg CO_2	
PEI erneuerbar	127,53 MJ / m²	3943060 MJ	
photochemical oxidation	0,03 kg C_2H_2 / m²	958 kg C_2H_2	
eutrophication	0,12 kg PO_4--- / m²	3838 kg PO_4---	
ozone layer depletion (ODP)	2,69E-06 kg CFC-11 / m²	8,32E-02 kg CFC-11	
		357	Points

Refurbishment (B5)	m² construction area	Total	
global warming (GWP100)	66,30 kg CO_2 / m²	2.049.882 kg CO_2	
acidification	0,27 kg SO_4 / m²	0 Kg SO_4	
PEI nicht erneuerbar	758,28 MJ / m²	758 MJ	
OI3S BG3BZF		**282**	Points

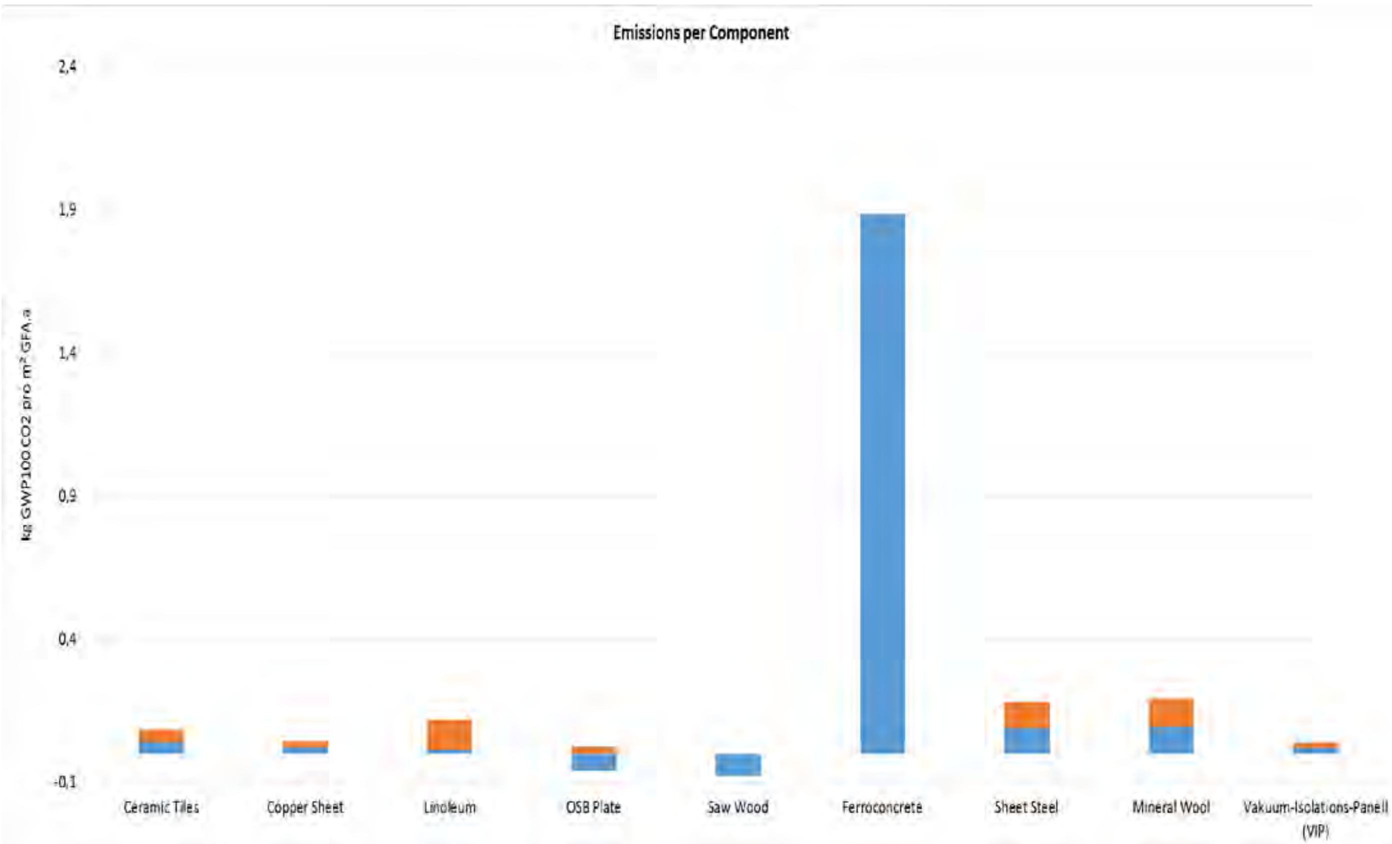
Source: Austrian Institute of Ecology – OI3 Index calculation

Materials Use and Quantities
The total consumption of building materials is estimated to approximately 22.984.139 kg or 1.532 kg/m² GFA.



The illustration shows an assortment of the components.

RESULTS OF STUDY PERIOD = 100 YEARS



Components	Lifetime in years
Concrete Floor	50
Ceramic Tiles	50
Cooper Sheet	50
Linoleum	25
OSB Plate	50
Saw Wood	50
Ferroconcrete	100
Sheet Steel	50
Mineral Wool	50
Vakuum- Isolations-Panell (VIP)	50

The illustration shows an assortment of the components.

RESULTS OF STUDY PERIOD = 100 YEARS

Total Primary Energy consumption:

87,57 kWh/m^2_{GFA}*year

- Production and Operation stage:10 %
- operational energy: 90 %

Embodied Energy:

8,97 kWh/m^2_{GFA}*year

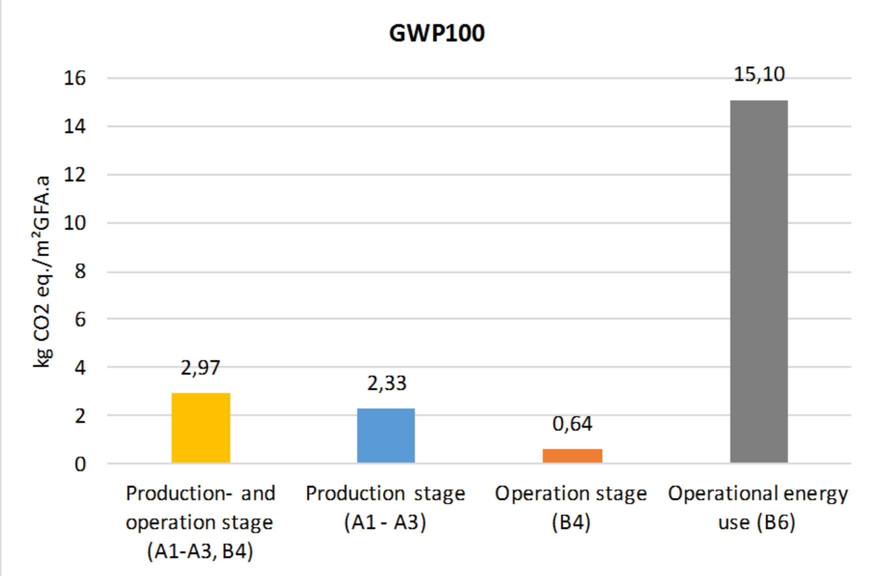
Total Global Warming Potential :

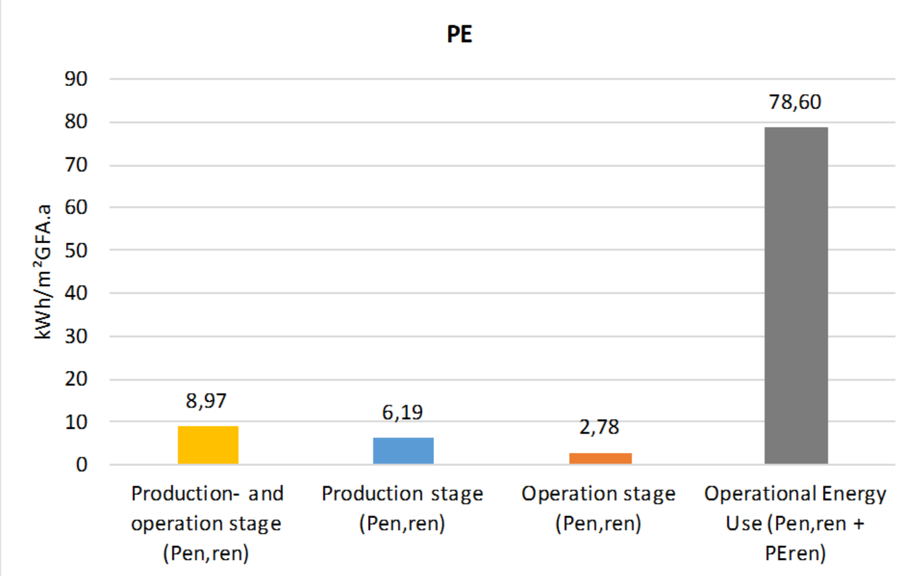
18,07 kg CO_2 equiv. /m^2_{GFA}*year

- Production and Operation stage: 16,4 %
- operational energy: 83,6 %

Embodied Global Warming Potential:

2,97 kg CO_2 equiv. /m^2_{GFA}*year





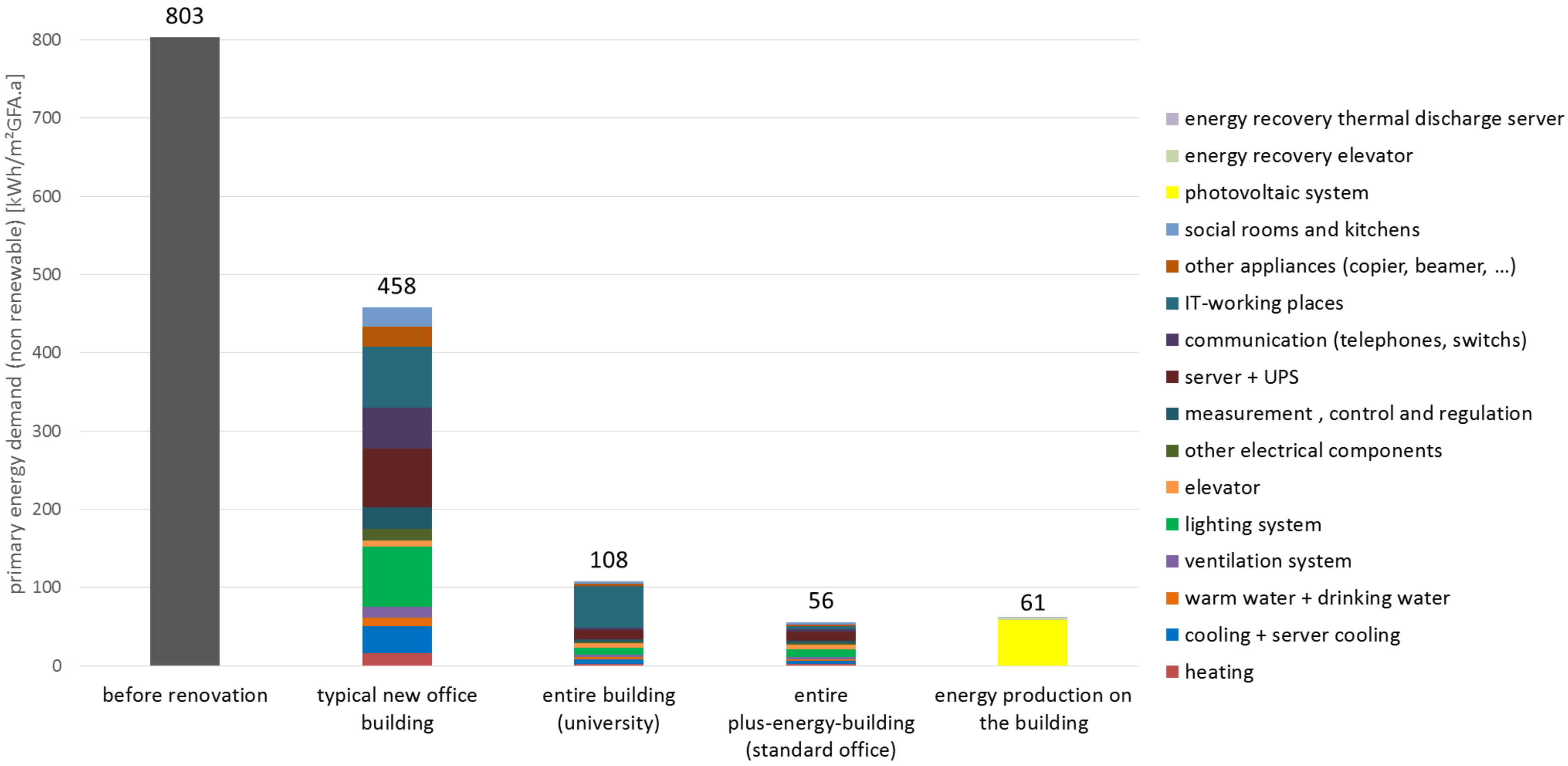
GWP: Global warming potential

PEn,ren: Primary Energy, non-renewable = EE_2

PEn, ren + PEren: Primary Energy, total = EE_3

Primary energy balance of the Plus-energy-office building situated on Getreidemarkt

The following graphic differentiates between university usage and standard office usage of the entire building. In the university usage in opposition to the standard office usage high-performance simulation computers are being used.



MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	Plus-energy-office building situated on Getreidemarkt – office buildung, renovation
Energy-standard	Plus-energy
Gross floor area/ Net floor area	10.526,25 m2
Gross volume/ Net volume	45.245 m³ / n/a
Reference area for EE/EG	8.421 m2
Surface/Volume ratio (m-1)	n/a / 0,19 m-1
Construction method	Masonry construction
Thermal insulation	Optimized passive house envelope (http://www.passivhausprojekte.de/index.php?lang=en#d_3995)
Ventilation system	Highly efficient central ventilation, ventilation system and air ducts with minimal pressure drops, no heating and cooling coils demand-actuated ventilation system
Heating and cooling system	Thermal activation of building structures (activated screed for heating and cooling) cooling machine with SEER > 9
Final energy demand electricity	n/a
Final energy demand for heating and hot water	According to OIB-RL 6 (2007): Annual heating demand (HWB*): 1.02 kWh/m³a // Annual heating demand (HWB): 0.52 kWh/m²a
Final energy demand for cooling	According to OIB-RL 6 (2007): Annual cooling demand (KB*): 0.00 kWh/m³a
Benchmark	-
Purpose of assessment	To determine GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	Calculation of the $OI3_{BG3,BZF}$ indicators using EcoSoft by IBO (Austrian Institute for Healthy and Ecological Building) See for more information: http://www.ibo.at/de/ecosoft.htm
Reference Study Period	100 years
Included life cycle stages	From cradle to grave Construction stage // Use stage // End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Thermal building envelope (constructions in their entirety) + subceilings (constructions in their entirety) interior walls in their entirety + buffer rooms in their entirety (e.g. unheated basement)
Scenarios and assumptions used	According to EcoSoft by IBO (LCA for buildings)
Accounting of electricity mix	According to EcoSoft by IBO (LCA for buildings)
Databases used	According to EcoSoft by IBO (LCA for buildings)
LCA Software used	According to EcoSoft by IBO (LCA for buildings)
Method of materials quantification	According to EcoSoft by IBO (LCA for buildings)
Values and sources of primary energy and emission factors	According to EcoSoft by IBO (LCA for buildings)
Character of the indicator used	According to EcoSoft by IBO (LCA for buildings)
Indicators assessed	GWP 100a (EcoSoft by IBO) Acidification (EcoSoft by IBO) CED non renewable (EcoSoft by IBO)

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

Bundesministerium für Verkehr, Innovation und Technologie

TU Graz in cooperation with Austrian Institute of Ecology:

Data based on: Schöberl & Pöll GmbH BAUPHYSIK und FORSCHUNG

Key issues related to Annex 57:
1.1 Selection of materials
2.3 Impact of off-site manufacture versus in situ
3.5 Reduction of EG gas by the Use of Wood construction

Case study AT4

e80^3 a plus energy building concept

KEY OBSERVATIONS

For this project the LCA was calculated according to the IEA EBC Annex 56 methodology. The study was performed for a reference study period of 60 years.

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_2	14,10	[kWh/m$^2_{GFA}$*year]
EE_2	10,90	[kWh/m$^2_{GFA}$*year]
OG_1	3,46	[kg CO_2-eq/m$^2_{GFA}$*year]
EG_1	2,77	[kg CO_2-eq/m$^2_{GFA}$*year]

The study evaluates:

- Development of concepts and strategies for renovation to plus-energy standard
- Development of pre-fabricated facade elements with integrated HVAC systems (PV, solar thermal collectors, etc.)
- Realization of a demonstration project in Kapfenberg including monitoring and user satisfaction

OBJECTIVES OF CASE STUDY

The aim of this research project is to develop a prefabricated construction for the refurbishment of houses, which were build in Austria between the 1950 and 1980's. Furthermore there should be given the possibilities to integrate technical equipment into the building skin in the stage of production.

BUILDING KEY FACTS

Intended use: residential building

Size: 2845 m^2 GFA (32 residential units, 4 floors)

Location: Kapfenberg, Austria

Architect: Nussmüller Architects

Building year: 1960 (renovation year: 2013)

Source: Nussmüller Architekten ZT GmbH

Building description

The analysed building is a residential building which was built between 1960 and 1961. The four-story building has a length of 65 m (east and west façade) and a depth of 10 m (north and south façade). On each floor eight apartments were located which varied from 20 to 65 m² living space. These apartments didn´t meet the current way of living because they were too small. For this reason not all flats were rented.

Building envelope

The existing building was a typical building from the 1960's made of prefabricated sandwich concrete elements without an additional insulation. The basement ceiling was insulated with approx. 60 mm polystyrene. The old roof was a pitched roof with no insulation. The ceiling to the unheated attic was insulated with 50 mm wood wool panels. The existing windows were double glazed windows with an U-value of 2.5 W/m²K.

Energy systems before retrofit

In the existing building a variety of different heating systems was installed: a central gas heating, electric furnaces, electric night storage heaters, oil heaters, wood-burning stoves and coal furnaces.

The ventilation of the existing building was accomplished by opening the windows; no mechanical ventilation system was installed.

The enormous energy demand caused very high heating and operating costs. A high quality refurbishment of the building with a change in the layout of the apartments should make the building more attractive to new residents and young families.

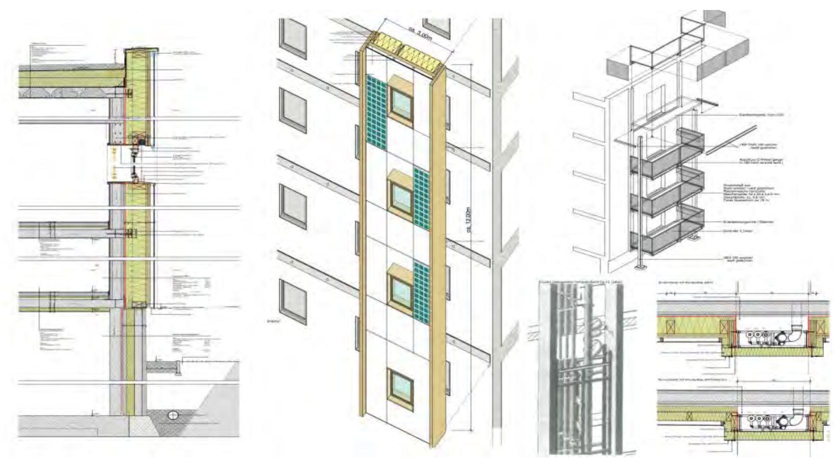
Source: Nussmüller Architekten ZT GmbH

Source: Nussmüller Architekten ZT GmbH

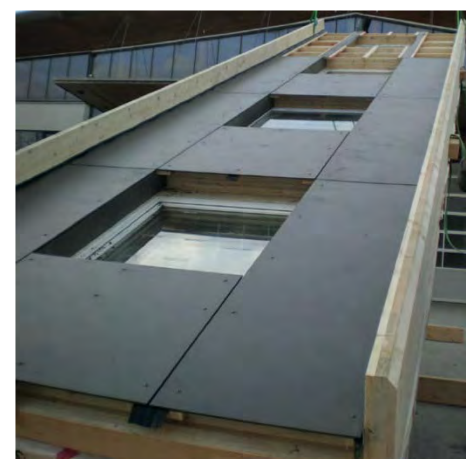
Specific renovation objectives

- Development of active and passive facade modules and modules for the building services.
- Realization of the developed modules in a demonstration building
- Optimization of the building through an innovative energy supply and disposal concept:
    - 80% reduction of the energy demand of the existing building
    - 80% reduction of the CO_2 emissions of the existing building
    - 80% use of renewable energy (based on the total energy consumption of the renovated building)
- Optimization of the energy concept by using the existing heat and electricity grids to achieve plus-energy.
- Changing the layout of the apartments to adapt them to the requirements and needs of the future residents.
- Raising awareness of the residents and the property management for sustainable energy efficient usage of the apartments.

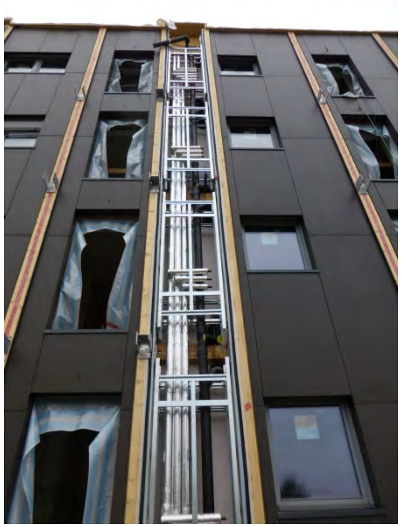
Source: Nussmüller Architekten ZT GmbH, AEE INTEC



Source: Nussmüller Architekten ZT GmbH, AEE INTEC



Source: Nussmüller Architekten ZT GmbH, AEE INTEC



Source: TU-Graz

Instead of conventional insulation systems the facade in this project is covered with large-sized active and passive facade elements.
Similar facade elements were developed and tested in previous projects. For this demonstration building the developed facade elements should comprise following alterations:

- The elements should be cheaper and allow more prefabrication.
- There should be less effort at the building site.
- The building services should be visible and also easy accessible (for service an maintenance)

With these facade elements it should be possible to reach an energy reduction and a reduction of the CO_2 emissions by 80%, as defined in the renovation objectives.
The idea was also to create a prefabricated façade element which allows the use of different surfaces with the same substructure. The surface materials can vary between e.g. wood, stone or fiber cement boards. Also active components like solar thermal or photovoltaic panels can be integrated in the façade element.
The supply and disposal lines are also integrated in the building envelope (in separate elements). This enables an easier installation as well as the possibility to access the supply and disposal lines from the outside without the disturbance of the residents.
These separate elements are also prefabricated and the building owner has the possibility to decide which ducts should be included (heating, domestic hot water, ventilation, electricity, waste water etc.)

Source: TU-Graz

Source: TU-Graz

Source: TU-Graz

SYSTEM BOUNDARIES

Building life cycle stages included in the study, according to EN15978

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						X		X		X			X	

LCA BACKGROUND

Reference study period: 60 years
Calculation of Energy: Total Primary Energy and Non-renewable Primary Energy
Calculation of GWP: Greenhouse gases emissions (100 years)
Standards/guidelines: IEA EBC Annex 56 methodology

Project Number: FFG Proj. Nr. 831023

Project partners: AEE – Institute for Sustainable Technologies
Kulmer Bau GesmbH & CoKG und Kulmer Holz-Leimbau GesmbH
Geberit Huter GmbH, p-solution gmbh
Nussmüller Architekten ZT GmbH
GREENoneTEC Solarindustrie GmbH
Stadtwerke Kapfenberg GmbH
Wohn- u. Siedlungsgenossenschaft ennstal
Institute of Technology and Testing of Building Materials, Working Group Sustainability Assessment, Graz University of Technology

Funding Program: Haus der Zukunft PLUS, funded by the Federal Ministry for Transport, Innovation and Technology

Assessor: AEE INTEC & TU Graz

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according to the developed methodology in the IEA EBC Annex 56 project.

End of life stage:
The end-of-life stage of a building begins after the use stage, when the building is decommissioned and is not intended to have any further use. In this study, the building would be deconstructed at the end of its life stage and would provide a source of materials to be reused, recycled, recovered, or landfilled, depending on the type of construction product.

Assessment results building components (ECO-BAT)

Element	No	Area [m²]	UBP'06 [Pts /(m²*y)]	CED [MJ /(m²*y)]	NRE [MJ /(m²*y)]	GWP [kg CO2-Eq /(m²*y)]
AW02 Außenwand	8	165.6	1.963.394	41.108	19.459	1.425
DA01 Dachdecke Flachdach	2	333.9	337.666	6.724	6.652	0.462
FE01 Fenster 50/70	32	0.35	41.593	0.575	0.551	0.034
FE02 Fenster 120/120	4	1.44	18.193	0.297	0.213	0.014
FE03 Fenster 110/215	48	2.37	359.309	5.875	4.203	0.286
FE04 Fenster 90/200	32	1.8	181.929	2.975	2.128	0.145
FE05 Fenster 170/130	32	2.21	223.368	3.652	2.613	0.178
FE06 Fenster 110/130	16	1.43	72.266	1.182	0.845	0.058
FE07 Fenster 130/130	7	1.69	37.365	0.611	0.437	0.03
FE08 Fenster 81/200	1	1.6	5.054	0.083	0.059	0.004
AT01 Außentüre 90/200	3	1.8	20.274	0.232	0.159	0.011
AT02 Außentüre 90/217	32	1.95	234.279	2.678	1.841	0.127

Source: AEE INTEC

Assessment Results building envelope (blue), HVAC (red) Eco-Bat

	UBP'06 [Pts /(m²*y)]	CED [MJ /(m²*y)]	NRE [MJ /(m²*y)]	GWP [kg CO2-Eq /(m²*y)]
Manufacturing	1.220.962	29.688	17.128	1.077
Transport	0	0	0	0
Replacement	1.563.269	35.677	21.416	1.35
Elimination	710.458	0.628	0.617	0.347
Total materials	3.494.689	65.993	39.161	2.774
Heat production	282.37	2.417	2.255	0.137
Heat distribution	630.903	7.272	7.024	0.424
Sanitary	0	0	0	0
Electrical	0	0	0	0
Ventilation	1.324.264	7.553	7.099	0.442
Solar thermal collectors	925.714	8.014	7.136	0.46
Photovoltaïc	2.643.75	30.656	27.094	1.997
Total BITS	5.807.002	55.913	50.607	3.461

Source: AEE INTEC

Assessment results operation phase

Life Cycle Impact Assessment		
GWP - Global Warming Potential [kgeq CO2/a/m2]	Materials - BITS	3,5
	Materials - Building Envelope	2,8
	heating	1,1
	DHW	1,1
	cooling	
	Electricity (misc.)	0,0
	total	*8,4*
NRPE - Non Renewable Primary Energy [kWh/m²a]	Materials - BITS	14,1
	Materials - Building Envelope	10,9
	heating	6,3
	DHW	6,6
	cooling	
	Electricity (misc.)	0,0
	total	*37,8*
PE - total Primary Energy [kWh/m²a]	Materials - BITS	15,5
	Materials - Building Envelope	18,3
	heating	31,6
	DHW	34,4
	cooling	
	Electricity (misc.)	0,0
	total	*99,9*

Source: AEE INTEC

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	Residential home, renovation
Energy-standard	Plus - energy
Gross floor area/ Net floor area	2 845 m² / 2 240 m²
Gross volume	8 673 m³
Reference area for EE/EG	
Surface/Volume ratio (m-1)	0.37 1/m
Construction method	Prefabricated timber elements
Thermal insulation	Insulation of ext. walls and roof
Ventilation system	Mechanical ventilation with heat recovery
Heating and cooling system	Heating: district heating supported by solar thermal installation on-site, 7500 litre storage tank, 2-pipe system (flow and return), radiators in the flats Cooling: n/a
Final energy demand electricity	16.43 $kWh/m^2_{GFA}a$
Final energy demand for heating and hot water	29.68 $kWh/m^2_{GFA}a$
Final energy demand for cooling	Cooling: n/a
Benchmark	-
Purpose of assessment	Determination of GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	According to the IEA EBC Annex 56 methodology
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	External walls (only renovated parts considered) Roof (only renovated parts considered) New doors and windows Installations (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	According to IEA EBC Annex 56 methodology
Accounting of electricity mix	According to IEA EBC Annex 56 methodology
Databases used	According to IEA EBC Annex 56 methodology
LCA Software used	Eco Balance Assessment Tool (Eco-Bat) – Version 4.0
Method of materials quantification	According to IEA EBC Annex 56 methodology
Values and sources of primary energy and emission factors	According to IEA EBC Annex 56 methodology
Character of the indicator used	According to IEA EBC Annex 56 methodology
Indicators assessed	GWP Total Primary Energy Non-renewable Primary Energy

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

TU Graz in cooperation with AEE – Institute for Sustainable Technologies:

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Reduction of the EE and EG vs. OE and OG
3.4 Application of new technologies
3.5 Reduction of EG by the use of wood

Case study AT5
ECR - Energy City Graz

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The project +ERS (plus energy Reininghaus South) is a multi-storey residential building object. Generally the project was realised as a wood and clay construction, excluding the staircase which for safety reasons was developed as a reinforced concrete construction. The LCA was calculated according to baubook eco2soft (LCA for buildings) for a study period of 100 years.

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_3	44,25	[kWh/m^2_{GFA}*year]
EE_2	11,84	[kWh/m^2_{GFA}*year]
OG_1	6,93	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	0,91	[kg CO_2-eq/m^2_{GFA}*year]

The study evaluates:
- Development of a low energy building stock
- Use renewable energy and recourses
- Use of innovative energy recourses
- Reduce the demand of energy in general
- Reduce of the Embodied Energy (EE)
- Reduce of the Embodied Greenhouse gas (EG)

OBJECTIVES OF CASE STUDY

The main objective of the research project Energy City Graz-Reininghaus (ECR) focuses on the development of an energy self-sufficient and CO_2- neutral city district in the City of Graz (Austria).

BUILDING KEY FACTS

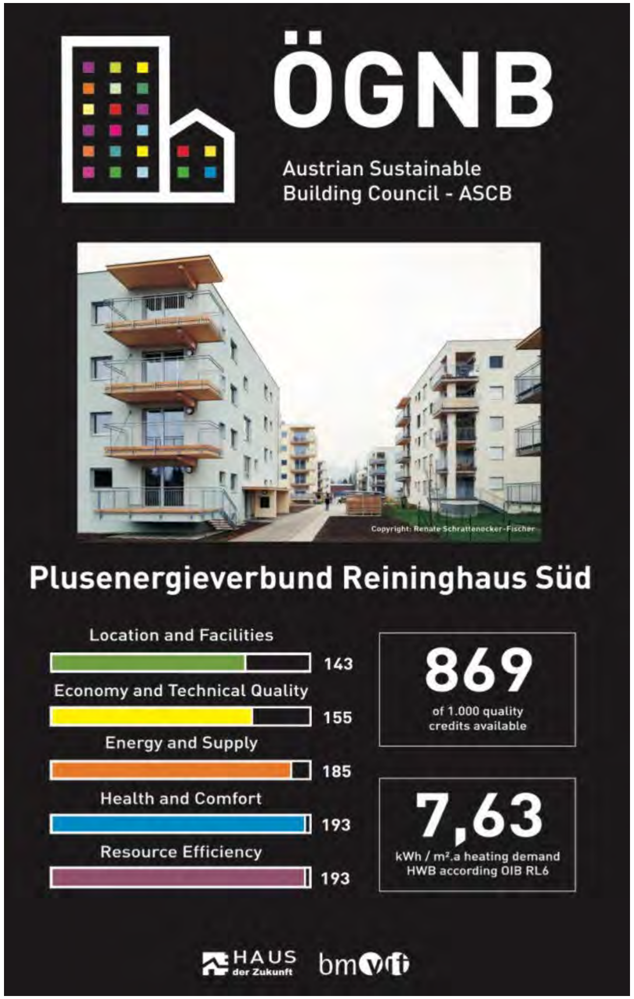
Intended use: residential, service, business and office building
Initiator: WEGRAZ
Architect: Nussmüller Architekten
Size of land: 28.943 m²
Gross floor area: 22.918 m²
Number of floors: 2 – 5
Residential units: 177
Additional use: Supermarket (1.070 m²); cafe and restaurant (410 m²); office (2.780 m²)
Construction works: 2011-2015

Source: Martin Grabner, TU Graz

Main focus of the Framework Plan Energy Graz-Reininghaus: In the framework plan Energy two main issues, resulting out of proposals and the guidelines of the Country of Styria and the City of Graz (Communal Energy Concept- KEK) have been defined: 1st is the scientific revision and performance of the vision for the energy self-sufficient CO2-neutral City district Graz-Reininghaus and 2nd the initiation and accompaniment of the city-district development process of the sustainable city-district Graz-Reininghaus.

Assessment of reference projects: In the frame of the potential analysis city development projects in selected European and Austrian cities have been analyzed. Their common characteristic was the definition of worldwide innovation-zones to realize the ambitious energetically objectives. The realization has been conceived in close cooperation between administration, company- platforms, experts and site owners. In these processes soft skills like synergies, networks and cooperation-models (PPP) are deliberately practiced. Moreover the City of Copenhagen has prepared guidelines, stipulating the use of the existing heat potential.

City-climate aspects: The Graz-Reininghaus site is situated in the north-western part of Graz and therefor in a city-climatic transition zone between the centrally located inner-city areas with typical shaping of the climate like heat-islands and modificated streaming conditions on the one side and the urban fringe districts in the north and west of the site on the other side. In the course of the project the modification concerning the dissemination of the pollution due to the development and for the same the eventual modifications concerning the most important pollution form of fine dust and nitric oxides.



Source: ÖGNB

PROJECT DESCRIPTION +ERS

+ERS is part of the project ECR. Until now plus-energy houses were frontrunners: very often single family houses or buildings in sparsely populated areas. But due to the ongoing urban sprawl new solutions have to be developed. The focus should be set using the infrastructure options of urban areas in a better way: Supply networks, effluent disposal, public transport and social and educational infrastructure. The development of innovative multifunctional neighbourhoods using synergies within the cluster provides a sustainable development for urban areas and a high level of living environment for residents. Further information's are available at http://www.hausderzukunft.at/results.html/id6858.

The main part of the working group Sustainability Assessment was a TQB assessment of this project. (see https://www.oegnb.net/tqb.htm) This is done in five steps:
Building documentation, handover of submitted project, verification of proof, approval of assessment result and publication of the assessment result.

Source: Nussmüller Architekten ZT GmbH

Source: Nussmüller Architekten ZT GmbH

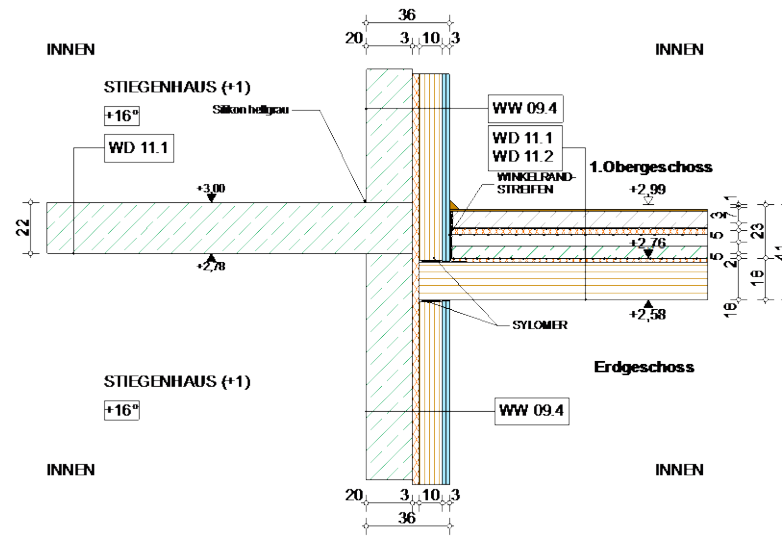
Source: Nussmüller Architekten ZT GmbH

PROJECT DESCRIPTION +ERS

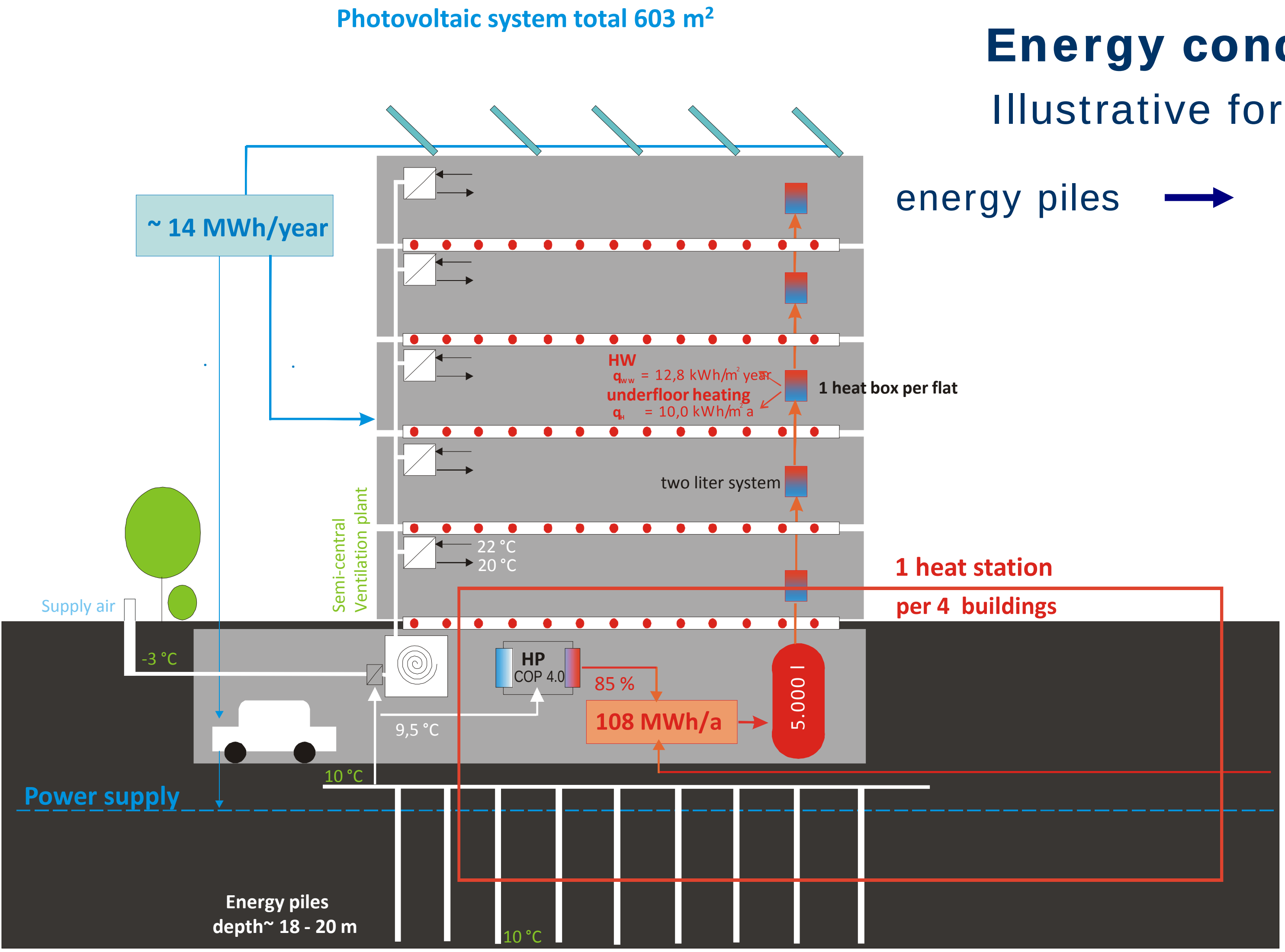
The project +ERS (plus energy Reininghaus South) is a multi-storey residential building object. The thermal insulation is designed to achieves a passive house standard . This high standard is substantial for realizing a plus energy project.

Generally the project was realised as a wood and loam construction, excluding the staircase which for safety reasons was developed as a reinforced concrete construction. All other walls where made out of CLT wood plates, which were prefabricated in a near by facility.
The high degree of prefabrication allows a rapid progress on the construction site – one storey per week.

Source: TU Graz



Source: Nussmüller Architekten ZT GmbH



Energy concept

Illustrative for one house

energy piles → heat pump

underfloor heating (40°C/32°C)

2-conductor system

flat stations („Heat Box“)

domestic ventilation 85% heat recovery

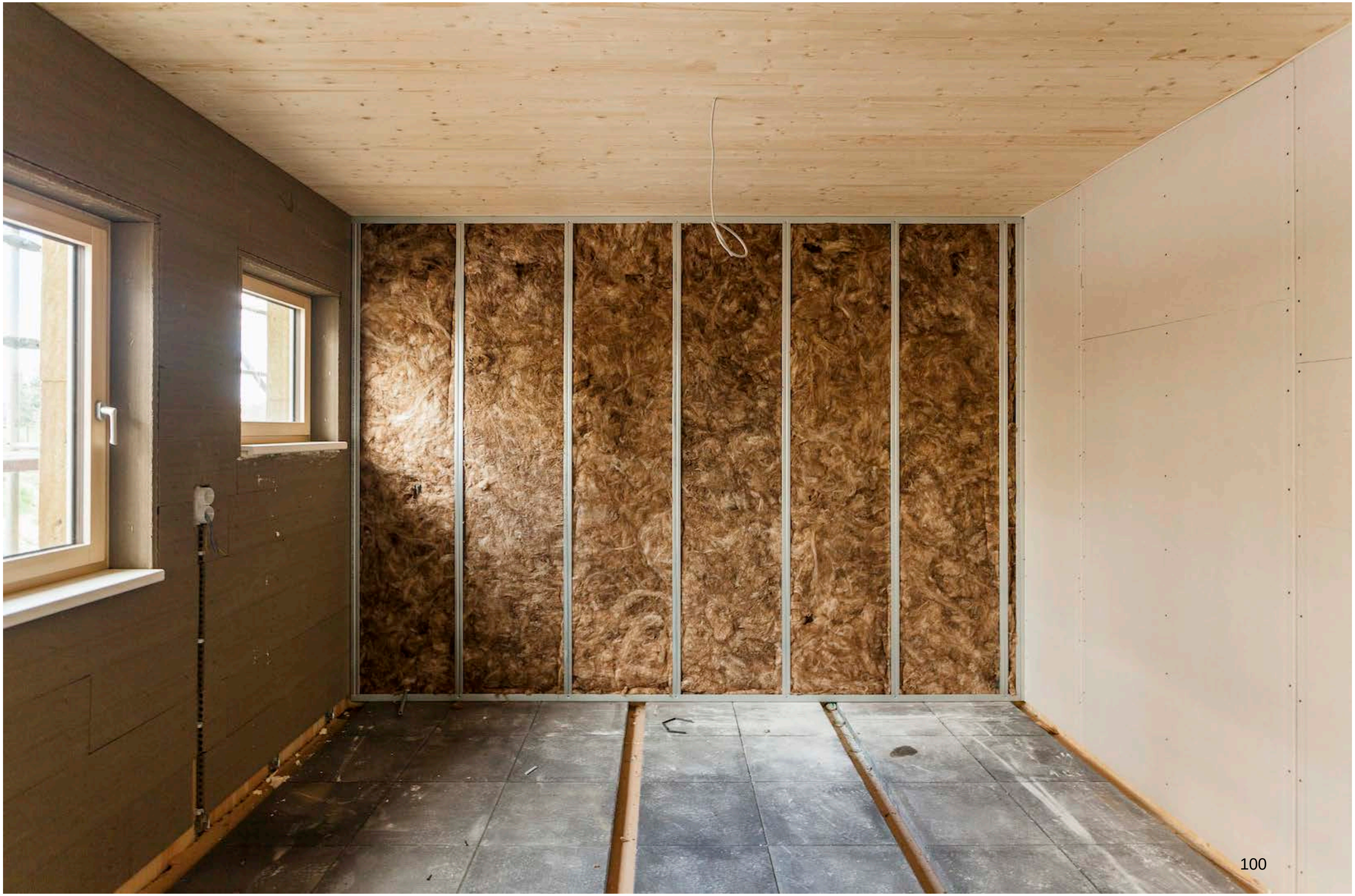
Photovoltaic

Source: AEE INTEC, Nussmüller Architekten

Source: Martin Grabner, TU Graz

Source: Martin Grabner, TU Graz

Source: Martin Grabner, TU Graz



Source: Martin Grabner, TU Graz

Source: Martin Grabner, TU Graz

Source: Martin Grabner, TU Graz

Source: Martin Grabner, TU Graz

SYSTEM BOUNDARIES

Building life cycle stages included in the study, according to EN15978

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						X		X						

LCA BACKGROUND

Reference study period: 100 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: according to baubook eco2soft (LCA for buildings)

Project Number: FFG Proj. Nr. 832742

Project partners: Aktiv Klimahaus Gmbh,
AEE INTEC
Nussmüller Architekten ZT GmbH
Graz University of Technology

Funding Program: Federal Ministry for Transport, Innovation and Technology, Haus der Zukunft

Website: http://www.hausderzukunft.at/results.html/id6858

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according baubook eco2soft (LCA for buildings).

End of life stage:
The end-of-life stage of a building begins after the use stage, when the building is decommissioned and is not intended to have any further use. In this study, the building would be deconstructed at the end of its life stage and would provide a source of materials to be reused, recycled, recovered, or landfilled, depending on the type of construction product.

DETAILED RESULTS OF THE RESIDENTIAL BUILDING +ERS: Product stage (A1 – A3)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m^2 reference area.

Product stage (A1 - A3)	per m² constuction area		Total	
global warming (GWP100)	-9,56	kg CO_2 / m²	-40684	kg CO_2
acidification	0,29	kg SO_4 / m²	1214	Kg SO_4
CED nr.	931,23	MJ / m²	3963089	MJ
GWP C - storage	-75,72	kg CO_2 / m²		kg CO_2
CO2 Prozess	66,16	kg CO_2 / m²	281565	kg CO_2
CED r.	1171,95	MJ / m²	4987525	MJ
photochemical oxidation	0,06	kg C_2H_2 / m²	258	kg C_2H_2
eutrophication	0,11	kg PO_4--- / m²	488	kg PO_4---
ozone layer depletion (ODP)	4,41E-06	kg CFC-11 / m²	1,87E-02	kg CFC-11
OI3 BG3,BZF			**171**	Points

Source: Österreichisches Ökologie Institut – OI3 Index calculation

DETAILED RESULTS OF THE RESIDENTIAL BUILDING +ERS: Use stage (B4)

Global warming potential (GWP 100a), acidification (AP), non renewable primary energy demand (CED nr.), global warming potential storage (GWP – storage), global warming potential process (CO2 process), renewable primary energy demand (CED r.), photochemical oxidation (POCP), eutrophication (EP), ozone layer depletion (ODP), referring to 1 m^2 reference area.

Replacement (B4)	per m² constuction area		Total	
global warming (GWP100)	45,34	kg CO_2 / m²	192946	kg CO_2
acidification	0,23	kg SO_4 / m²	999	Kg SO_4
CED nr.	748,78	MJ / m²	3186592	MJ
GWP C - storage		kg CO_2 / m²		kg CO_2
CO2 Prozess	45,34	kg CO_2 / m²	192946	kg CO_2
CED r.	841,26	MJ / m²	3580161	MJ
photochemical oxidation	0,05	kg C_2H_2 / m²	202	kg C_2H_2
eutrophication	0,09	kg PO_4 --- / m²	389	kg PO_4 ---
ozone layer depletion (ODP)	3,44E-06	kg CFC-11 / m²	1,46E-02	kg CFC-11
OI3 BG3,BZF			**333**	Points

Source: Österreichisches Ökologie Institut – OI3 Index calculation

RESULTS OF STUDY PERIOD = 100 YEARS

Total Primary Energy consumption:

56,09 kWh/m$^2_{GFA}$*year

- Production and Operation stage: 21%
- Operational energy: 79%

Embodied Energy:

11,84 kWh/m$^2_{GFA}$*year

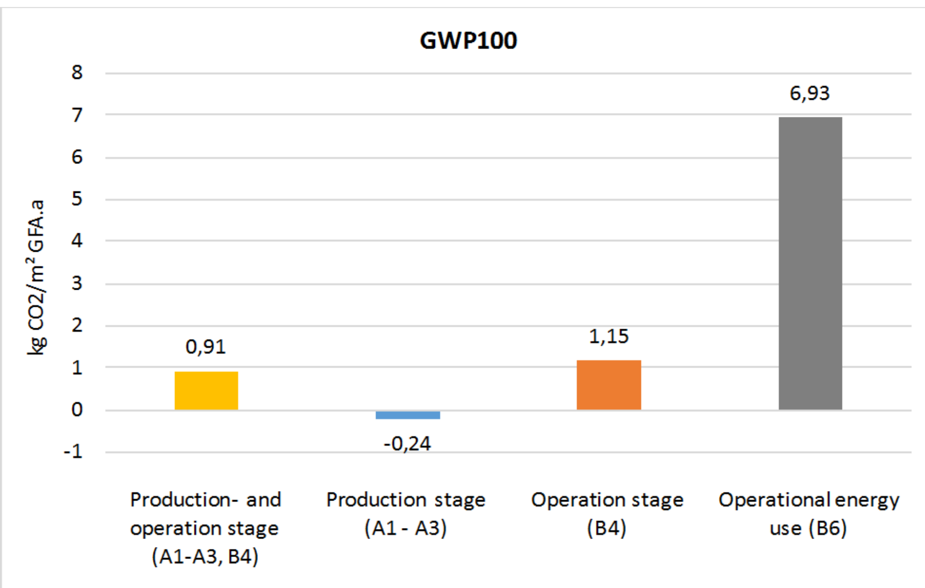
Total Global Warming Potential :

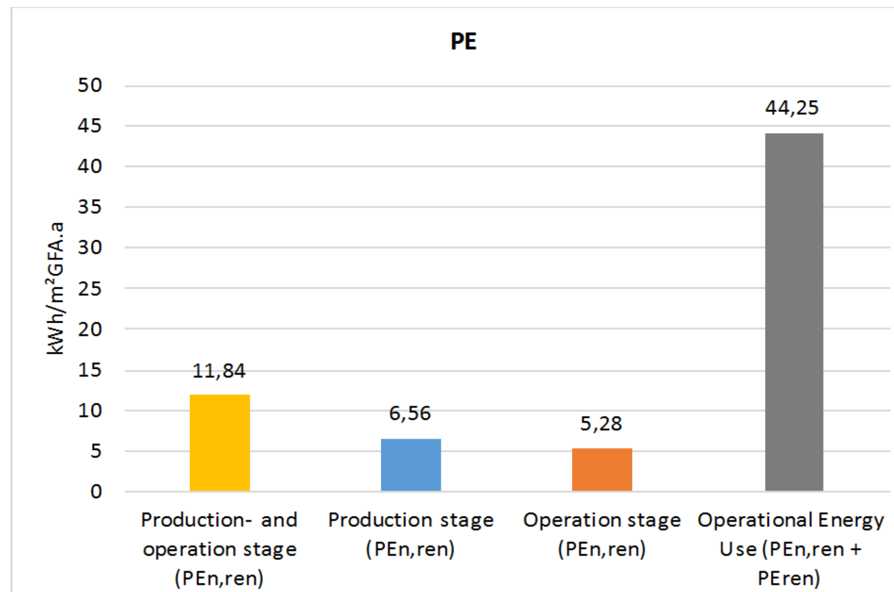
7,84 kg CO_2 equiv. /m$^2_{GFA}$*year

- Production and Operation stage: 12 %
- operational energy: 88 %

Embodied Global Warming Potential:

0,91 kg CO_2 equiv. /m$^2_{GFA}$*year





GWP: Global warming potential
PEn,ren: Primary Energy, non-renewable = EE_2
PEn, ren + PEren: Primary Energy, total = EE_3

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	+ERS residential home, new construction
Energy-standard	plus energy
Gross floor area/ Net floor area	1677,97 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EG	energy reference area 1.349,19 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Light construction (reinforced concrete core and primary wood construction)
Thermal insulation	Insulation of ext. walls and roof
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump (water/brine) equipped with a borehole heat exchanger, heat distribution with ventilation Cooling: n/a
Final energy demand electricity	n/a
Final energy demand for heating and hot water	n/a
Final energy demand for cooling	Cooling: n/a
Benchmark	-
Purpose of assessment	to determine GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	According to the methodology of IBO – Guidelines to calculating the OI3 indicators for buildings
Reference Study Period	100 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Basement and foundation External walls (underground and above ground) Internal walls (underground and above ground) Ceilings Roof Doors and windows Installations (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	According to baubook eco2soft (LCA for buildings)
Accounting of electricity mix	According to baubook eco2soft (LCA for buildings)
Databases used	According to baubook eco2soft (LCA for buildings)
LCA Software used	According to baubook eco2soft (LCA for buildings)
Method of materials quantification	According to baubook eco2soft (LCA for buildings)
Values and sources of primary energy and emission factors	According to baubook eco2soft (LCA for buildings)
Character of the indicator used	According to baubook eco2soft (LCA for buildings)
Indicators assessed	GWP 100a (baubook eco2soft) Acidification (baubook eco2soft) CED non renewable (baubook eco2soft)

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

TU Graz in cooperation with AEE – Institute for Sustainable Technologies:

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Impact for the respective life cycle phases
3.4 Application of new technologies

Case study AT6
KH – Karmeliterhof Austria

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated according to the standards EN 15978, EN 15804 for an reporting period of 50 years.

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value	[unit]
OE_2	74,78	[kWh/m^2_{GFA}*year]
EE_2	26,72	[kWh/m^2_{GFA}*year]
OG_1	23,00	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	7,99	[kg CO_2-eq/m^2_{GFA}*year]

GOAL OF THE STUDY

- Modernization of whole building complex of building
- Restructuring and renovation of the existing facade
- Close the gap between existing buildings
- Enhancement of the attractiveness of the surrounding area
- Improvement of the local density
- Disabled accessibility

OBJECTIVES OF CASE STUDY

In this research project an critical examination of the ecological performance from the Office Building Karmeliterhof was done. Also an assessment based on the criteria from the DGNB – system have been done. All this investigations were done for the manufacturing of the construction materials, as also for the energy use during the life cycle.

BUILDING KEY FACTS

Intended use: Office Building

Building phase: in use

Building Owner: LIG – Landesimmobilien – Gesellschaft mbH

Architect: LOVE architecture and urbanism. zt gesmbh

Source: TU Graz

PROJECT DESCRIPTION

The investigated office building is located in the city of Graz (Austria). The building owner and operator is the Landesimobiliengesellschaft (LIG Steiermark). It serves several public authorities and services. The building is a new office building (Part A1) built within the refurbishment of the whole building complex pictured above.

Load bearing walls are constructed in concrete and bricks. The heat insulation composite system consists of 16 cm EPS. The roof construction consists of 20 cm reinforced concrete, 16 cm heat insulation and fibre cement panels for roving assembled on an integrated sub construction. Inner walls are constructed as plasterboard walls Glazing was fitted as double glazing with aluminum frame. The building is heated by district heating supplied via convectors and in ground floor area via underfloor heating

Source: TU Graz

SYSTEM BOUNDARIES

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: EN 15978, EN 15804, EN 15686

Project partners: LOVE architecture and urbanism. zt gesmbh

Funding Program: LIG – Landesimmobilien – Gesellschaft mbH

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building skin. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according EN 15978. Their estimated service life was taken assuming the values by the ESL-Catalogue in Austria.

End of life stage:
The end-of-life stage of a building begins after the use stage, when the building is decommissioned and is not intended to have any further use. In this study, the building would be deconstructed at the end of its life stage and would provide a source of materials to be reused, recycled, recovered, or landfilled, depending on the type of construction product.

LCA Assessment Results

LCA BACKGROUND

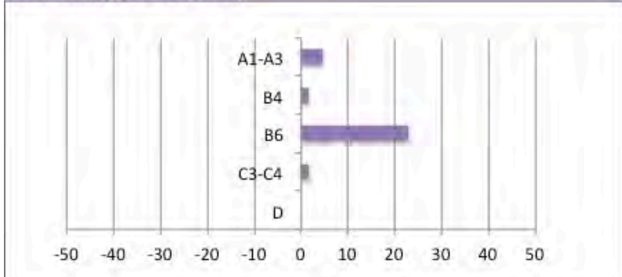
Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: EN 15978, EN 15804, EN 15686

Life Cycle Assessment — Annex 57

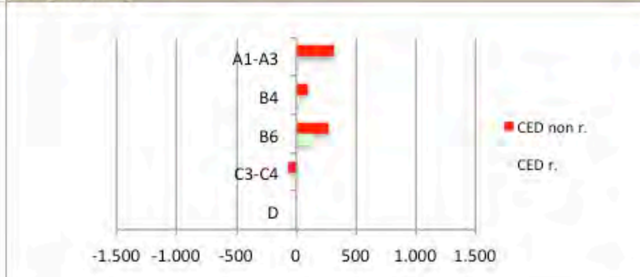
AT6	0					
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,69E+00	1,56E+00	2,30E+01	1,74E+00	0,00E+00
CED non r.	MJ/m²a	3,13E+02	9,73E+01	2,69E+02	-6,45E+01	0,00E+00
CED r.	MJ/m²a	1,29E+01	2,30E+01	1,44E+02	-2,54E+00	0,00E+00
CED complete	MJ/m²a	3,26E+02	1,20E+02	4,13E+02	-6,70E+01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



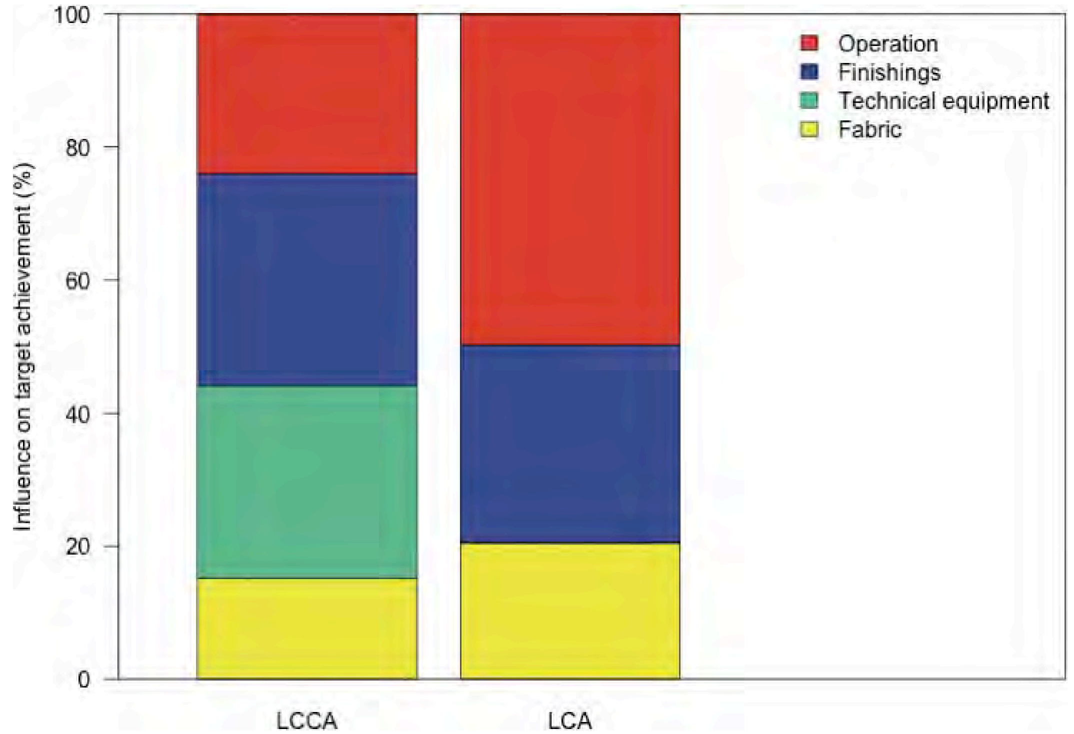
CED [MJ/m²a]



Project: Karmeliterhof City Graz
Carried out by: KH
Database: Ökobaudat 2009

Source: TU Graz

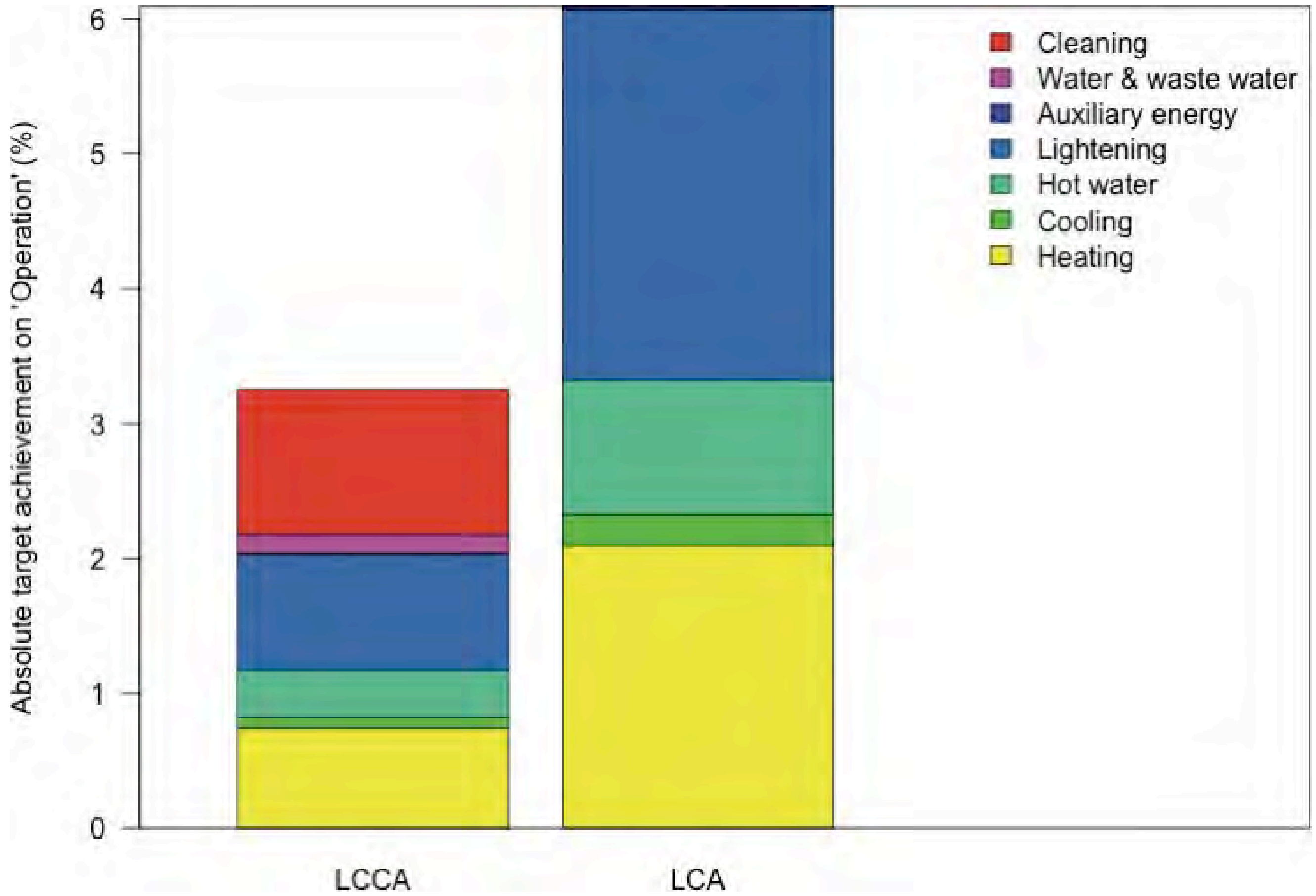
LCA and LCC Assessment Results [1]



	LCC	GWP	ODP	POCP	AP	EP	PEne	PEges
Fabric	15%	14%	42%	22%	15%	18%	24%	16%
Technical eq.	29%	0%	0%	0%	0%	0%	0%	0%
finishing	32%	9%	40%	39%	33%	34%	35%	39%
Operation	24%	77%	18%	38%	51%	48%	41%	45%

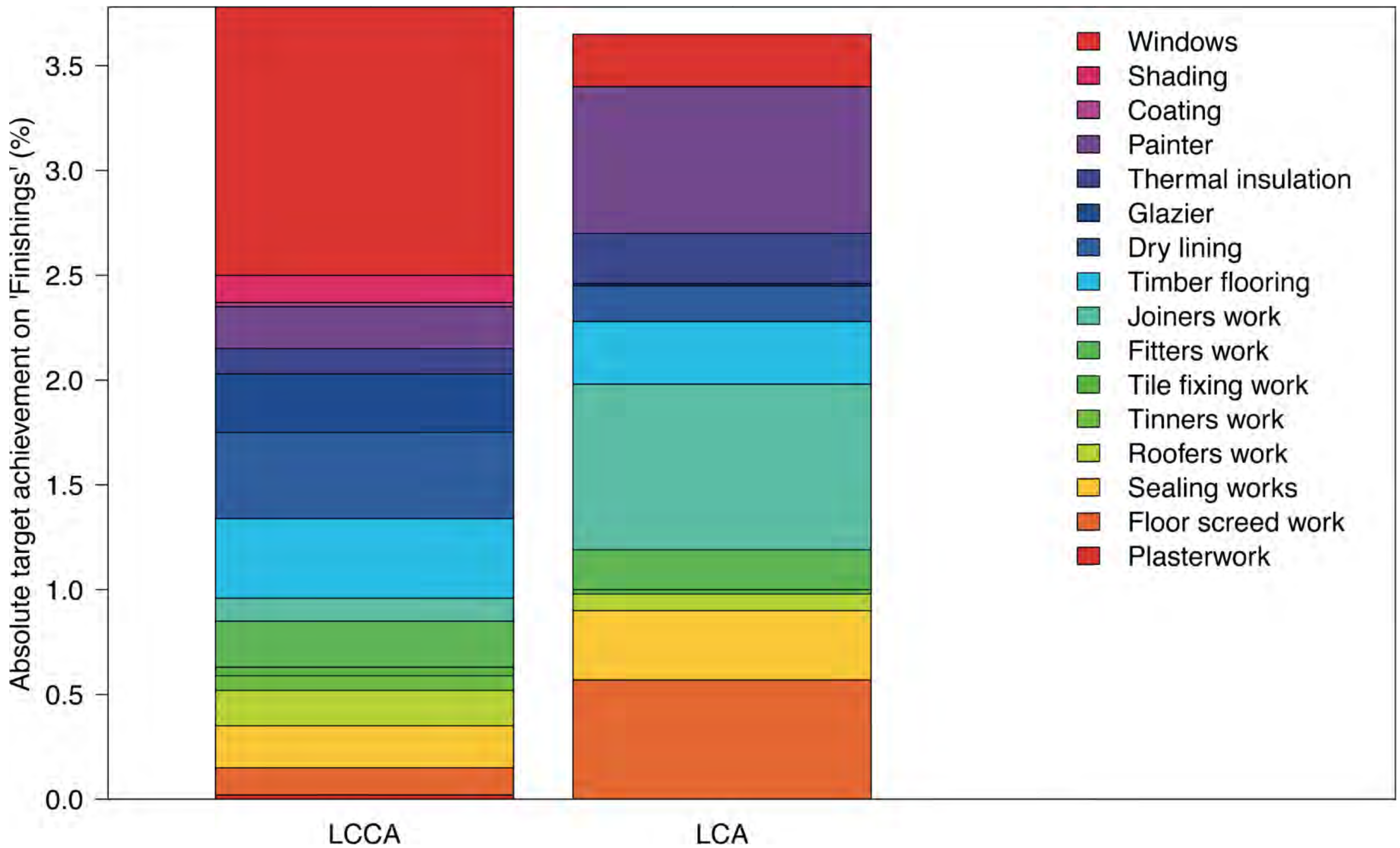
Source: [1]

LCA and LCC building operation [1]



Source: [1]

LCA and LCC finishings [1]



Source: [1]

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	Office Building
Energy-standard	Low energy house (Energy certificat B); 39kWh/m2·a
Gross floor area/ Net floor area	2310 / 2037 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EG	Energy reference area 2034 m^2
Surface/Volume ratio (m-1)	0,21
Construction method	Reinforced Concrete / bricks
Thermal insulation	Insulation composite system
Ventilation system	Manually
Heating and cooling system	District heating, / convectors, manual ventilation
Final energy demand electricity	n/a
Final energy demand for heating and hot water	n/a
Final energy demand for cooling	Cooling: no cooling with the exception of a multi functional room; multi split air conditioning
Benchmark	-
Purpose of assessment	To determine GWP 100a, acidification and CED nr. for construction, operation, replacement, disposal
Assessment methodology	EN 15978
Reference Study Period	50 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Basement and foundation External walls (underground and above ground) Internal walls (underground and above ground) Ceilings Roof Doors and windows Heating system
Scenarios and assumptions used	According to ÖGNI/DGNB assessment regulations
Accounting of electricity mix	According to ÖGNI/DGNB assessment regulations
Databases used	Ökobaudat 2009
LCA Software used	Excel-based assessment conducted with ÖGNI/DGNB calculation conventions
Method of materials quantification	Based on plan documentation and the bill of quantities in accordance to ÖGNI/DGNB regulations
Values and sources of primary energy and emission factors	Ökobaudat 2009
Character of the indicator used	Ökobaudat 2009
Indicators assessed	GWP; AP, EP; POCP, ODP, PE (n.r) PE (r)

[1] Kreiner, Helmuth ; Passer, Alexander: Interdependency of LCCA and LCA in the assessment of buildings. In: Third International Symposium on Life-Cycle Civil Engineering : TAYLOR and FRANCIS GROUP, 2012 — ISBN 9780415621267, S. 1794–1801

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

bmvit Bundesministerium für Verkehr, Innovation und Technologie

IEA RESEARCH COOPERATION

FFG

TU Graz

Key issues related to Annex 57:
1.1 Comparison of different materials
2.2 Significance of elements for different life cycle stages
3.4 Application of new technologies

Case study AT7
ÖKOVERGLEICHE

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The aim of this research project is to subject a number of building concept models to a comprehensive comparative analysis and evaluation in terms of ecological and economic key-figures. The study was performed for an reporting period of **100 years.**

Operational Energy (OE), Embodied Energy (EE), Operational Greenhouse gas (OG) and Embodied Greenhouse gas (EG), was evaluated.

	Value (from-to)	[unit]
OE_2	-21,07 – 89,31	[kWh/m^2_{GFA}*year]
EE_2	27,37 – 33,57	[kWh/m^2_{GFA}*year]
OG_1	-4,46 – 20,24	[kg CO_2-eq/m^2_{GFA}*year]
EG_1	7,08 – 9,40	[kg CO_2-eq/m^2_{GFA}*year]

Comparison of four different energy standards

- Low energy house
- Solar house (Sonnenhaus)
- Passive house
- Plus energy house

Comparison of different construction materials

- Brick
- Concrete
- Wood – composite
- Wood

OBJECTIVES OF CASE STUDY

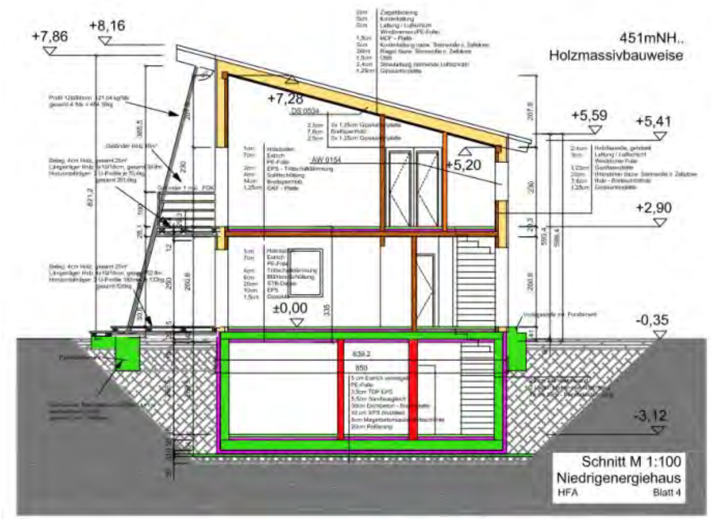
The main objective of this research project is to subject a number of building concept models to a comprehensive comparative analysis and evaluation in terms of ecological and economic key-figures.

DATA AND FACTS

Intended use: single family home

Gross floor area: 162 - 175 m^2

Number of floors: 2



Source: Project Ökovergleiche

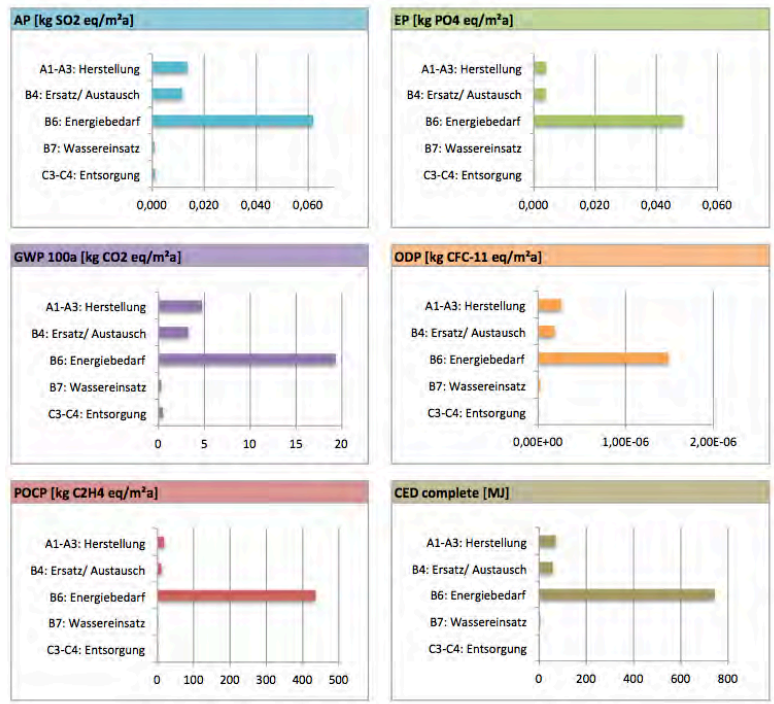
The aim of this research project is to subject a number of building concept models to a comprehensive comparative analysis and evaluation in terms of ecological and economic key-figures. The basis for comparison used are four construction types (low-energy house, solar house, passive house, energy-plus house) and a number of primary construction materials (wood, bricks, concrete) as well as installation designs for which both life cycle assessments and costing are carried out in a variety of combinations. The data volumes created are evaluated using life cycle analyses of the individual building concepts and subsequently assessed using common Austrian building certification systems.
The project has a number of objectives:
The main focus is on the creation of an objective knowledge base by an extensive project consortium consisting of key building material experts from the ACR-Austrian Cooperative Research (Structural Engineering Institute Linz, Structural Engineering Experimental and Research Institute Salzburg, Research Institute of the Association of the Austrian Cement Industry, Wood Research Austria, Austrian Research Institute for Chemistry and Technology) in collaboration with external experts from the Austrian construction industry (PORR AG) to work out the individual costing analyses as well as independent consultants to carry out the life cycle assessments.
Creating further extensive data volumes will enable a relevant contribution to be made to the development and dissemination of innovative building concepts (energy-plus house, solar house) and to the evaluation of a variety of construction methods in terms of the building life span. This is designed to remedy currently significant gaps in knowledge and data, which relate inter alia to questions of primary energy requirements of different building materials and construction concepts, other key ecological figures for building materials and also the efficiency (including the economic efficiency) of installation concepts.

Datenblatt Auswertung

Ökobilanz

Umwelt Indikatoren	Einheit	Herstellung	Nutzung			Entsorgung
		A1-A3: Herstellung	B4: Ersatz/ Austausch	B6: Energiebedarf	B7: Wasser-einsatz	C3-C4: Entsorgung
AP	kgSO2/m²a	1,35E-02	1,15E-02	6,20E-02	8,48E-04	9,13E-04
EP	kgPO4/m²a	3,91E-03	3,75E-03	4,88E-02	3,56E-04	3,33E-04
GWP	kgCO2/m²a	4,72E+00	3,23E+00	1,93E+01	2,84E-01	4,53E-01
ODP	kgCFC-11/m²a	2,64E-07	1,89E-07	1,49E-06	2,32E-08	8,21E-09
POCP	kg C2H4/m²a	1,02E-03	1,04E-03	3,72E-03	8,54E-05	1,47E-05
CED non r.	MJ/m²a	5,43E+01	4,73E+01	3,07E+02	3,73E+00	1,04E+00
CED r.	MJ/m²a	1,78E+01	1,10E+01	4,36E+02	1,62E+00	5,95E-02
CED complete	MJ/m²a	7,21E+01	5,84E+01	7,43E+02	5,35E+00	1,09E+00

* AP (Potential für den Abbau der stratosphärischen Ozonschicht) *EP (Eutrophierungspotential) * GWP (Treibhauspotential) *ODP (Potential für den Abbau der stratosphärischen Ozonschicht) *POCP (Potenzial für die Bildung von bodennahem Ozon durch photochemische Oxidantien)



Source: TU Graz

SYSTEM BOUNDARIES

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Reference study period: 100 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Standards/guidelines: EN 15978, EN 15804, EN 15686

Project Number: FFG Proj. Nr. 827192

Project partners: Forschungsgesellschaft für Wohnen, Bauen und Planen (FGW)
Bautechnisches Institut Linz (BTI)
Bautechnische Versuchs- und Forschungsanstalt Salzburg (bvfs)
Holzforschung Austria (HFA)
Österreichisches Forschungsinstitut für Chemie und Technik (ofi)
Forschungsinstitut der Vereinigung der Österreichischen Zementindustrie (VÖZFI)
Graz University of Technology

Funding Program: Federal Ministry for Transport, Innovation and Technology, Haus der Zukunft
http://www.nachhaltigwirtschaften.at/results.html/id6530

Production stage:
The production stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction for the building. The LCI matrix is based on the different construction and support components.

Operation stage:
The operation stage spans the period from the completion of the construction works to the point when the building reaches its end of life. The system boundary in the use stage includes the use of construction products (replacement) and services for operating the building skin. For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8. The number of replacement rates for all specific construction products used in the buildings was calculated according EN 15978. Their estimated service life was taken assuming the values by the ESL- Catalogue in Austria.

End of life stage:
The end-of-life stage of a building begins after the use stage, when the building is decommissioned and is not intended to have any further use. In this study, the building would be deconstructed at the end of its life stage and would provide a source of materials to be reused, recycled, recovered, or landfilled, depending on the type of construction product.

[1]Sölkner, P. ; Oberhuber, A. ; Spaun, S. ; Preininger, R. ; Dolezal, F. ; Passer, A. ; Fischer, G.: Innovative Gebäudekonzepte im ökologischen und ökonomischen Vergleich über den Lebenszyklus, 2014; Berichte aus Energie- und Umweltforschung 51/2014, Bundesministerium für Verkehr, Innovation und Technologie

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Austria / moderate climate
Building/ Usage type	Ökovergleiche - single family house in, new construction
Energy-standard	Four different energy standards: low energy house, “Sonnenhaus”, passive-house, plus energy house
Gross floor area/ Net floor area	162 - 175 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EG	Energy reference area 162 - 175 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Different types of construction: brick construction; concrete construction; wood massive construction; wood frame construction; wood – composite
Thermal insulation	Insulation of ext. walls and roof
Ventilation system	n/a
Heating and cooling system	Different Heating systems: heat pump; single furnance heater; pellets stove Cooling: n/a
Final energy demand electricity	Range for the different house types between 1.110 kWh/a and 4.114 kWh/a
Final energy demand for heating and hot water	Range for the different house types between 10.410 kWh/a and 21.296 kWh/a
Final energy demand for cooling	Cooling: n/a
Benchmark	-
Purpose of assessment	To determine global warming potential (GWP 100a), acidification (AP), nutrification (EP), ozone depletion potential (ODP), photochemical oxidation formation potential (POCP) and cumulative energy demand CED r. and nr. for construction, operation, replacement, disposal
Assessment methodology	LCA – Methodology (according to EN 15978 and EN 15804 as also EN ISO 14044)
Reference Study Period	100 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Thermal building envelope (constructions in their entirety) Subceilings (constructions in their entirety) Interior walls in their entirety Housing technolog
Scenarios and assumptions used	According to EN 15978
Accounting of electricity mix	Austrian consumer mix
Databases used	EcoInvent V 2.2
LCA Software used	SimaPro 7.3.3
Method of materials quantification	LCI (life cycle inventory)
Values and sources of primary energy and emission factors	EcoInvent V 2.2
Character of the indicator used	According to EN 15804
Indicators assessed	Global warming potential (GWP 100a) Acidification (AP) Nutrification (NP) Ozone depletion potential (ODP) Photochemical oxidation formation potential (POCP) Cumulative energy demand non renewable (CED n.r.) Cumulative energy demand renewable (CED r.)

The preparation of this case study was part of the Austrian contribution to the IEA EBC Annex 57, which is financially supported by the IEA RESEARCH COOPERATION via the Austrian Research Promotion Agency (FFG) and BMVIT.

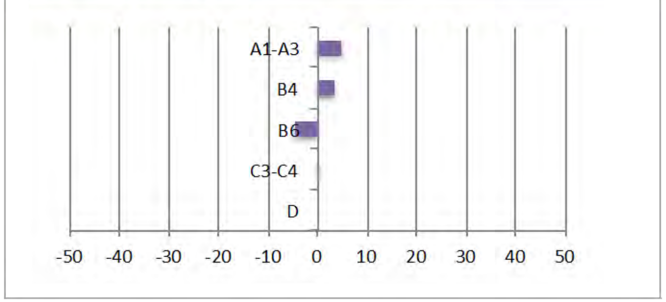
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

Life Cycle Assessment		Annex 57
AT07	low-energy house - concrete + TICS + pellet heating	

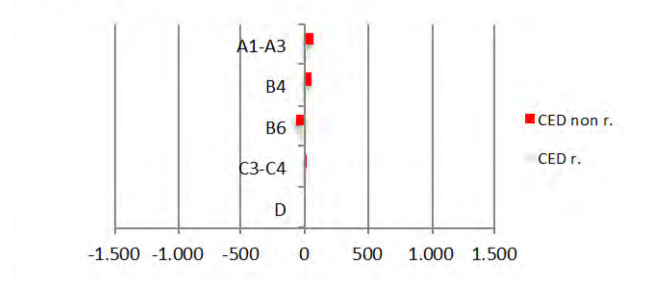
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,95E+00	3,48E+00	-4,46E+00	4,86E-01	0,00E+00
CED non r.	MJ/m²a	5,83E+01	5,20E+01	-7,59E+01	9,85E-01	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,15E+01	-2,47E+01	5,54E-02	0,00E+00
CED complete	MJ/m²a	7,83E+01	6,35E+01	-1,01E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

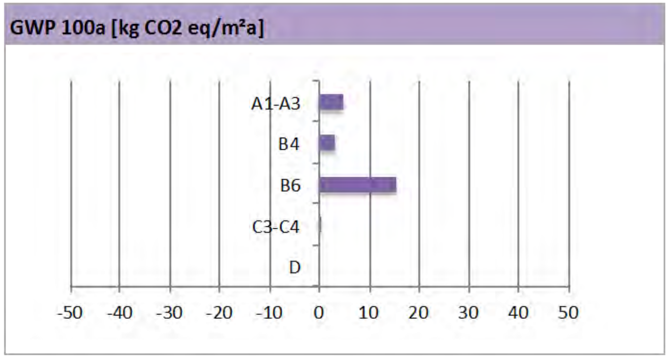
Source: TU Graz

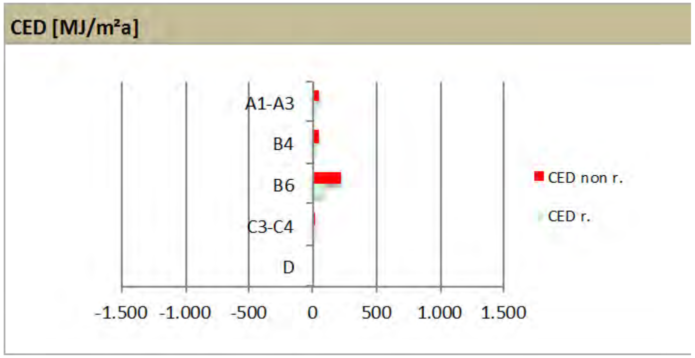
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

Life Cycle Assessment		Annex 57
AT07	low-energy house - concrete + TICS + heat pump	

Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,68E+00	3,20E+00	1,54E+01	4,48E-01	0,00E+00
CED non r.	MJ/m²a	5,38E+01	4,69E+01	2,22E+02	1,02E+00	0,00E+00
CED r.	MJ/m²a	1,76E+01	1,09E+01	8,57E+01	5,89E-02	0,00E+00
CED complete	MJ/m²a	7,14E+01	5,78E+01	3,07E+02	1,08E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)





Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

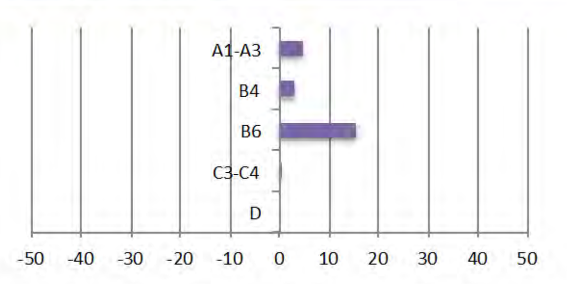
Life Cycle Assessment	
AT07	Sonnenhaus - concrete + TICS + single furnace

Annex 57

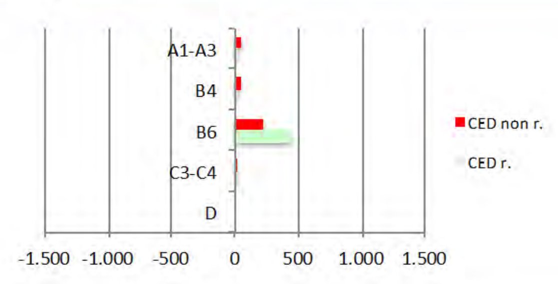
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,68E+00	3,20E+00	1,55E+01	4,48E-01	0,00E+00
CED non r.	MJ/m²a	5,38E+01	4,69E+01	2,22E+02	1,02E+00	0,00E+00
CED r.	MJ/m²a	1,76E+01	1,09E+01	4,47E+02	5,89E-02	0,00E+00
CED complete	MJ/m²a	7,14E+01	5,78E+01	6,69E+02	1,08E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

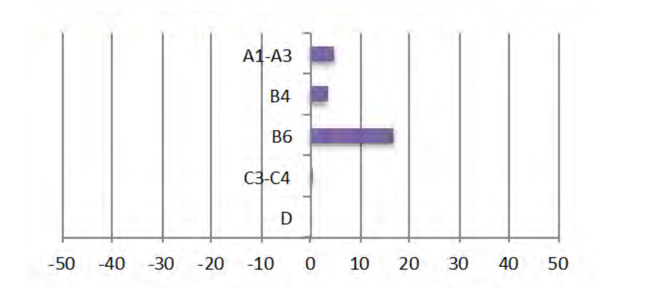
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

Life Cycle Assessment		Annex 57
AT07	passive house - concrete + TICS + pellet heating	

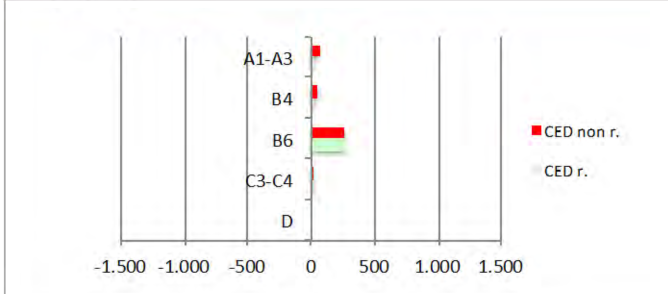
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,95E+00	3,48E+00	1,69E+01	4,86E-01	0,00E+00
CED non r.	MJ/m²a	5,83E+01	5,20E+01	2,62E+02	9,85E-01	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,15E+01	2,68E+02	5,54E-02	0,00E+00
CED complete	MJ/m²a	7,83E+01	6,35E+01	5,30E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

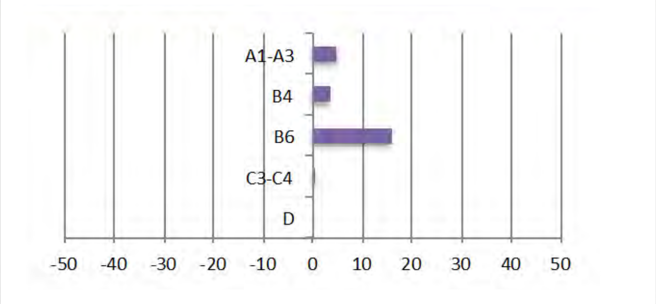
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

Life Cycle Assessment		Annex 57
AT07	passive house - concrete + TICS + heat pump	

Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,95E+00	3,48E+00	1,57E+01	4,86E-01	0,00E+00
CED non r.	MJ/m²a	5,83E+01	5,20E+01	2,26E+02	9,85E-01	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,15E+01	8,72E+01	5,54E-02	0,00E+00
CED complete	MJ/m²a	7,83E+01	6,35E+01	3,14E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



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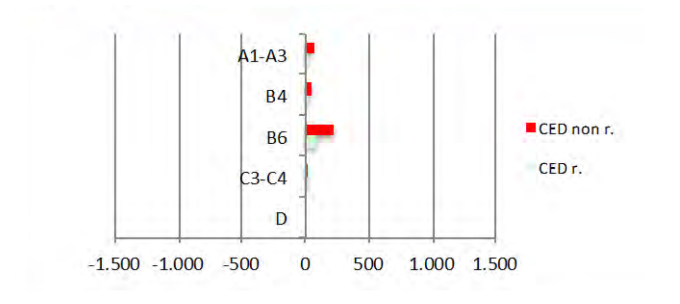


Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

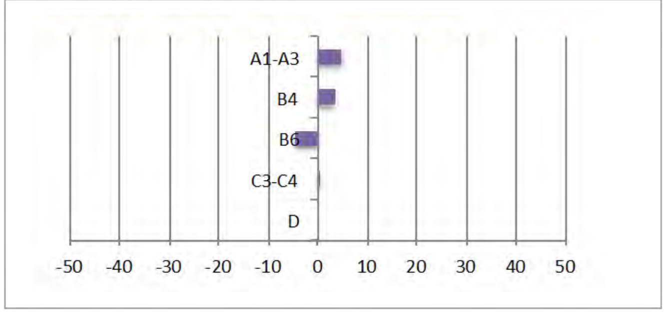
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR CONCRETE

Life Cycle Assessment		Annex 57
AT07	plus-energy house - concrete + TICS	

Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,95E+00	3,48E+00	-4,46E+00	4,86E-01	0,00E+00
CED non r.	MJ/m²a	5,83E+01	5,20E+01	-7,59E+01	9,85E-01	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,15E+01	-2,47E+01	5,54E-02	0,00E+00
CED complete	MJ/m²a	7,83E+01	6,35E+01	-1,01E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



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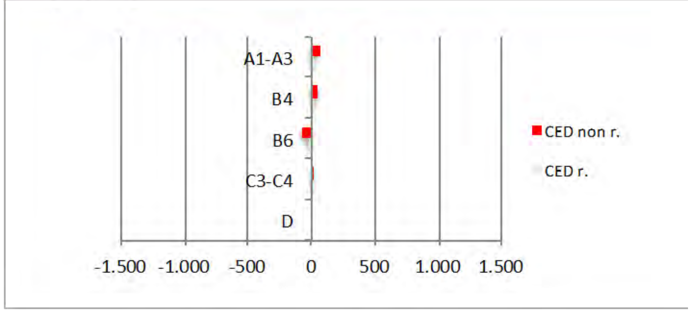


Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

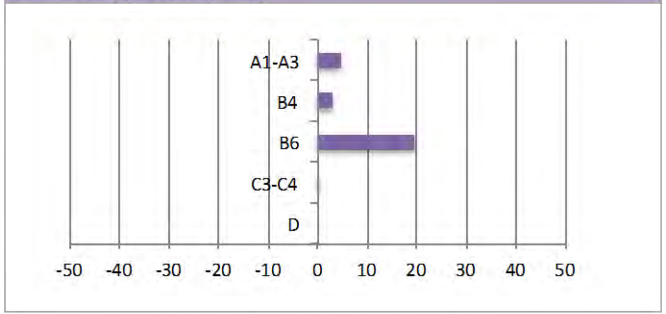
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment	
AT07	low-energy house-wood-chip concrete+TICS wood fiber+pellet heating

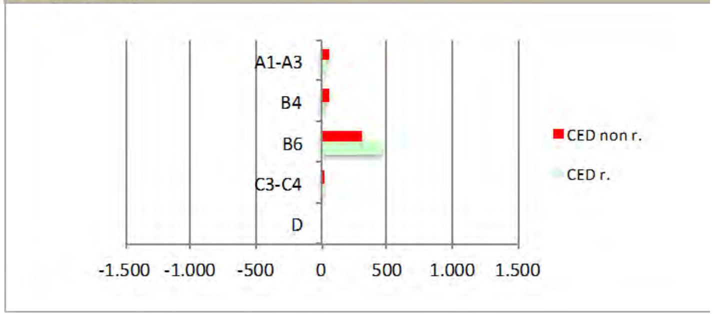
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,59E+00	3,10E+00	1,96E+01	3,59E-01	0,00E+00
CED non r.	MJ/m²a	5,23E+01	4,75E+01	3,11E+02	9,84E-01	0,00E+00
CED r.	MJ/m²a	3,12E+01	2,05E+01	4,53E+02	5,25E-02	0,00E+00
CED complete	MJ/m²a	8,35E+01	6,80E+01	7,64E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

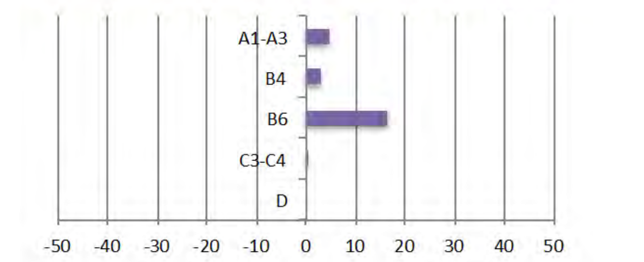
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		57 Annex 57
AT07	low-energy house - wood-chip concrete+TICS wood fiber+heat pump	

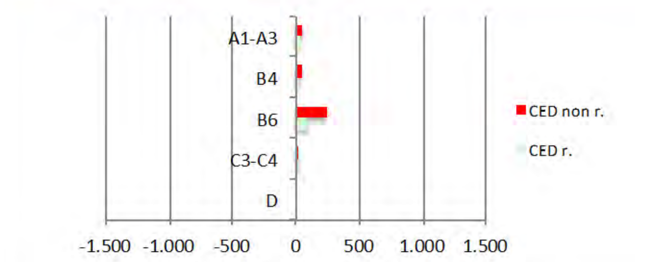
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,59E+00	3,10E+00	1,65E+01	3,59E-01	0,00E+00
CED non r.	MJ/m²a	5,23E+01	4,75E+01	2,37E+02	9,84E-01	0,00E+00
CED r.	MJ/m²a	3,12E+01	2,05E+01	9,21E+01	5,25E-02	0,00E+00
CED complete	MJ/m²a	8,35E+01	6,80E+01	3,29E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

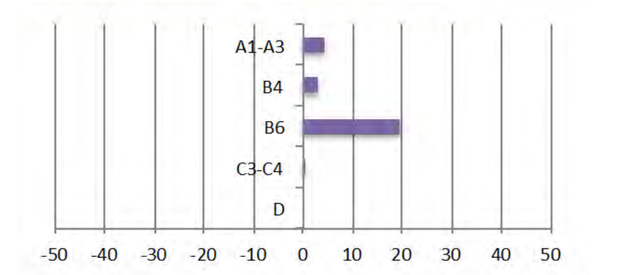
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	low-energy house - wood-chip concrete + TICS EPS + pellet heating	

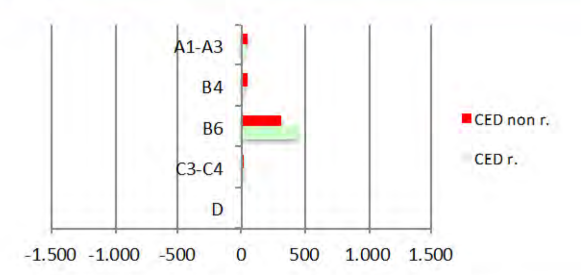
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,07E+00	1,95E+01	4,40E-01	0,00E+00
CED non r.	MJ/m²a	5,16E+01	4,60E+01	3,11E+02	9,75E-01	0,00E+00
CED r.	MJ/m²a	2,65E+01	1,10E+01	4,50E+02	5,24E-02	0,00E+00
CED complete	MJ/m²a	7,80E+01	5,70E+01	7,60E+02	1,03E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

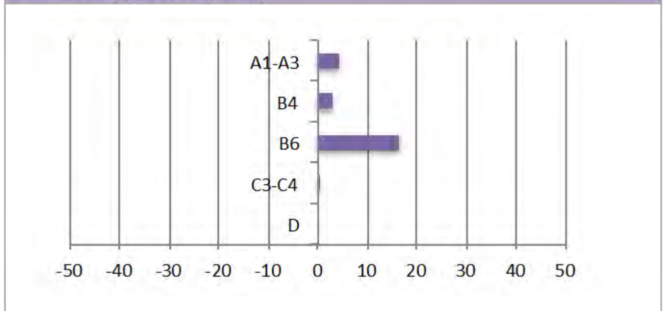
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	low-energy house - wood-chip concrete + TICS EPS + heat pump	

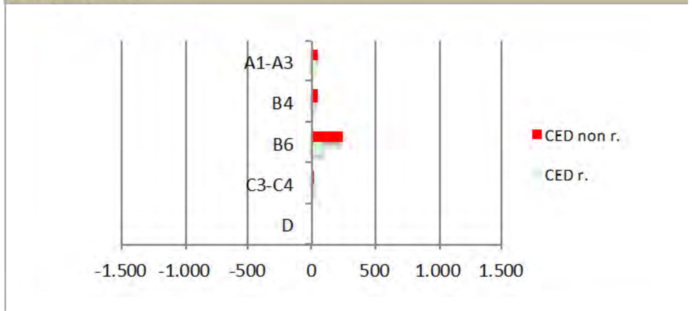
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,07E+00	1,65E+01	4,40E-01	0,00E+00
CED non r.	MJ/m²a	5,16E+01	4,60E+01	2,37E+02	9,75E-01	0,00E+00
CED r.	MJ/m²a	2,65E+01	1,10E+01	9,21E+01	5,24E-02	0,00E+00
CED complete	MJ/m²a	7,80E+01	5,70E+01	3,29E+02	1,03E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

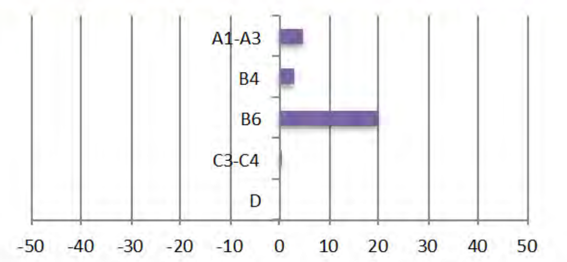
Life Cycle Assessment

AT07 | **low-energy house - wood-chip concrete + pellet heating**

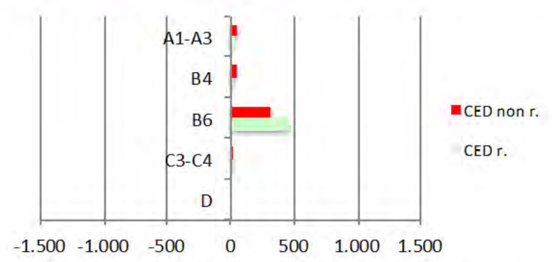
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,68E+00	2,77E+00	1,99E+01	4,52E-01	0,00E+00
CED non r.	MJ/m²a	5,54E+01	4,20E+01	3,17E+02	1,11E+00	0,00E+00
CED r.	MJ/m²a	2,70E+01	1,12E+01	4,66E+02	5,74E-02	0,00E+00
CED complete	MJ/m²a	8,24E+01	5,32E+01	7,83E+02	1,16E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

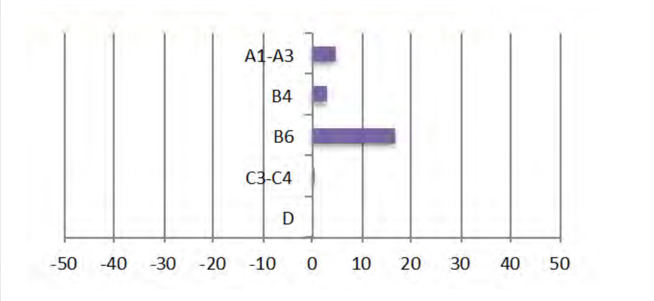
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	low-energy house - wood-chip concrete + heat pump	

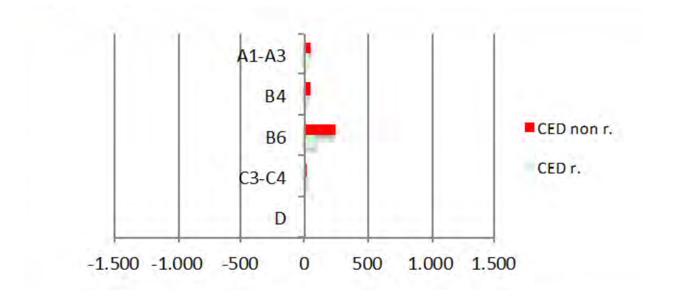
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,68E+00	2,77E+00	1,66E+01	4,52E-01	0,00E+00
CED non r.	MJ/m²a	5,54E+01	4,20E+01	2,39E+02	1,11E+00	0,00E+00
CED r.	MJ/m²a	2,70E+01	1,12E+01	9,29E+01	5,74E-02	0,00E+00
CED complete	MJ/m²a	8,24E+01	5,32E+01	3,32E+02	1,16E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

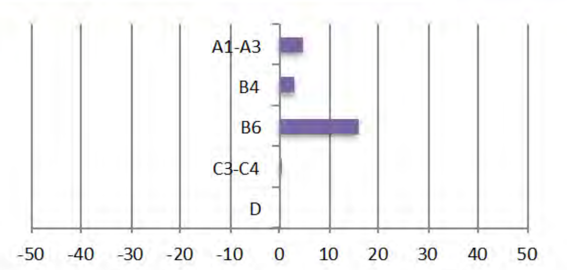
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	solar house - wood-chip concrete + TICS wood fiber + single furnace	

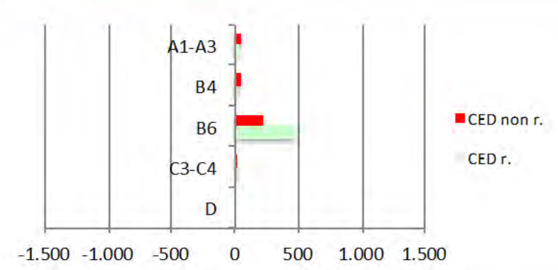
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,59E+00	3,10E+00	1,58E+01	3,59E-01	0,00E+00
CED non r.	MJ/m²a	5,23E+01	4,75E+01	2,26E+02	9,84E-01	0,00E+00
CED r.	MJ/m²a	3,12E+01	2,05E+01	4,77E+02	5,25E-02	0,00E+00
CED complete	MJ/m²a	8,35E+01	6,80E+01	7,02E+02	1,04E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

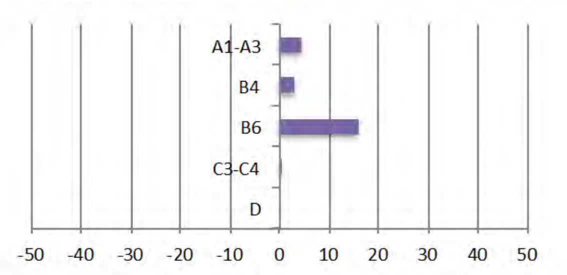
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	solar house - wood-chip concrete + TICS EPS + single furnace	

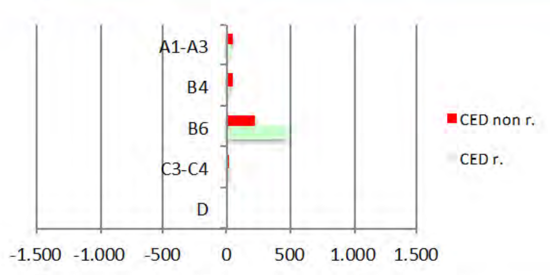
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,07E+00	1,58E+01	4,40E-01	0,00E+00
CED non r.	MJ/m²a	5,16E+01	4,60E+01	2,26E+02	9,75E-01	0,00E+00
CED r.	MJ/m²a	2,65E+01	1,10E+01	4,77E+02	5,24E-02	0,00E+00
CED complete	MJ/m²a	7,80E+01	5,70E+01	7,02E+02	1,03E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

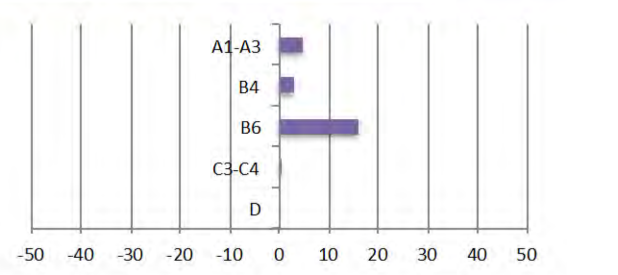
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	solar house - wood-chip concrete + single furnace	

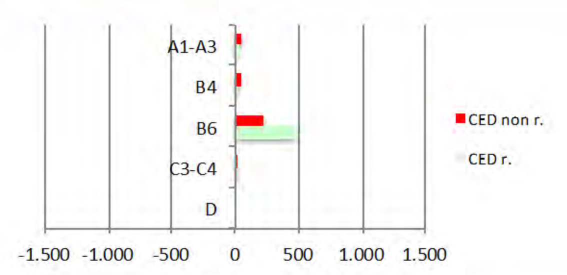
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,68E+00	2,77E+00	1,59E+01	4,52E-01	0,00E+00
CED non r.	MJ/m²a	5,54E+01	4,20E+01	2,28E+02	1,11E+00	0,00E+00
CED r.	MJ/m²a	2,70E+01	1,12E+01	4,81E+02	5,74E-02	0,00E+00
CED complete	MJ/m²a	8,24E+01	5,32E+01	7,09E+02	1,16E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

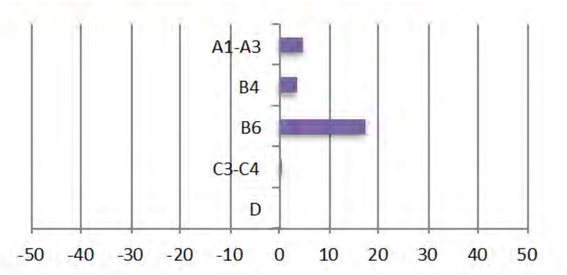
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment	
AT07	passive house - wood-chip concrete + TICS EPS + pellet heating

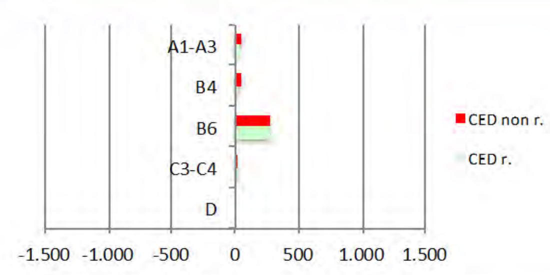
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,70E+00	3,37E+00	1,73E+01	4,82E-01	0,00E+00
CED non r.	MJ/m²a	5,56E+01	5,12E+01	2,69E+02	9,15E-01	0,00E+00
CED r.	MJ/m²a	2,87E+01	1,14E+01	2,80E+02	4,76E-02	0,00E+00
CED complete	MJ/m²a	8,43E+01	6,26E+01	5,49E+02	9,62E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

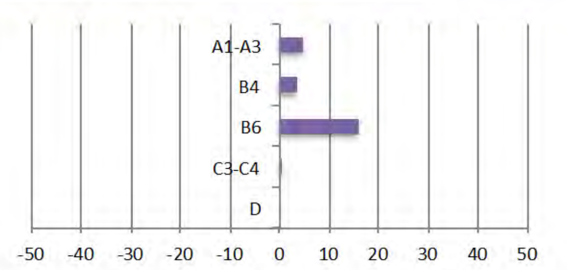
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	passive house - wood-chip concrete + TICS 26cm + heat pump	

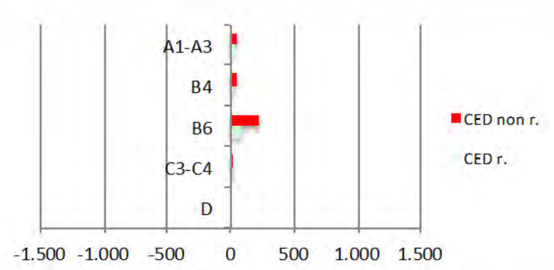
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,70E+00	3,37E+00	1,57E+01	4,82E-01	0,00E+00
CED non r.	MJ/m²a	5,56E+01	5,12E+01	2,27E+02	9,15E-01	0,00E+00
CED r.	MJ/m²a	2,87E+01	1,14E+01	8,75E+01	4,76E-02	0,00E+00
CED complete	MJ/m²a	8,43E+01	6,26E+01	3,14E+02	9,62E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

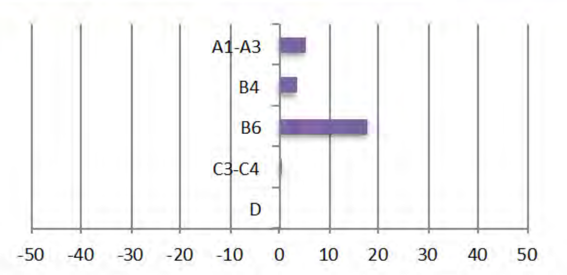
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	passive house - wood-chip concrete + TICS EPS + pellet heating	

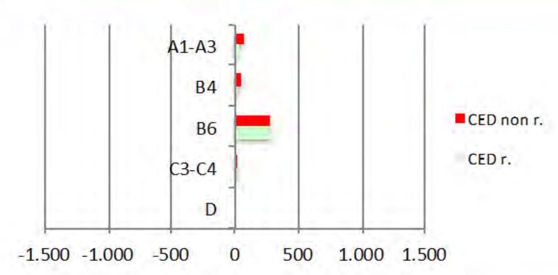
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,00E+00	3,28E+00	1,77E+01	5,07E-01	0,00E+00
CED non r.	MJ/m²a	6,20E+01	5,20E+01	2,75E+02	9,30E-01	0,00E+00
CED r.	MJ/m²a	2,94E+01	1,16E+01	2,90E+02	4,84E-02	0,00E+00
CED complete	MJ/m²a	9,14E+01	6,36E+01	5,65E+02	9,78E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

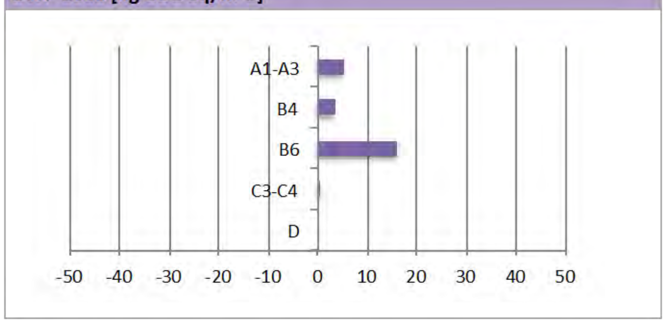
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	passive house - wood-chip concrete + TICS 11cm + heat pump	

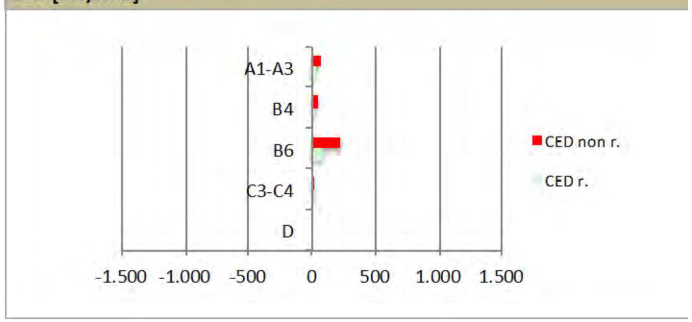
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,00E+00	3,28E+00	1,60E+01	5,07E-01	0,00E+00
CED non r.	MJ/m²a	6,21E+01	5,20E+01	2,30E+02	9,30E-01	0,00E+00
CED r.	MJ/m²a	2,94E+01	1,16E+01	8,89E+01	4,84E-02	0,00E+00
CED complete	MJ/m²a	9,14E+01	6,36E+01	3,19E+02	9,79E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

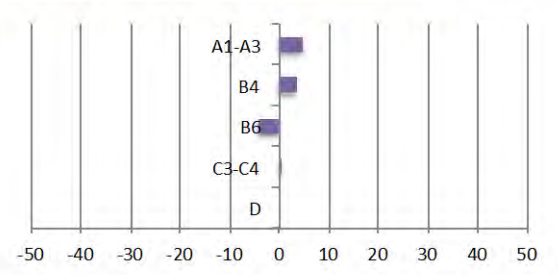
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

Life Cycle Assessment		Annex 57
AT07	plus-energy house - wood-chip concrete + TICS 26cm + heat pump	

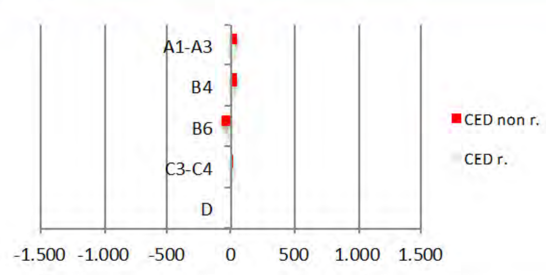
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,70E+00	3,37E+00	-4,14E+00	4,82E-01	0,00E+00
CED non r.	MJ/m²a	5,56E+01	5,12E+01	-7,15E+01	9,15E-01	0,00E+00
CED r.	MJ/m²a	2,87E+01	1,14E+01	-2,26E+01	4,76E-02	0,00E+00
CED complete	MJ/m²a	8,43E+01	6,26E+01	-9,41E+01	9,62E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD-Composite

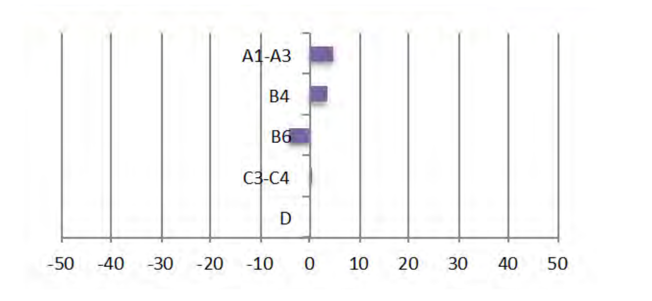
Life Cycle Assessment

AT07 | **plus-energy house - wood-chip concrete + TICS 11cm + heat pump**

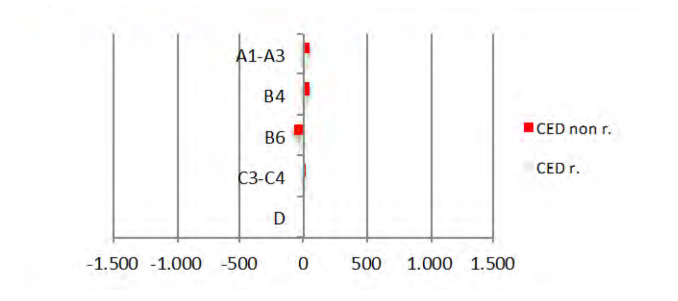
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,78E+00	3,42E+00	-4,20E+00	4,90E-01	0,00E+00
CED non r.	MJ/m²a	5,65E+01	5,21E+01	-7,27E+01	9,30E-01	0,00E+00
CED r.	MJ/m²a	2,92E+01	1,16E+01	-2,30E+01	4,84E-02	0,00E+00
CED complete	MJ/m²a	8,57E+01	6,36E+01	-9,57E+01	9,78E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

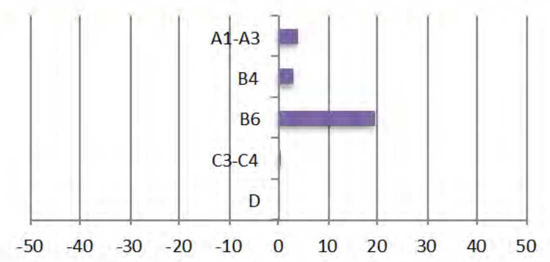
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	low-energy house - wooden frame + mineral wool + pellet heating	

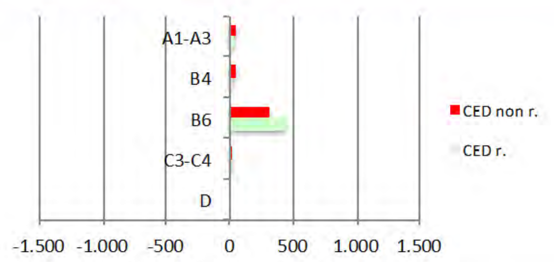
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,74E+00	2,99E+00	1,92E+01	3,47E-01	0,00E+00
CED non r.	MJ/m²a	4,99E+01	4,84E+01	3,06E+02	8,59E-01	0,00E+00
CED r.	MJ/m²a	3,65E+01	2,16E+01	4,42E+02	4,26E-02	0,00E+00
CED complete	MJ/m²a	8,64E+01	7,00E+01	7,47E+02	9,02E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

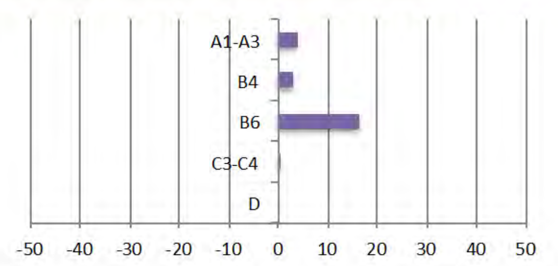
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	low-energy house - wooden frame + mineral wool + heat pump	

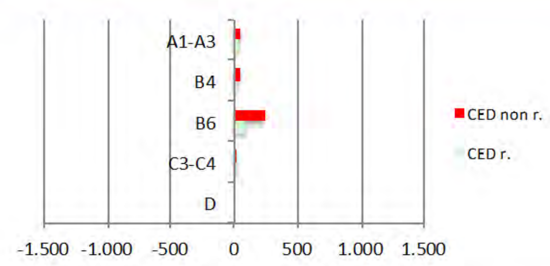
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,74E+00	2,99E+00	1,63E+01	3,47E-01	0,00E+00
CED non r.	MJ/m²a	4,99E+01	4,84E+01	2,34E+02	8,59E-01	0,00E+00
CED r.	MJ/m²a	3,65E+01	2,16E+01	9,09E+01	4,26E-02	0,00E+00
CED complete	MJ/m²a	8,64E+01	7,00E+01	3,24E+02	9,02E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

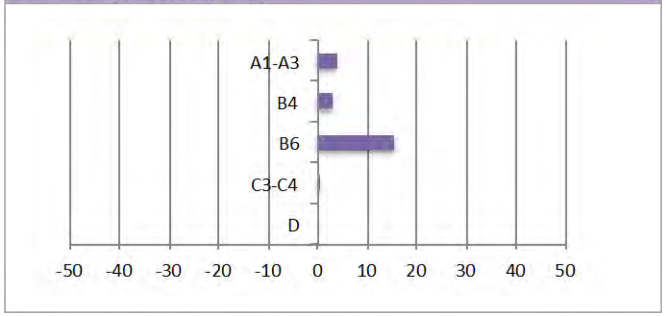
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	solar house - wooden frame + mineral wool + single furnace	

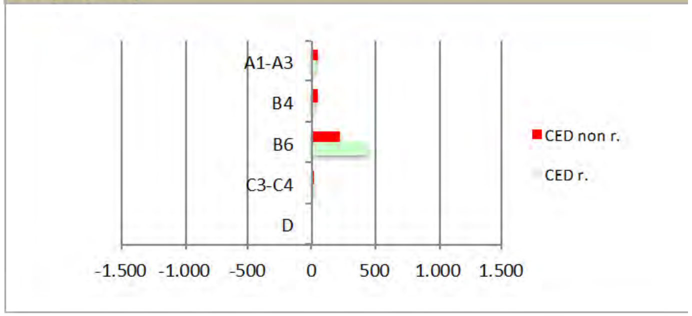
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,74E+00	2,99E+00	1,54E+01	3,47E-01	0,00E+00
CED non r.	MJ/m²a	4,99E+01	4,84E+01	2,21E+02	8,59E-01	0,00E+00
CED r.	MJ/m²a	3,65E+01	2,16E+01	4,50E+02	4,26E-02	0,00E+00
CED complete	MJ/m²a	8,64E+01	7,00E+01	6,71E+02	9,02E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

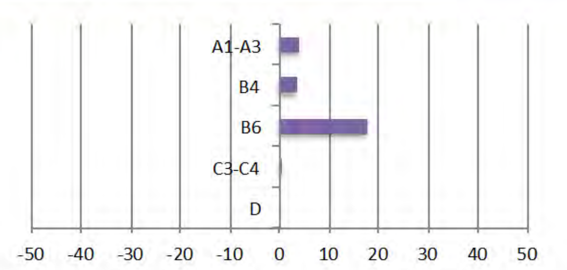
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	passive house - wooden frame + mineral wool + pellet heating	

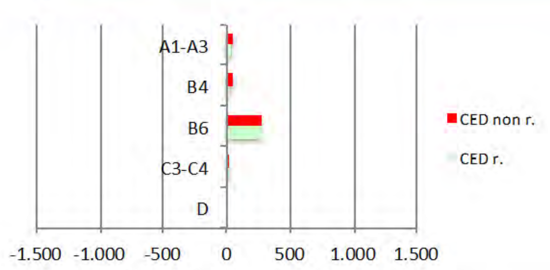
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,89E+00	3,33E+00	1,74E+01	3,63E-01	0,00E+00
CED non r.	MJ/m²a	5,33E+01	5,48E+01	2,70E+02	8,64E-01	0,00E+00
CED r.	MJ/m²a	4,04E+01	2,29E+01	2,76E+02	3,98E-02	0,00E+00
CED complete	MJ/m²a	9,36E+01	7,77E+01	5,46E+02	9,04E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

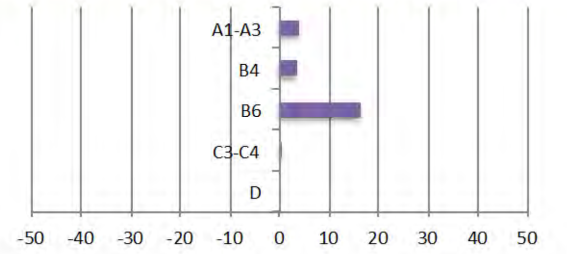
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	passive house - wooden frame + mineral wool + heat pump	

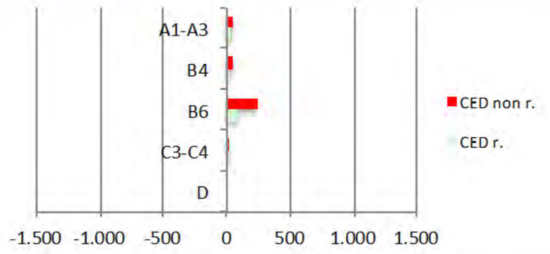
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,89E+00	3,33E+00	1,62E+01	3,63E-01	0,00E+00
CED non r.	MJ/m²a	5,33E+01	5,48E+01	2,33E+02	8,64E-01	0,00E+00
CED r.	MJ/m²a	4,04E+01	2,29E+01	8,99E+01	3,98E-02	0,00E+00
CED complete	MJ/m²a	9,36E+01	7,77E+01	3,23E+02	9,04E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

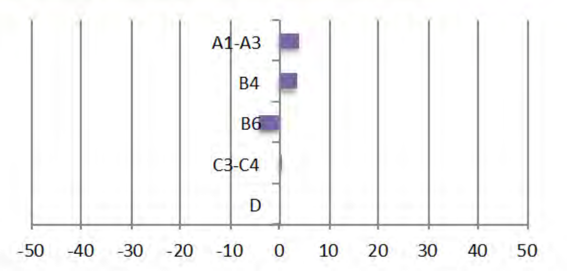
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD FRAME

Life Cycle Assessment		Annex 57
AT07	**plus-energy house - wooden frame + mineral wool insulation**	

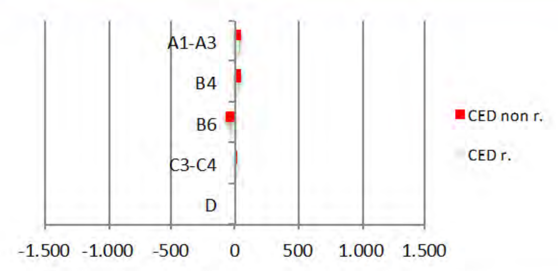
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3,89E+00	3,33E+00	-4,15E+00	3,63E-01	0,00E+00
CED non r.	MJ/m²a	5,33E+01	5,48E+01	-7,20E+01	8,64E-01	0,00E+00
CED r.	MJ/m²a	4,04E+01	2,29E+01	-2,23E+01	3,98E-02	0,00E+00
CED complete	MJ/m²a	9,36E+01	7,77E+01	-9,43E+01	9,04E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

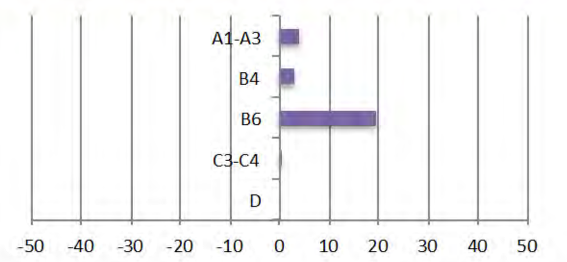
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		Annex 57
AT07	low-energy house - solid wood + mineral wool + pellet heating	

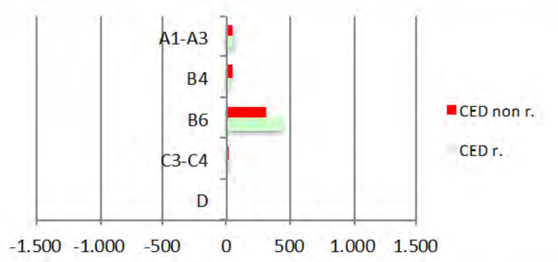
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,01E+00	3,00E+00	1,93E+01	3,52E-01	0,00E+00
CED non r.	MJ/m²a	5,48E+01	4,91E+01	3,08E+02	8,95E-01	0,00E+00
CED r.	MJ/m²a	5,73E+01	2,75E+01	4,45E+02	4,34E-02	0,00E+00
CED complete	MJ/m²a	1,12E+02	7,65E+01	7,53E+02	9,38E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

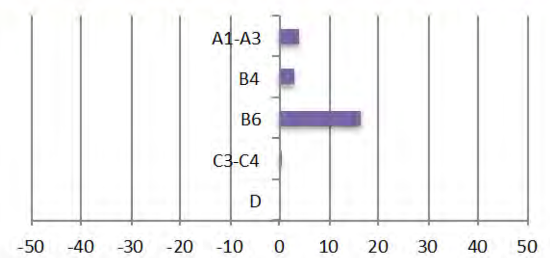
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		57 Annex 57
AT07	low-energy house - solid wood + mineral wool + heat pumpe	

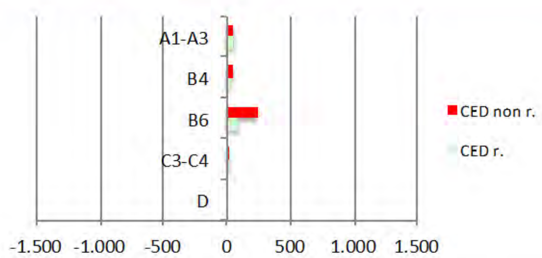
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,01E+00	3,00E+00	1,64E+01	3,52E-01	0,00E+00
CED non r.	MJ/m²a	5,48E+01	4,91E+01	2,35E+02	8,95E-01	0,00E+00
CED r.	MJ/m²a	5,73E+01	2,75E+01	9,15E+01	4,34E-02	0,00E+00
CED complete	MJ/m²a	1,12E+02	7,65E+01	3,27E+02	9,38E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

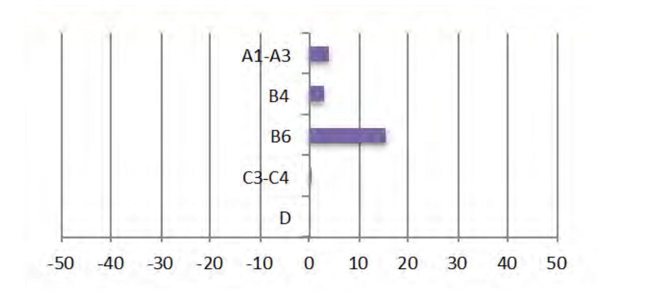
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		Annex 57
AT07	solar house - solid wood + mineral wool + single furnace	

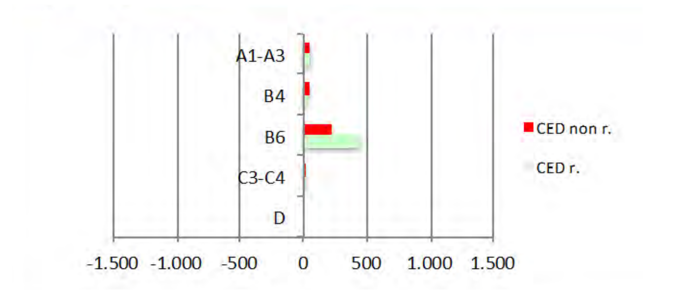
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,01E+00	3,00E+00	1,55E+01	3,52E-01	0,00E+00
CED non r.	MJ/m²a	5,48E+01	4,91E+01	2,23E+02	8,95E-01	0,00E+00
CED r.	MJ/m²a	5,73E+01	2,75E+01	4,53E+02	4,34E-02	0,00E+00
CED complete	MJ/m²a	1,12E+02	7,65E+01	6,76E+02	9,38E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

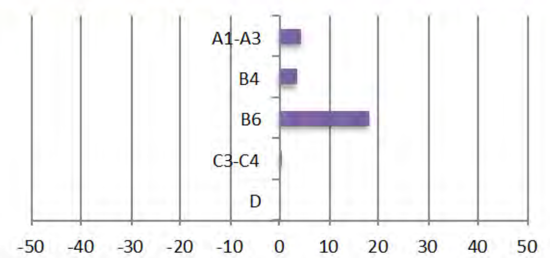
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		Annex 57
AT07	pasive house - solid wood + mineral wool + pellet heating	

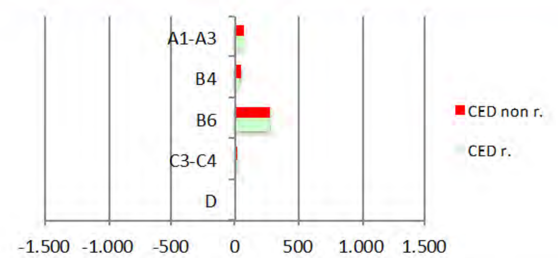
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,44E+00	1,79E+01	3,77E-01	0,00E+00
CED non r.	MJ/m²a	6,26E+01	5,73E+01	2,77E+02	9,29E-01	0,00E+00
CED r.	MJ/m²a	6,74E+01	2,99E+01	2,84E+02	4,17E-02	0,00E+00
CED complete	MJ/m²a	1,30E+02	8,72E+01	5,61E+02	9,70E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

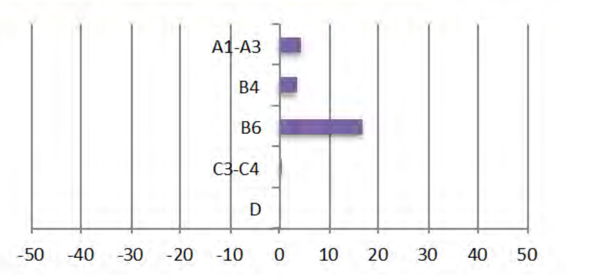
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		Annex 57
AT07	pasive house - solid wood + mineral wool + heat pumpe	

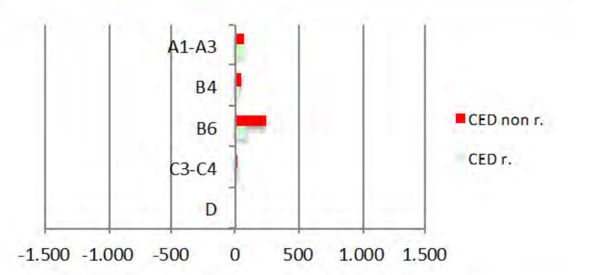
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,44E+00	1,66E+01	3,77E-01	0,00E+00
CED non r.	MJ/m²a	6,26E+01	5,73E+01	2,40E+02	9,29E-01	0,00E+00
CED r.	MJ/m²a	6,74E+01	2,99E+01	9,23E+01	4,17E-02	0,00E+00
CED complete	MJ/m²a	1,30E+02	8,72E+01	3,32E+02	9,70E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

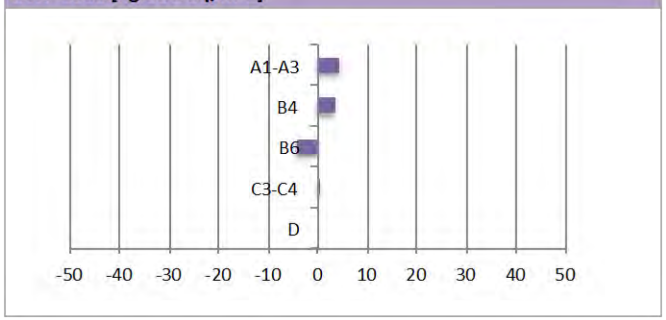
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR WOOD MASSIVE

Life Cycle Assessment		Annex 57
AT07	plus-energy house - solid wood + mineral wool insulation	

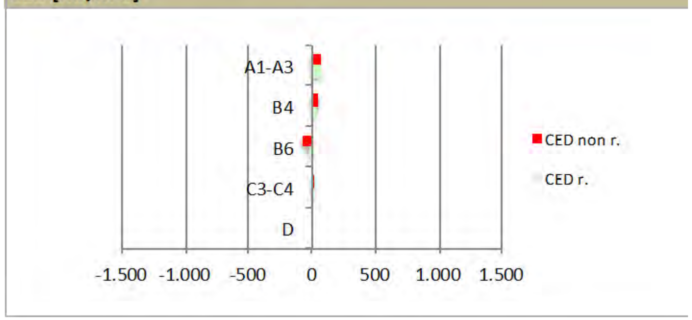
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,50E+00	3,44E+00	-4,26E+00	3,77E-01	0,00E+00
CED non r.	MJ/m²a	6,26E+01	5,73E+01	-7,40E+01	9,29E-01	0,00E+00
CED r.	MJ/m²a	6,74E+01	2,99E+01	-2,29E+01	4,17E-02	0,00E+00
CED complete	MJ/m²a	1,30E+02	8,72E+01	-9,69E+01	9,70E-01	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

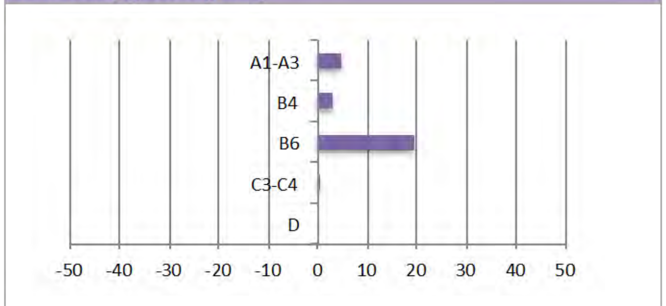
Life Cycle Assessment

AT07	low-energie house - brick + TICS + pellet heating

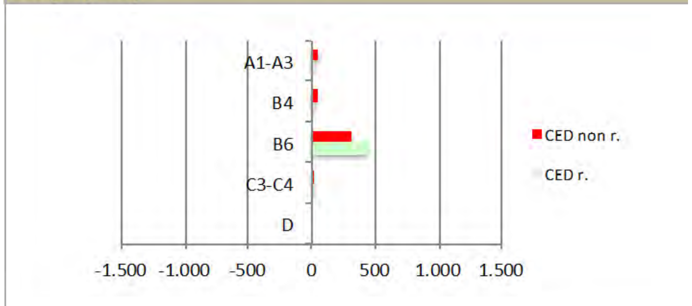
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,79E+00	3,05E+00	1,93E+01	4,32E-01	0,00E+00
CED non r.	MJ/m²a	5,53E+01	4,48E+01	3,06E+02	1,23E+00	0,00E+00
CED r.	MJ/m²a	1,81E+01	1,09E+01	4,43E+02	7,05E-02	0,00E+00
CED complete	MJ/m²a	7,34E+01	5,57E+01	7,50E+02	1,30E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

DOCUMENTATION REQUIREMENTS SINGLE FAMILY HOUSE - ÖKOVERGLEICHE

Annex 57

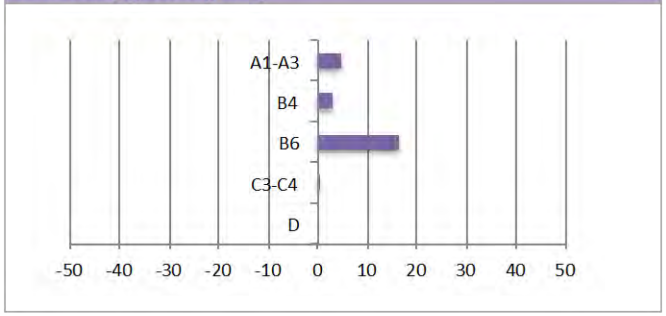
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment	
AT07	low-energie house - brick + TICS + heat pump

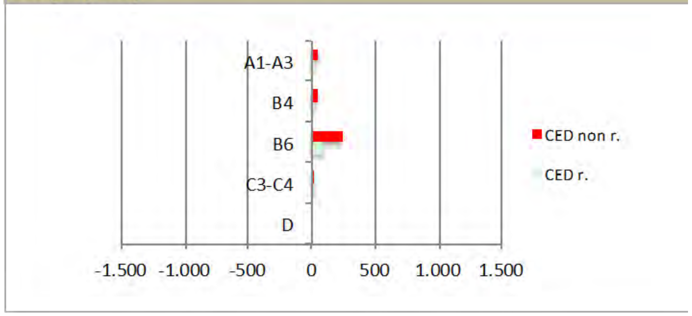
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,79E+00	3,05E+00	1,63E+01	4,32E-01	0,00E+00
CED non r.	MJ/m²a	5,53E+01	4,48E+01	2,34E+02	1,23E+00	0,00E+00
CED r.	MJ/m²a	1,81E+01	1,09E+01	9,11E+01	7,05E-02	0,00E+00
CED complete	MJ/m²a	7,34E+01	5,57E+01	3,25E+02	1,30E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

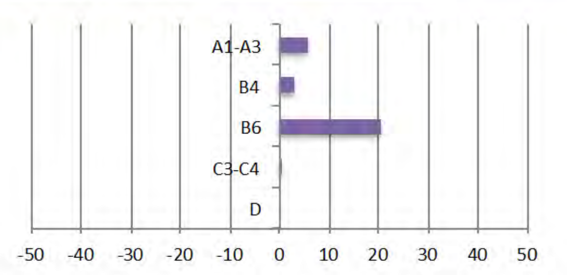
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	low-energie house - brick + pellet heating	

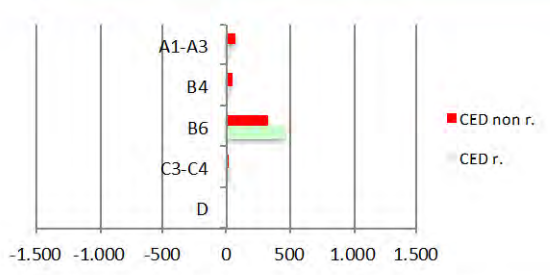
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,68E+00	2,98E+00	2,02E+01	4,06E-01	0,00E+00
CED non r.	MJ/m²a	6,30E+01	4,41E+01	3,22E+02	1,62E+00	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,17E+01	4,61E+02	9,27E-02	0,00E+00
CED complete	MJ/m²a	8,30E+01	5,58E+01	7,83E+02	1,72E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment

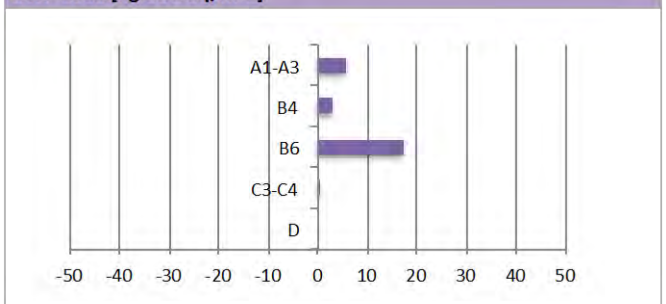
AT07 | **low-energie house - brick + heat pump**

Annex 57

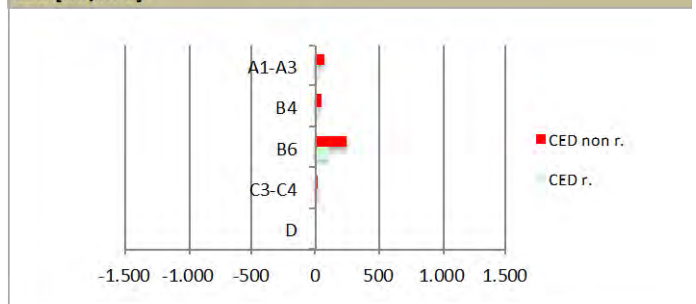
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,68E+00	2,98E+00	1,72E+01	4,06E-01	0,00E+00
CED non r.	MJ/m²a	6,30E+01	4,41E+01	2,47E+02	1,62E+00	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,17E+01	9,59E+01	9,27E-02	0,00E+00
CED complete	MJ/m²a	8,30E+01	5,58E+01	3,43E+02	1,72E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

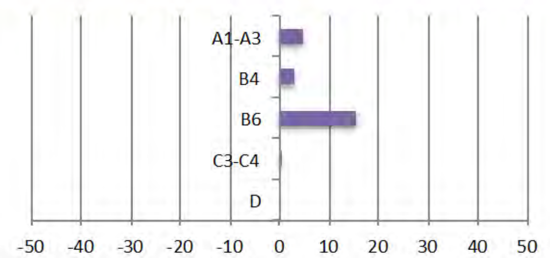
Life Cycle Assessment	
AT07	passive house - brick + TICS + pellet heating

Annex 57

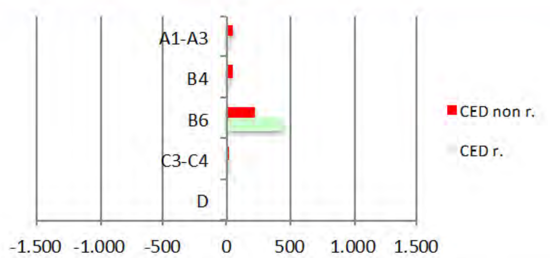
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	4,79E+00	3,05E+00	1,55E+01	4,32E-01	0,00E+00
CED non r.	MJ/m²a	5,53E+01	4,48E+01	2,22E+02	1,23E+00	0,00E+00
CED r.	MJ/m²a	1,81E+01	1,09E+01	4,51E+02	7,05E-02	0,00E+00
CED complete	MJ/m²a	7,34E+01	5,57E+01	6,73E+02	1,30E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

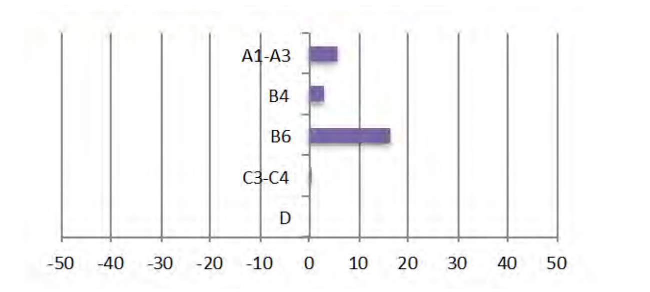
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment	
AT07	solar house - brick + single furance

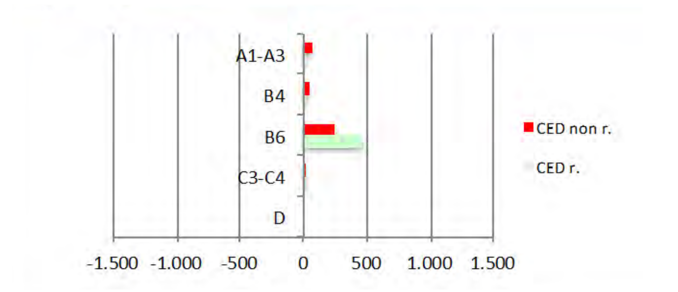
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,68E+00	2,98E+00	1,63E+01	4,06E-01	0,00E+00
CED non r.	MJ/m²a	6,30E+01	4,41E+01	2,34E+02	1,62E+00	0,00E+00
CED r.	MJ/m²a	2,00E+01	1,17E+01	4,68E+02	9,27E-02	0,00E+00
CED complete	MJ/m²a	8,30E+01	5,58E+01	7,02E+02	1,72E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

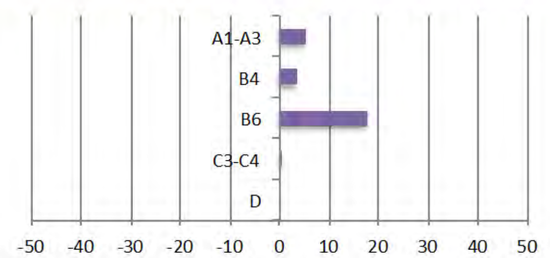
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	passive house - brick + TICS + pellet heating	

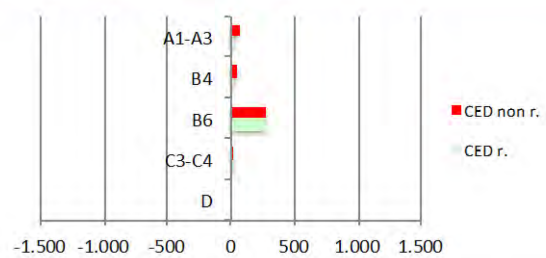
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,09E+00	3,27E+00	1,75E+01	4,51E-01	0,00E+00
CED non r.	MJ/m²a	5,99E+01	4,89E+01	2,70E+02	1,20E+00	0,00E+00
CED r.	MJ/m²a	2,08E+01	1,16E+01	2,77E+02	6,77E-02	0,00E+00
CED complete	MJ/m²a	8,07E+01	6,05E+01	5,47E+02	1,27E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

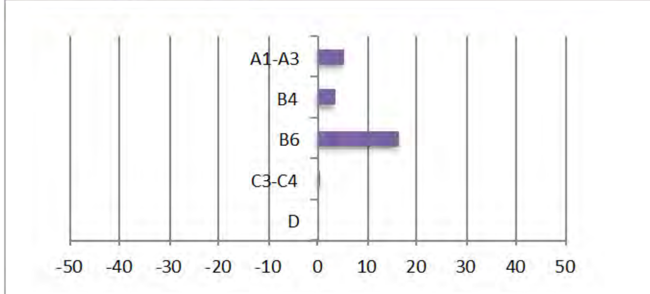
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	passive house - brick + TICS + heat pump	

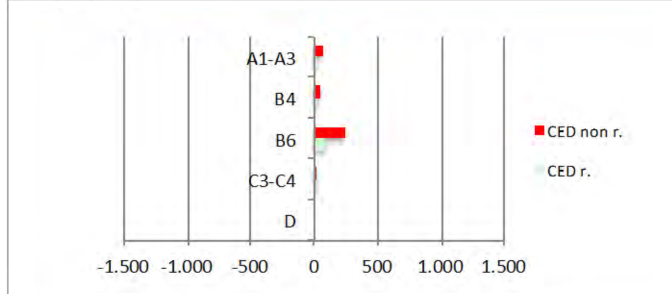
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,09E+00	3,27E+00	1,62E+01	4,51E-01	0,00E+00
CED non r.	MJ/m²a	5,99E+01	4,89E+01	2,34E+02	1,20E+00	0,00E+00
CED r.	MJ/m²a	2,08E+01	1,16E+01	9,00E+01	6,77E-02	0,00E+00
CED complete	MJ/m²a	8,07E+01	6,05E+01	3,24E+02	1,27E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

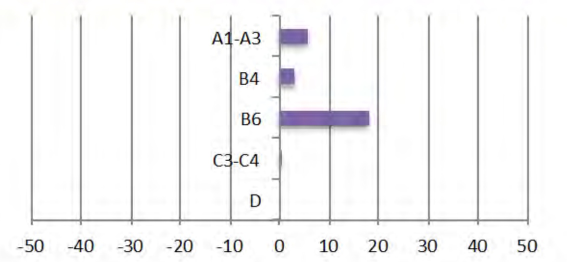
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	passive house - brick + pellet heating	

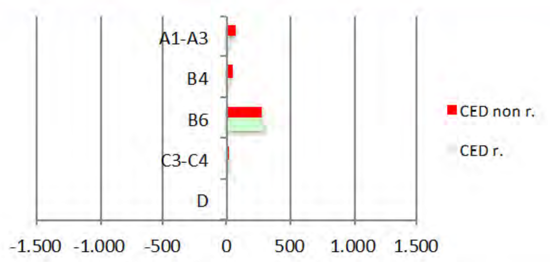
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,81E+00	3,16E+00	1,79E+01	4,28E-01	0,00E+00
CED non r.	MJ/m²a	6,60E+01	4,80E+01	2,78E+02	1,67E+00	0,00E+00
CED r.	MJ/m²a	2,20E+01	1,20E+01	2,97E+02	9,15E-02	0,00E+00
CED complete	MJ/m²a	8,80E+01	6,00E+01	5,75E+02	1,76E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

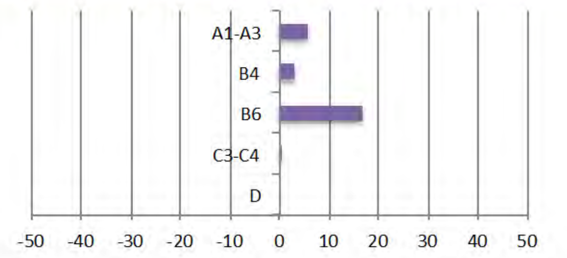
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	passive house - brick + heat pump	

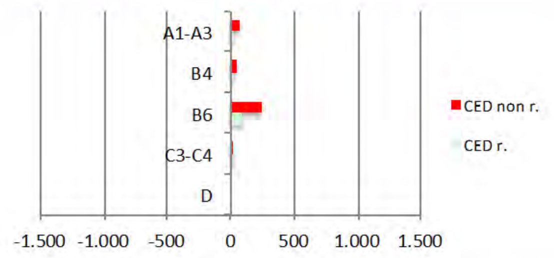
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,81E+00	3,16E+00	1,67E+01	4,28E-01	0,00E+00
CED non r.	MJ/m²a	6,60E+01	4,80E+01	2,40E+02	1,67E+00	0,00E+00
CED r.	MJ/m²a	2,20E+01	1,20E+01	9,29E+01	9,15E-02	0,00E+00
CED complete	MJ/m²a	8,80E+01	6,00E+01	3,33E+02	1,76E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

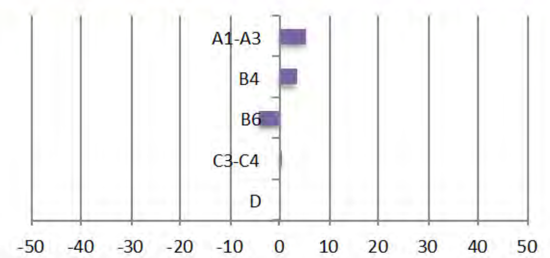
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	plus-energie house - brick + TICS	

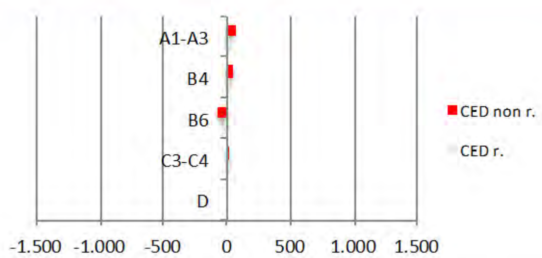
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,09E+00	3,27E+00	-4,15E+00	4,51E-01	0,00E+00
CED non r.	MJ/m²a	5,99E+01	4,89E+01	-7,21E+01	1,20E+00	0,00E+00
CED r.	MJ/m²a	2,08E+01	1,16E+01	-2,23E+01	6,77E-02	0,00E+00
CED complete	MJ/m²a	8,07E+01	6,05E+01	-9,44E+01	1,27E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

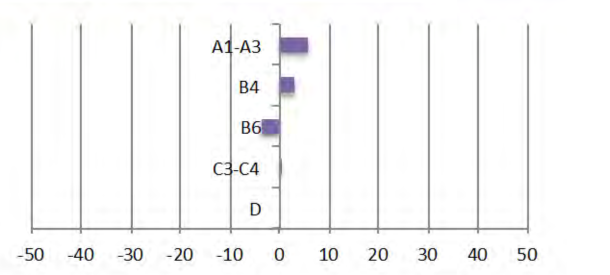
MINIMUM DOCUMENTATION REQUIREMENTS – RESULTS FOR BRICK

Life Cycle Assessment		Annex 57
AT07	plus-energie house - brick	

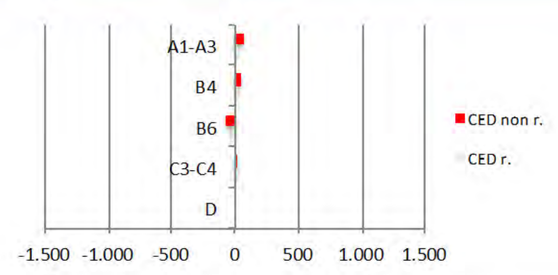
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5,81E+00	3,16E+00	-3,69E+00	4,28E-01	0,00E+00
CED non r.	MJ/m²a	6,60E+01	4,80E+01	-6,52E+01	1,67E+00	0,00E+00
CED r.	MJ/m²a	2,20E+01	1,20E+01	-1,96E+01	9,15E-02	0,00E+00
CED complete	MJ/m²a	8,80E+01	6,00E+01	-8,49E+01	1,76E+00	0,00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Ökovergleiche
Carried out by: TUG
Database: EcoInvent V2.2

Source: TU Graz

Switzerland

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH1

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building (renovated school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school A has a total env. impact of 25'000 eco-points/m^{2}a, primary energy demand (non renew.) of 420 MJ/m^{2}a and a GWP of 11 kg CO_2/m^{2}a. The building meets the target values for refurbished schools regarding global warming potential but not for primary energy demand (non renew). For all indicators the operation phase is dominating the results.

The roof, windows, flooring and the infrastructure cause the main impact within the construction stage (for CED and GWP) whereas the room heating (from electric heat pump equipped with a borehole heat exchanger) causes the largest impact in the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school A is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School

Size: 2968 m^2 gross floor area, 2'606 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed 2015 (originally constructed in 1907)

Source: Stadt Zürich, Amt für Hochbauten, Foto: Beat Bühler

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr nonrenewable

School A

The school building A was originally built in 1907 and renovated in the 1970ties. Within the present renewal the façade, all technical installations and the interior structure will be replaced and refurbished. The refurbishment is combined with operational optimizations: the day care capability is extended from 80 to 100 positions.

The heat and hot water demand is covered by an electric heat pump equipped with a borehole heat exchanger while the heat distribution works with radiators.

CHARACTERISTIC FACTORS OPERATION

Floor area	2’968 m^2
Energy reference area	2‘606 m^2
Energy demand room heating	238 MJ/m^2a
Energy demand hot water	10 MJm^2a
Energy demand electrical power	38 MJ/m^2a
- Energy demand ventilation:	0 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.74 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL A, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school A in Zurich, referring to 1 m^2 energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^{2}a	UBP/m^2				MJ/m^{2}a	MJ/m^2				kg CO_2/m^{2}a	kg CO_2/m^2			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0.06	3	3	-	-	0.0	0.0	0	-	-	0.00	0.00	0.00	-	-
	backfill	0	0	0	-	-	0.0	0.0	0.0	-	-	0.00	0.00	0.00	-	-
	fundament	18	1'101	823	-	279	0.3	15.1	14.6	-	0.5	0.02	1.06	0.72	-	0.34
	ceiling	92	5'526	4'857	-	669	0.6	34.0	29.1	-	4.9	0.06	3.78	3.51	-	0.27
	roof	385	23'089	11'345	5'672	6'072	4.8	287.3	187.4	93.7	6.1	0.30	18.02	9.99	5.00	3.03
	pillars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls basement	23	1'375	1'248	-	127	0.2	14.6	13.8	-	0.9	0.03	1.87	1.83	-	0.04
	outer walls upper floors	41	2'445	2'319	-	127	0.6	35.1	34.3	-	0.8	0.06	3.47	3.44	-	0.03
	windows	764	45'866	18'959	18'959	7'948	8.5	510.4	252.6	252.6	5.2	0.56	33.73	15.55	15.55	2.63
	inner walls raw	95	5'722	4'980	-	742	0.9	52.3	47.0	-	5.4	0.08	5.06	4.77	-	0.28
	separation walls/inner doors	176	10'541	4'424	4'424	1'693	1.6	98.0	47.8	47.8	2.3	0.10	5.87	2.67	2.67	0.52
	flooring	885	53'125	20'734	20'734	11'657	7.7	463.8	227.5	227.5	8.7	0.53	32.07	14.22	14.22	3.63
	wall cover	210	12'628	5'358	5'358	1'911	1.9	114.6	54.5	54.5	5.7	0.18	10.76	4.64	4.64	1.47
	ceiling cover	575	34'489	16'509	16'509	1'470	4.0	242.1	118.6	118.6	4.9	0.26	15.60	7.19	7.19	1.23
	infrastructure	3'261	195'655	95'908	92'658	7'089	24.4	1'466.5	765.0	688.5	13.0	1.49	89.35	41.76	37.66	9.93
	sum building	**6'526**	**391'565**	**187'467**	**164'315**	**39'783**	**55.6**	**3'334.0**	**1'792.3**	**1'483.2**	**58.4**	**3.68**	**220.63**	**110.30**	**86.93**	**23.41**
Operation	room heating	9'489	569'339				196.0	11'757.1				3.07	183.95			
	hot water	631	37'878				13.2	790.4				0.21	12.37			
	ventilation	-	-				-	-				-	-			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	14'876	**892'583**				309.2	**18'554.3**				4.84	**290.29**			
Building induced mobility	**sum mobility**	**3'224**	**193'430**				**49.6**	**2'975.4**				**2.65**	**158.85**			
sum total	**construction, operation und building induced mobility**	**24'626**					**414.4**					**11.16**				
target							**350.0**					**13.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school A per m² energy reference area and 60 years lifespan.

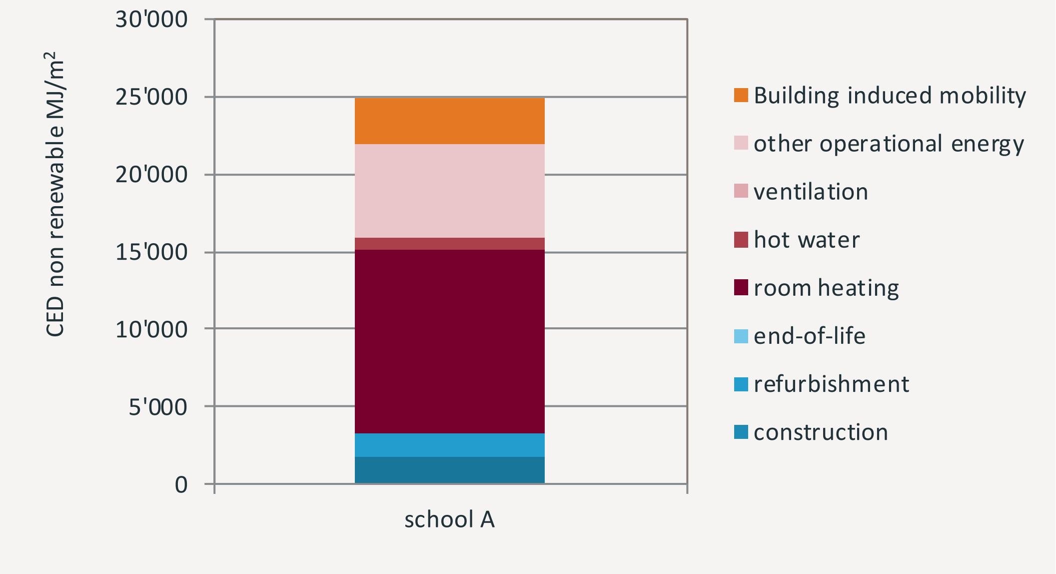


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school A

Total construction (construction, renewal and deconstruction): The total construction has a share of 13 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 54 % to this. The main impacts come from the floor and ceiling covers, windows, the roof, as well as the infrastructure. The renewal phase contributes to 44% to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 2 %.
The Swiss reference value regarding primary energy demand (non renew.) is not exceeded.

Operation: With 75 % the total operation has the main impact on the primary energy demand. The room heating has a share of 63% and the residual electricity demand causes 32% of the impacts. The Swiss reference level for refurbished school buildings is exceeded by 34 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility lies 17 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished building is about 18 % above than the target value. The main impact is caused by the operation phase.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School A, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	Gross floor area 2968.06 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 2’606 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete/brick construction)
Thermal insulation	Exterior insulation of walls, roof insulation
Ventilation system	Ventilation of sanitary modules
Heating and cooling system	Heating: Bore hole heat exchanger, heat pump, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 0 MJ/m^{2}a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^{2}a (per energy reference area)
Final energy demand for heating and hot water	Room heating 238 MJ/m^{2}a (per energy reference area) Hot water 10 MJ/m^{2}a (per energy reference area)
Final energy demand for cooling	0 MJ/m^{2}a
Benchmark	Minergie standard
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Building pit Foundation plate Ceilings Roof External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

DOCUMENTATION REQUIREMENTS SCHOOL A (III)

Annex 57

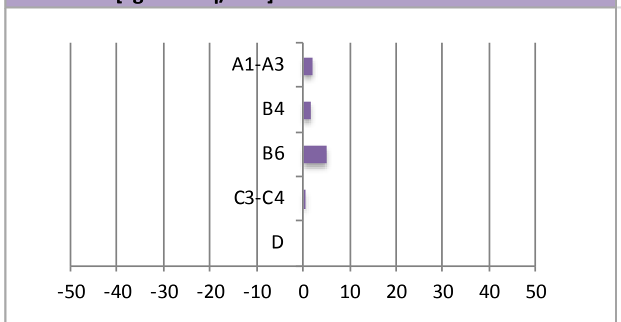
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH1	School A

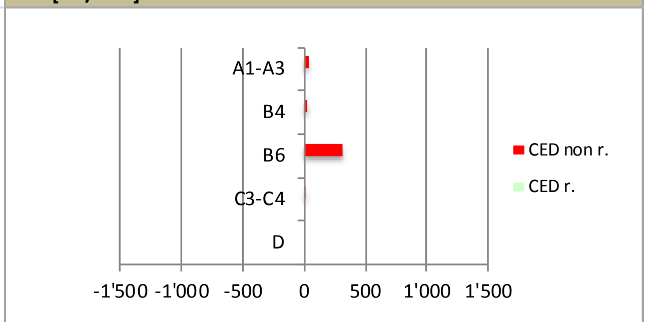
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	1.84E+00	1.45E+00	4.84E+00	3.90E-01	0.00E+00
CED non r.	MJ/m²a	2.99E+01	2.47E+01	3.09E+02	9.74E-01	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH2

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building (renovated school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school B has a total env. impact of 23’000 eco-points/m^{2}a, primary energy demand (non renew.) of 400 MJ/m^{2}a and a GWP of 19 kg CO_2/m^{2}a. The building does not meet the target values for refurbished schools regarding global warming potential nor for primary energy demand (non renew). For all indicators the operation phase is dominating the results.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school B is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School

Size: 2’419 m^2 gross floor area, 1’759 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed 2013 (originally constructed in 1877)

Source: Stadt Zürich, Foto: Baugeschichtliches Archiv, o.J.

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distribution, hot water generation as well as ventilation are considered.
The replacements of building materials and components during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

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School B

The school building B was originally built in 1877. Within the present renewal the facade (wall insulation), all technical installations and the interior structure will be replaced and refurbished. The building reaches the label Minergie. Windows are automatized for ventilation.
The heat and hot water demand is covered by district heat. The heat distribution works with radiators.

CHARACTERISTIC FACTORS OPERATION

Floor area	2’419 m²
Energy reference area	1‘759 m²
Energy demand room heating	208 MJ/m²a
Energy demand hot water	10 MJm²a
Energy demand electrical power	38 MJ/m²a
- Energy demand ventilation:	0 MJ/m²a
- Energy demand residual operation:	38 MJ/m²a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.74 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL B, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school B in Zurich, referring to 1 m^2 energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^{2}a	UBP/m^2				MJ/m^{2}a	MJ/m^2				kg CO_2/m^2	kg CO2/m^2			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0.04	2	2	-	-	0.0	0.0	0.0	-	-	0.00	0.00	0.00	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	19	1'158	1'008	-	151	0.1	7.3	6.1	-	1.1	0.01	0.63	0.57	-	0.06
	ceiling	47	2'819	2'479	-	340	0.3	17.3	14.8	-	2.5	0.03	1.93	1.79	-	0.14
	roof	550	33'007	20'792	10'396	1'820	7.9	471.4	305.1	152.5	13.8	0.67	39.97	26.20	13.10	0.68
	pillars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls basement	37	2'204	1'258	588	358	0.3	20.0	11.4	7.5	1.1	0.04	2.69	1.40	0.91	0.38
	outer walls upper floors	332	19'892	9'094	9'094	1'704	3.4	205.2	97.2	97.2	10.8	0.40	24.04	11.77	11.77	0.49
	windows	734	44'052	17'974	17'974	8'104	7.9	473.8	234.2	234.2	5.5	0.52	31.22	14.28	14.28	2.67
	inner walls raw	152	9'121	8'096	-	1'025	1.0	58.7	51.5	-	7.2	0.10	6.03	5.62	-	0.40
	separation walls/inner doors	143	8'586	3'247	3'247	2'092	1.3	78.1	38.3	38.3	1.5	0.07	4.43	1.90	1.90	0.63
	flooring	582	34'950	8'045	8'045	18'860	4.5	268.8	73.5	73.5	121.9	0.27	16.01	4.76	4.76	6.50
	wall cover	176	10'534	4'112	4'112	2'311	1.4	82.6	40.3	40.3	2.0	0.10	6.19	2.24	2.24	1.71
	ceiling cover	780	46'803	22'420	22'420	1'962	6.0	362.1	177.2	177.2	7.8	0.39	23.58	11.04	11.04	1.51
	infrastructure	5'244	314'622	152'795	156'095	5'731	26.8	1'610.1	785.7	812.0	12.4	1.62	97.47	44.03	45.63	7.81
	sum building	**8'796**	**527'750**	**251'322**	**231'971**	**44'457**	**60.9**	**3'655.5**	**1'835.4**	**1'632.7**	**187.5**	**4.24**	**254.19**	**125.59**	**105.63**	**22.96**
Operation	room heating	5'414	324'833				173.6	10'417.4				9.72	583.27			
	hot water	380	22'825				12.2	732.0				0.68	40.98			
	ventilation	-	-				-	-				-	-			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	10'550	**633'023**				285.9	**17'156.3**				11.97	**718.24**			
Building induced mobility	**sum mobility**	**3'224**	**193'430**				**49.6**	**2'975.4**				**2.65**	**158.85**			
sum total	**construction, operation und building induced mobility**	**22'570**					**396.5**					**18.85**				
target		**350.0**										**13.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school B per m² energy reference area and 60 years lifespan.

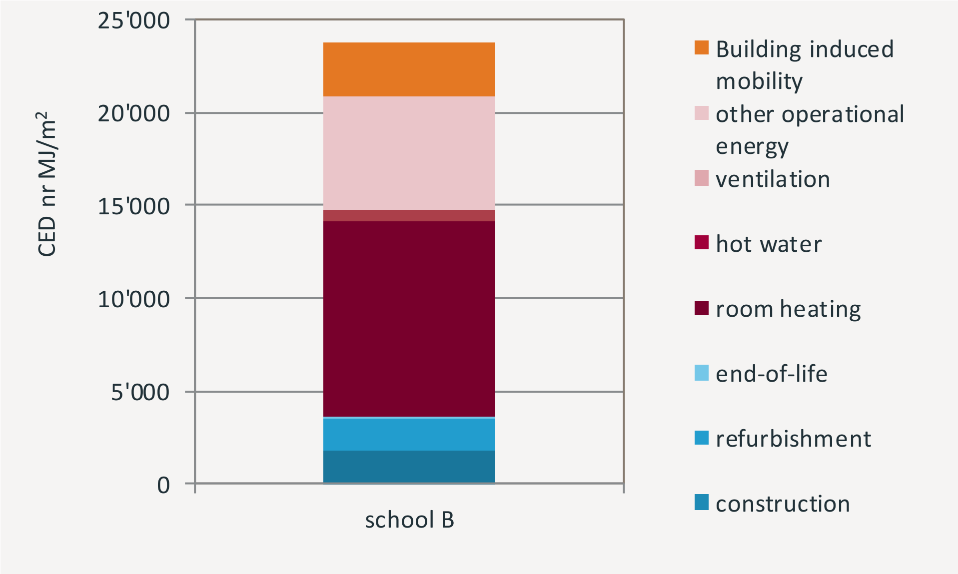


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school B.

Total construction (construction, renewal and decon-struction): The total construction has a share of 15 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 50 % to this. The main impacts come from the floor and ceiling covers, windows, the roof, as well as the infrastructure. The renewal phase contributes to 45 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 5 %.
The Swiss reference value regarding primary energy demand (non renew.) is slightly exceeded.

Operation: With 72 % the total operation has the main impact on the primary energy demand. The room heating has a share of 61% and the residual electricity demand causes 35 % of the impacts. The Swiss reference level for refurbished school buildings is exceeded by 24 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility lies 17 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished building is about 13 % above than the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school B per m^2 energy reference area and 60 years lifespan.

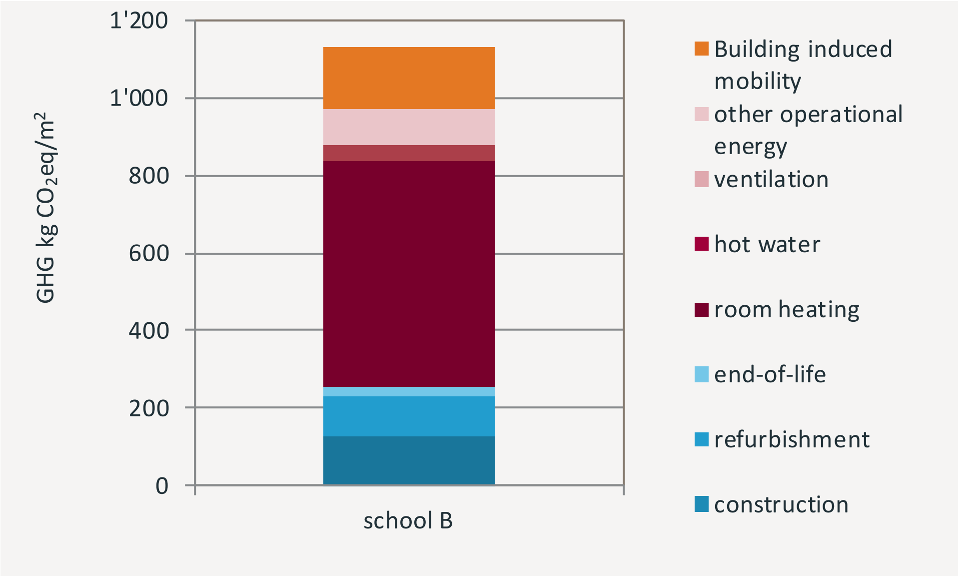


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school B.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 22 %. Within the construction phase the materialization is dominating the GWP (49 %). The main impacts come from the floor and ceiling covers, windows, the roof, as well as the infrastructure. The renewal per year contributes about 42 % to the GWP of the total construction. The deconstruction has a share of 9 %. The reference level regarding GWP for refurbished schools is not exceeded.

Operation: In the building's use phase the GWP is mainly influenced by the room heating (81 %). The property school B is heated with district heat. The reference level is exceeded by 140 %.

Induced mobility: The global warming potential of the induced mobility lies 12 % below the reference value.

Conclusion: The impacts of the operation phase on the GWP are highest. The room heating has the main impact. Overall the GWP of the building school B exceeds the target level for refurbished school buildings by 40 %.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School B, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	2’419 m^2/ n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 1’759 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (stone/concrete/brick construction)
Thermal insulation	Exterior insulation of walls, roof insulation
Ventilation system	Automatic window ventilation
Heating and cooling system	Heating: district heat, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 0 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 208 MJ/m^2a (per energy reference area) Hot water 10 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	Minergie standard
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

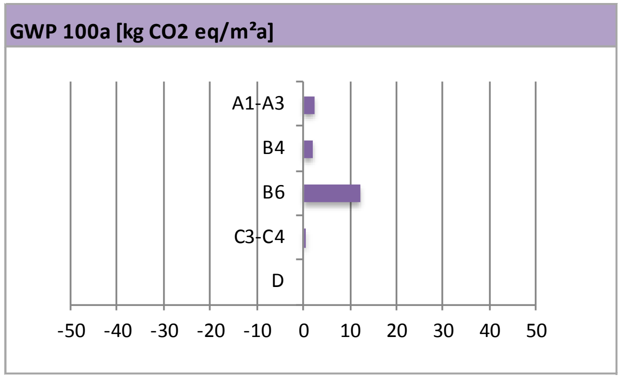
Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Building pit Foundation plate Ceilings Roof External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	-
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

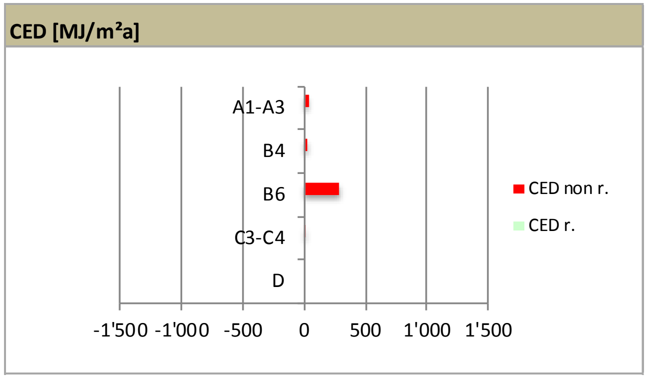
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH2	School B

Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	2.09E+00	1.76E+00	1.20E+01	3.83E-01	0.00E+00
CED non r.	MJ/m²a	3.06E+01	2.72E+01	2.86E+02	3.12E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)





Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH3

The total environmental impacts of buildings

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building (renovated school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school C has a total env. impact of 21’000 eco-points/m^{2}a, primary energy demand (non renew.) of 360 MJ/m^{2}a and a GWP of 17 kg CO_2/m^{2}a. The building does not meet the target values for refurbished schools regarding global warming potential nor for primary energy demand (non renew). For all indicators the operation phase is dominating the results.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze
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OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assess-ment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school C is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School
Size: 3’560 m^2 gross floor area, 2’900 m^2 energy reference area
Location: Zurich, Switzerland
Building year: Completed 2013 (originally constructed in 1877)

Source: Stadt Zürich, Amt für Hochbauten, Foto: Hannes Henz

ABBREVIATIONS

CED cumulative energy demand
GHG greenhouse gases
GWP global warming potential
LCA life cycle assessment
nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distribution, hot water generation as well as ventilation are considered.

The replacements of building materials and components during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

School C

The school building C was originally built in 1877. Within the present renewal the façade (wall insulation), all technical installations and the interior structure will be replaced and refurbished. The building reaches the label Minergie. Windows are automatized for ventilation.
The heat and hot water demand is covered by district heat. The heat distribution works with radiators.

CHARACTERISTIC FACTORS OPERATION

Floor area	3’560 m^2
Energy reference area	2‘900 m^2
Energy demand room heating	158 MJ/m^2a
Energy demand hot water	20 MJm^2a
Energy demand electrical power	38 MJ/m^2a
- Energy demand ventilation:	0 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.74 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL C, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school C in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²a	kg CO_2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0.02	1	1	-	-	0.0	0.0	0.0	-	-	0.00	0.00	0.00	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	12	703	611	-	91	0.1	4.4	3.7	-	0.7	0.01	0.38	0.34	-	0.04
	ceiling	41	2'487	2'187	-	300	0.3	15.3	13.1	-	2.2	0.03	1.70	1.58	-	0.12
	roof	483	28'991	18'294	9'147	1'549	6.9	413.7	267.7	133.9	12.2	0.59	35.26	23.11	11.56	0.59
	pillars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls basement	11	640	397	143	99	0.1	5.5	3.3	1.8	0.3	0.01	0.73	0.41	0.22	0.10
	outer walls upper floors	319	19'143	8'848	8'704	1'592	3.4	202.1	97.2	94.8	10.1	0.38	22.99	11.38	11.15	0.46
	windows	576	34'562	14'099	14'099	6'363	6.2	371.9	183.8	183.8	4.3	0.41	24.50	11.20	11.20	2.09
	inner walls raw	99	5'956	5'261	-	695	0.7	40.4	35.5	-	4.9	0.07	4.11	3.84	-	0.27
	separation walls/inner doors	397	23'810	10'713	9'717	3'380	4.2	249.5	128.5	115.2	5.8	0.28	16.72	8.37	7.13	1.22
	flooring	256	15'359	6'440	6'440	2'479	1.9	116.7	57.7	57.7	1.2	0.12	7.28	3.45	3.45	0.38
	wall cover	162	9'715	3'851	3'851	2'013	1.3	77.8	37.9	37.9	2.1	0.10	5.78	2.11	2.11	1.57
	ceiling cover	302	18'117	8'439	8'439	1'238	2.4	142.2	69.6	69.6	3.1	0.16	9.56	4.21	4.21	1.14
	infrastructure	5'244	314'622	152'795	156'095	5'731	26.8	1'610.1	785.7	812.0	12.4	1.62	97.47	44.03	45.63	7.81
	sum building	**7'902**	**474'106**	**231'938**	**216'637**	**25'532**	**54.2**	**3'249.6**	**1'683.7**	**1'506.6**	**59.3**	**3.77**	**226.48**	**114.02**	**96.67**	**15.79**
Operation	room heating	4'112	246'744				131.9	7'913.1				7.38	443.06			
	hot water	761	45'650				24.4	1'464.0				1.37	81.97			
	ventilation	-	-				-	-				-	-			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	9'629	**577'760**				256.4	**15'384.0**				10.32	**619.01**			
Building induced mobility	**sum mobility**	**3'224**	**193'430**				**49.6**	**2'975.4**				**2.65**	**158.85**			
sum total	**construction, operation und building induced mobility**	**20'755**					**360.1**					**16.74**				
target							**350.0**					**13.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school C per m² energy reference area and 60 years lifespan.

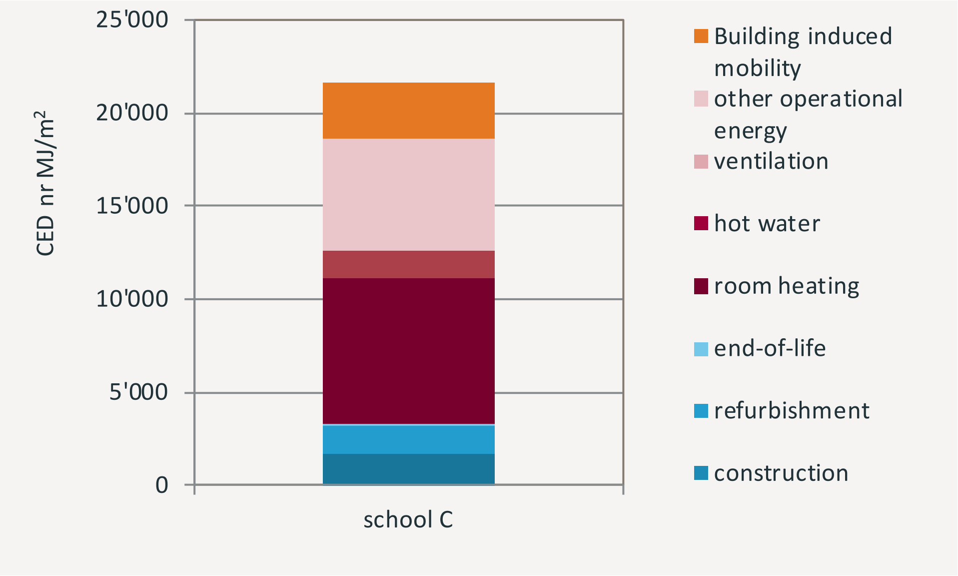


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school C.

Total construction (construction, renewal and deconstruction): The total construction has a share of 15 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 52 % to this. The main impacts come from the outer and inner walls, windows, the roof, as well as the infrastructure. The renewal phase contributes to 46 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 2 %.
The Swiss reference value regarding primary energy demand (non renew.) is slightly exceeded.

Operation: With 71 % the total operation has the main impact on the primary energy demand. The room heating has a share of 51 % and the residual electricity demand causes 39 % of the impacts. The Swiss reference level for refurbished school buildings is exceeded by 11 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility lies 29 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished building is about 3% above than the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school C per m² energy reference area and 60 years lifespan.

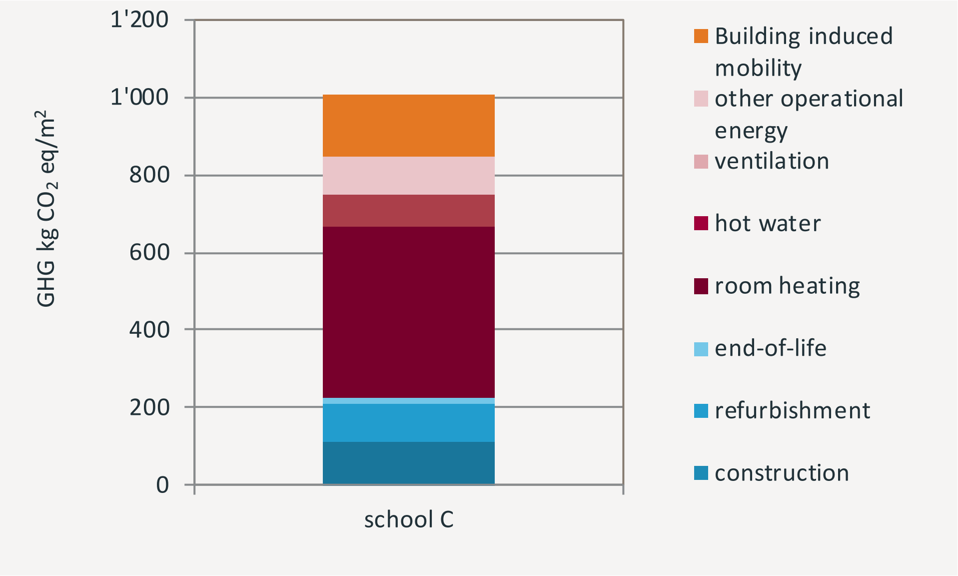


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school C.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 23 %. Within the construction phase the materialization is dominating the GWP (50 %). The main impacts come from the outer walls, windows, the roof, as well as the infrastructure. The renewal per year contributes about 43 % to the GWP of the total construction. The deconstruction has a share of 7 %. The reference level regarding GWP for refurbished schools is not exceeded.

Operation: In the building's use phase the GWP (62 %) is mainly influenced by the room heating and the electricity demand (72 % resp. 15 %). The property school C is heated with district heat. The reference level is exceeded by 106 %.

Induced mobility: The global warming potential of the induced mobility lies 12 % below the reference value.

Conclusion: The impacts of the operation phase on the GWP are highest. The room heating has the main impact. Overall the GWP of the building school C exceeds the target level for refurbished school buildings by 24 %.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School C, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	3’560 m^2/ n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 2’900 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (stone/concrete/brick construction)
Thermal insulation	Exterior insulation of walls, roof insulation
Ventilation system	Automatic window ventilation
Heating and cooling system	Heating: district heat, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 0 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 158 MJ/m^2a (per energy reference area) Hot water 20 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	Minergie standard
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Building pit Foundation plate Ceilings Roof External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

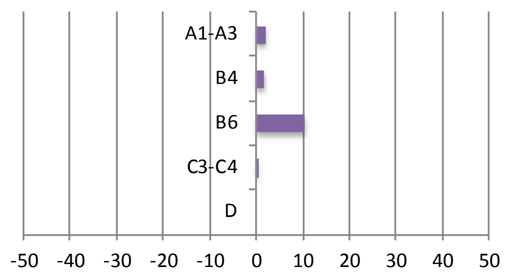
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		
CH3	School C	Annex 57

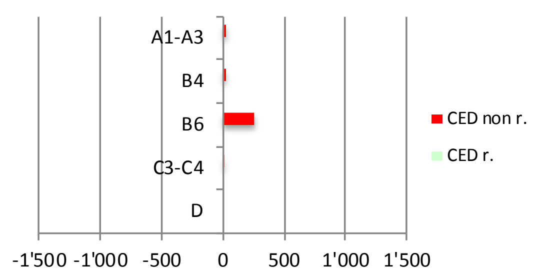
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	1.90E+00	1.61E+00	1.03E+01	2.63E-01	0.00E+00
CED non r.	MJ/m²a	2.81E+01	2.51E+01	2.56E+02	9.88E-01	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH4
The total environmental impacts of buildings

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building D (refurbished school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school D has a total env. impact of 34'000 eco-points/m^{2}a, primary energy demand (non renew.) of 560 MJ/m^{2}a and a GWP of 17 kg CO_2/m^{2}a. The building does not meet the target values for refurbished schools regarding global warming potential nor for primary energy demand (non renew). For the indicators total environmental impact and CED nr the operation stage is dominating the results while the construction stage dominates the GHG emissions.

The roof, windows and the infrastructure cause the main impact within the construction stage (for CED and GWP) whereas the room heating (from electric heat pump equipped with a borehole heat exchanger) causes the largest impact in the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze
fair life cycle thinking

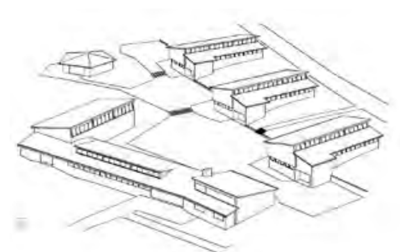
OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assess-ment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school D is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School
Size: Gross floor area n/a, 3'057 m^2 energy reference area
Location: Zurich, Switzerland
Building year: Completed 2010 (originally constructed in 1950)



Source: Boltshauser Architekten, Zürich

ABBREVIATIONS

CED cumulative energy demand
GHG greenhouse gases
GWP global warming potential
LCA life cycle assessment
nr non renewable

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
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- Frischknecht R., Jungbluth N., Althaus H.-J., Bauer C., Doka G., Dones R., Hellweg S., Hischier R., Humbert S., Margni M. and Nemecek T. (2007) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.
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- SIA D 0236 (2011), SIA-Effizienzpfad Energie – Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

School D

The school building D was originally built in the 1950ies. It consists of three school pavilions and a kindergarten. Within the present renewal the façade (wall, roof and ceiling insulation), all technical installations and the interior structure will be refurbished. The building reaches the label Minergie. Sanitary rooms have automatized ventilation.

The heat and hot water demand is covered by electric heat pump equipped with a borehole heat exchanger. The heat distribution works with radiators.

CHARACTERISTIC FACTORS OPERATION

Floor area	n/a
Energy reference area	3‘057 m^2
Energy demand room heating	300 MJ/m^2a
Energy demand hot water	10 MJm^2a
Energy demand electrical power	38 MJ/m^2a
- Energy demand ventilation:	0 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.74 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL D, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school D in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²a	kg CO2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	1.72	103	103	-	-	0.0	1.2	1.2	0.0	0.0	0.00	0.08	0.08	-	-
	backfill	2	93	93	-	-	0.0	1.1	1.1	0.0	0.0	0.00	0.08	0.08	-	-
	fundament	57	3'440	2'947	-	493	0.4	21.5	17.8	0.0	3.7	0.03	1.93	1.73	-	0.20
	ceiling	32	1'938	1'709	-	229	0.2	11.9	10.1	0.0	1.7	0.02	1.33	1.24	-	0.09
	roof	3'167	190'005	81'779	40'889	67'337	60.3	3'619.3	2'405.5	1'202.7	11.1	3.88	232.93	85.49	42.74	104.70
	pillars	93	5'556	5'556	-	-	0.5	32.2	32.2	0.0	0.0	0.03	1.91	1.91	-	-
	outer walls basement	8	490	432	-	58	0.0	3.0	2.6	0.0	0.4	0.01	0.34	0.31	-	0.02
	outer walls upper floors	339	20'358	8'198	8'198	3'961	3.8	229.8	112.4	112.4	5.0	0.50	30.01	12.34	12.34	5.33
	windows	1'324	79'455	33'668	33'668	12'118	15.3	918.9	455.5	455.5	7.9	1.06	63.59	28.73	28.73	6.12
	inner walls raw	19	1'165	1'008	-	157	0.3	17.8	16.8	0.0	1.1	0.03	1.56	1.49	-	0.07
	separation walls/inner doors	126	7'547	2'722	2'722	2'103	1.2	73.7	36.1	36.1	1.6	0.07	4.48	1.90	1.90	0.68
	flooring	483	28'987	11'603	11'603	5'780	6.5	391.8	194.1	194.1	3.6	0.36	21.36	8.59	8.59	4.18
	wall cover	248	14'864	6'856	6'856	1'153	2.0	121.5	58.6	58.6	4.2	0.12	6.99	3.09	3.09	0.81
	ceiling cover	917	55'031	25'802	25'802	3'428	7.5	452.3	221.5	221.5	9.4	0.43	25.52	11.81	11.81	1.90
	infrastructure	5'989	359'322	165'895	187'695	5'731	42.8	2'568.3	1'106.6	1'449.4	12.4	2.50	150.07	61.62	80.65	7.81
	sum building	**12'806**	**768'355**	**348'373**	**317'434**	**102'548**	**141.1**	**8'464.5**	**4'672.1**	**3'730.4**	**62.0**	**9.04**	**542.18**	**220.41**	**189.86**	**131.91**
Operation	room heating	12'336	740'154				255.0	15'297.7				3.99	239.34			
	hot water	631	37'878				13.2	790.4				0.21	12.37			
	ventilation	-	-				0.0	0.0				-	-			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	17'723	**1'063'398**				368.2	**22'094.9**				5.76	**345.69**			
Building induced mobility	**sum mobility**	**3'224**	**193'430**				**49.6**	**2'975.4**				**2.65**	**158.85**			
sum total	**construction, operation und building induced mobility**	**33'753**					**558.9**					**17.45**				
target							**350.0**					**13.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school D per m² energy reference area and 60 years lifespan.

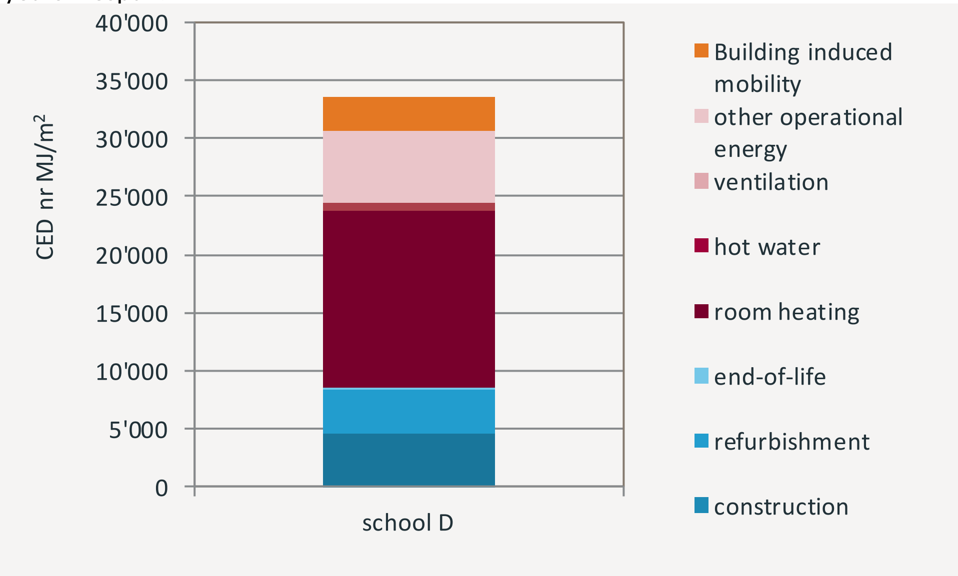


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school D.

Total construction (construction, renewal and deconstruction): The total construction has a share of 25 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 55 % to this. The main impacts come from the roof, windows, as well as the infrastructure. The renewal phase contributes to 44 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 1 %.
The Swiss reference value regarding primary energy demand (non renew.) is exceeded by 135 %.

Operation: With 66 % the total operation has the main impact on the primary energy demand. The room heating has a share of 69 % and the residual electricity demand causes 27 % of the operational impacts. The Swiss reference level for refurbished school buildings is exceeded by 60 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility lies 17 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished school building is about 60 % above than the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school D per m² energy reference area and 60 years lifespan.

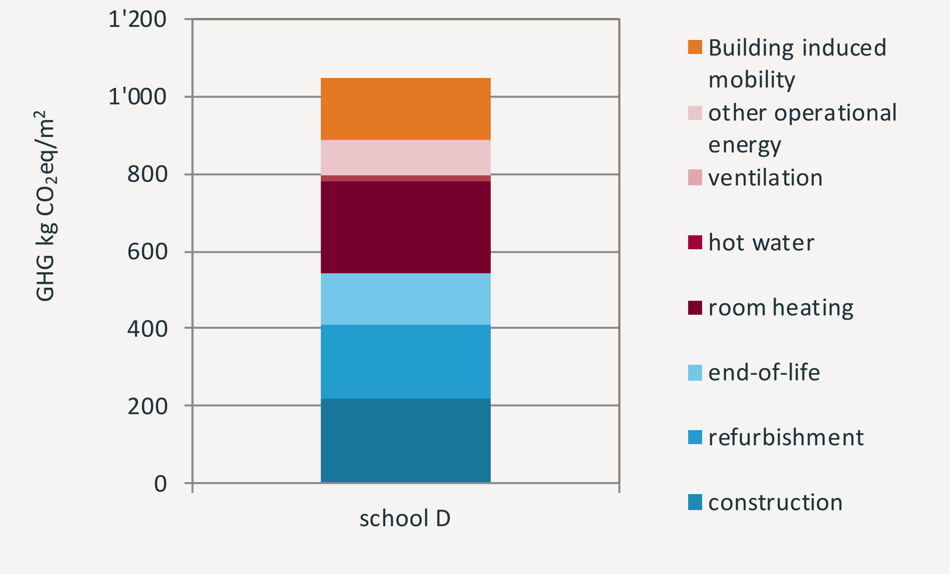


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school D.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 52 %. Within the construction phase the materialization is dominating the GWP (41 %). The main impacts come from the roof, the windows as well as the infrastructure. The renewal per year contributes about 35 % to the GWP of the total construction. The deconstruction has a share of 24 %. The reference level regarding GWP for refurbished schools is exceeded by 64 %.

Operation: In the building's use phase the GWP (33 %) is mainly influenced by the room heating and the electricity demand (69 % resp. 27 %). The property school D is heated with district heat. The reference level is exceeded by 15 %.

Induced mobility: The global warming potential of the induced mobility lies 12 % below the reference value.

Conclusion: The impacts of the construction phase on the GWP are highest. The roof and the infrastructure have the main impact. Overall the GWP of the building school D exceeds the target level for refurbished school buildings by 29 %.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School D, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 3’057 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (stone/concrete/brick construction)
Thermal insulation	Exterior insulation of walls, roof insulation
Ventilation system	Automatic window ventilation
Heating and cooling system	Heating:electric heat pump equipped with a borehole heat exchanger, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 0 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 300 MJ/m^2a (per energy reference area) Hot water 10 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	Minergie standard
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials uses for the renewal were considered. Building pit Backfill Foundation plate Ceilings Roof Pillars External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

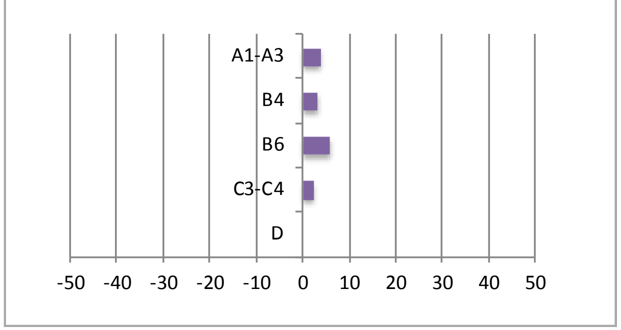
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH4	School D

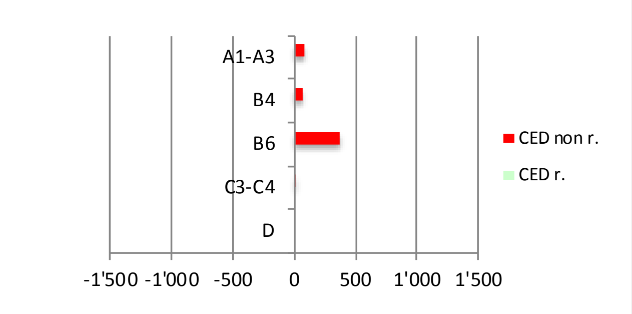
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3.67E+00	3.16E+00	5.76E+00	2.20E+00	0.00E+00
CED non r.	MJ/m²a	7.79E+01	6.22E+01	3.68E+02	1.03E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH5

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building E (refurbished school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school E has a total env. impact of 31'000 eco-points/m^{2}a, primary energy demand (non renew.) of 320 MJ/m^{2}a and a GWP of 14 kg CO_2/m^{2}a. The building holds the target values for refurbished schools regarding global warming potential and for primary energy demand (non renew). For all indicators the operation stage is dominating the results.

The roof, windows, flooring and the infrastructure cause the main impact within the construction stage (for CED and GWP) whereas the electricity demand (CED) and room heating (GWP, from wood pellet furnace) causes the largest impact in the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assess-ment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school E is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School
Size: 14'058 m^2 Gross floor area, 8'033 m^2 energy reference area
Location: Zurich, Switzerland
Building year: Completed 2009 (originally constructed in 1930)

Source: Stadt Zürich, Amt für Hochbauten, Foto: Walter Mair

ABBREVIATIONS

CED cumulative energy demand
GHG greenhouse gases
GWP global warming potential
LCA life cycle assessment
nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
- Frischknecht R., Steiner R. and Jungbluth N. (2008) Methode der ökologischen Knappheit - Ökofaktoren 2006. Umwelt-Wissen Nr. 0906. Bundesamt für Umwelt (BAFU), Bern, retrieved from: www.bafu.admin.ch/publikationen/publikation/01031/index.html?lang=de.
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- ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1-25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org.
- SIA D 0236 (2011), SIA-Effizienzpfad Energie – Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distribution, hot water generation as well as ventilation are considered.
The replacements of building materials and components during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

School E

The building E is a school property built in 1930. Only few modifications were made in the past. In 2009 the school was completely renovated and the building corresponds to the Swiss Minergie standard for refurbished buildings. The classroom wing was broadly renovated and the classrooms were enlarged.

The structural components are sandstone blocks, concrete and building bricks. The new windows have wooden frames.

The heat and hot water demand is covered by district heat and wood pellets and the heat is distributed by radiators. The building is equipped with an automatic ventilation.

CHARACTERISTIC FACTORS OPERATION

Floor area	14’058
Energy reference area	8‘033 m^2
Energy demand room heating	239 MJ/m^2a
Energy demand hot water	10 MJm^2a
Energy demand electrical power	38 MJ/m^2a
- Energy demand ventilation:	0 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.20 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL E, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school E in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²a	kg CO2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0	14	14	-	-	0.0	0.2	0.2	0.0	0.0	0.00	0.01	0.01	-	-
	backfill	0	10	10	-	-	0.0	0.1	0.1	0.0	0.0	0.00	0.01	0.01	-	-
	fundament	7	405	348	-	57	0.0	2.5	2.1	0.0	0.4	0.00	0.23	0.20	-	0.02
	ceiling	377	22'634	19'965	-	2'669	2.3	138.6	118.3	0.0	20.3	0.26	15.55	14.46	-	1.09
	roof	668	40'103	16'933	16'933	6'236	3.8	225.1	109.0	109.0	7.0	0.26	15.74	6.62	6.62	2.50
	pillars	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-
	outer walls basement	29	1'740	1'496	11	233	0.2	12.1	10.6	0.2	1.4	0.02	1.38	1.21	0.02	0.15
	outer walls upper floors	209	12'560	5'286	5'286	1'987	2.7	159.6	77.7	77.7	4.3	0.28	16.59	7.05	7.05	2.49
	windows	479	28'730	11'817	11'817	5'097	5.3	319.9	158.2	158.2	3.6	0.35	21.11	9.70	9.70	1.71
	inner walls raw	159	9'553	8'354	-	1'199	1.6	95.4	86.3	0.0	9.1	0.16	9.34	8.87	-	0.47
	separation walls/inner doors	186	11'176	4'511	4'511	2'154	1.8	106.4	51.7	51.7	2.9	0.11	6.77	3.04	3.04	0.68
	flooring	995	59'711	25'706	25'706	8'298	8.6	516.6	250.7	250.7	15.2	0.62	37.09	14.86	14.86	7.36
	wall cover	255	15'277	6'277	6'277	2'722	2.4	145.5	68.9	68.9	7.7	0.25	15.26	6.55	6.55	2.15
	ceiling cover	612	36'732	16'575	16'575	3'583	4.9	294.6	143.3	143.3	8.0	0.32	19.30	8.44	8.44	2.42
	infrastructure	5'228	313'671	151'220	156'720	5'731	28.1	1'686.6	815.1	859.1	12.4	1.70	101.92	45.72	48.39	7.81
	sum building	**9'205**	**552'317**	**268'513**	**243'836**	**39'968**	**61.7**	**3'703.3**	**1'892.3**	**1'718.8**	**92.3**	**4.34**	**260.29**	**126.75**	**104.67**	**28.86**
Operation	room heating	11'648	698'901				88.3	5'297.5				4.46	267.38			
	hot water	732	43'901				5.5	332.8				0.28	16.80			
	ventilation	-	-				0.0	0.0				-	-			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	17'136	**1'028'167**				194.0	**11'637.2**				6.30	**378.16**			
Building induced mobility	**sum mobility**	**4'618**	**277'105**				**64.5**	**3'872.7**				**3.67**	**220.00**			
sum total	construction, operation und building induced mobility	**30'960**					**320.2**					**14.31**				
target							**350.0**					**13.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school E per m² energy reference area and 60 years lifespan.

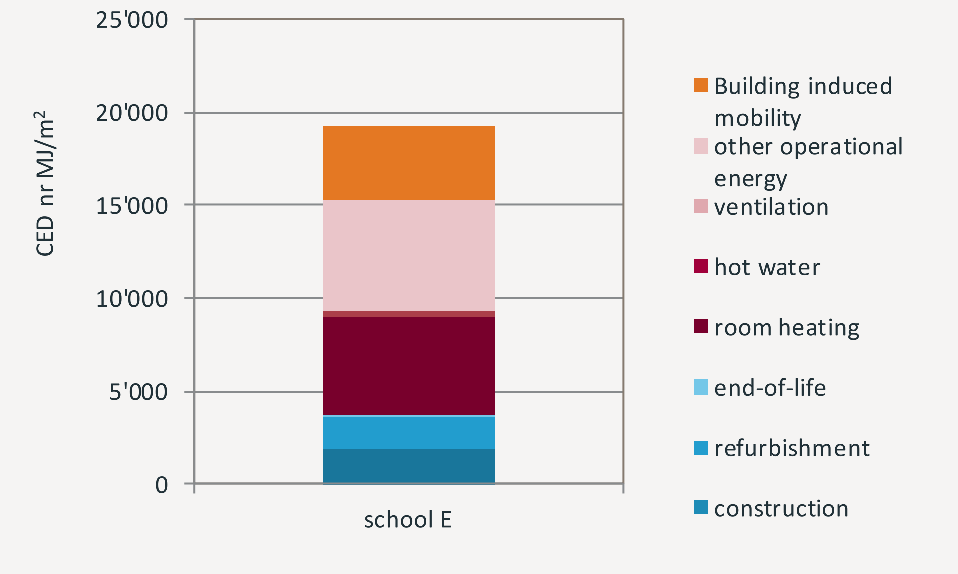


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school E.

Total construction (construction, renewal and deconstruction): The total construction has a share of 19 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 51 % to this. The main impacts come from the roof, windows, flooring as well as the infrastructure. The renewal phase contributes to 46 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 2 %.
The Swiss reference value regarding primary energy demand (non renew.) is slightly exceeded.

Operation: With 61 % the total operation has the main impact on the primary energy demand. The room heating has a share of 46 % and the residual electricity demand causes 52 % of the operational impacts. The Swiss reference level for refurbished school buildings is not exceeded.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 20 % and lies 17 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished school building meets the Swiss target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school E per m² energy reference area and 60 years lifespan.

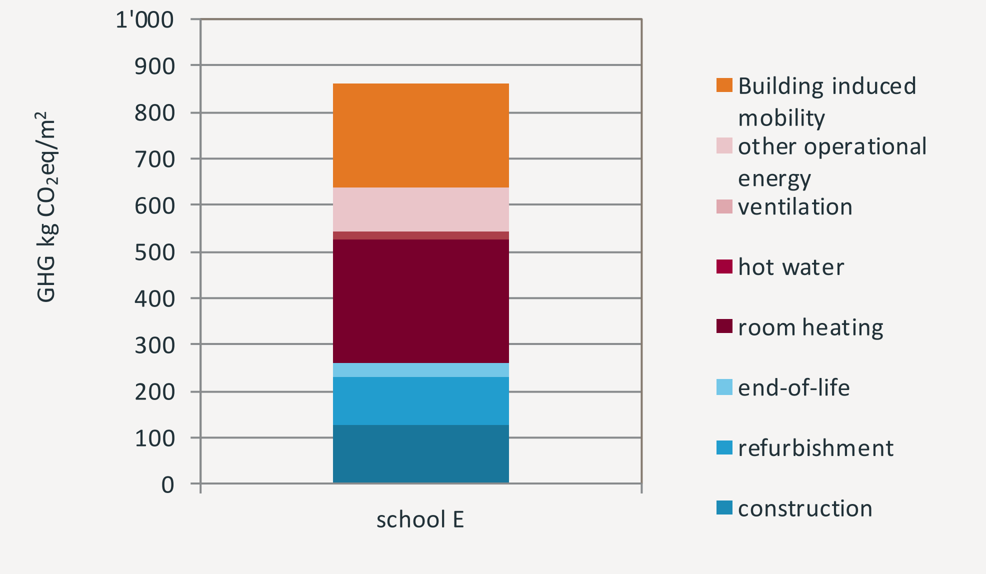


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school E.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 30 %. Within the construction phase the materialization is dominating the GWP (49 %). The main impacts come from the roof, the windows as well as the infrastructure. The renewal per year contributes about 40 % to the GWP of the total construction. The deconstruction has a share of 11 %.

Operation: In the building's use phase the GWP (44 %) is mainly influenced by the room heating and the electricity demand (71 % resp. 25%). The property school E is heated with wood pellets. The reference level is exceeded by 26 %.

Induced mobility: The global warming potential of the induced mobility has a share of 26 % and it lies 12 % below the reference value.

Conclusion: The impacts of the use stage on the GWP are highest. The room heating has the main impact. Overall the GWP of the building school E exceeds the target level for refurbished school buildings slightly.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School E, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	14’058
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 8’033 m2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (stone/concrete/brick construction)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic window ventilation
Heating and cooling system	Heating:wood pellet, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 0 MJ/m2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 239 MJ/m2a (per energy reference area) Hot water 10 MJ/m2a (per energy reference area)
Final energy demand for cooling	0 MJ/m2a
Benchmark	Minergie standard
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

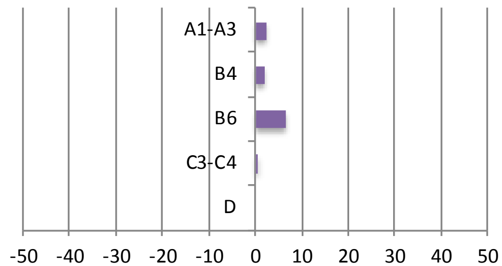
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		Annex 57
CH5	School E	

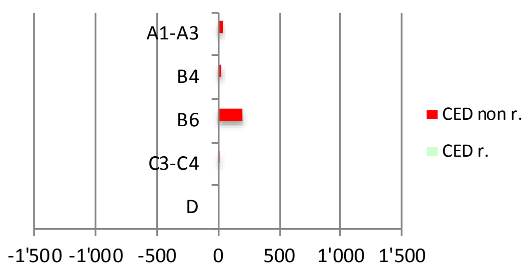
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	2.11E+00	1.74E+00	6.30E+00	4.81E-01	0.00E+00
CED non r.	MJ/m²a	3.15E+01	2.86E+01	1.94E+02	1.54E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH6

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The school building F (new school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school F has a total env. impact of 36'000 eco-points/m^{2}a, primary energy demand (non renew.) of 440 MJ/m^{2}a and a GWP of 24 kg CO_2/m^{2}a. The building does not meet the target values for new schools regarding global warming potential nor for primary energy demand (non renew). For the indicator CED the construction stage and the use stage cause the same level of impact, whereas the construction stage clearly dominates the greenhouse gas emissions and the total environmental impacts.

The roof, ceilings, the fundament, pillars, flooring and the infrastructure cause the main impact within the construction stage (for CED and GWP) whereas the electricity demand (CED) and room heating (GWP, from district heat) causes the largest impact in the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assess-ment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school F is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School

Size: Gross floor area 9'582 m^2, energy reference area 9'279 m^2

Location: Zurich, Switzerland

Building year: Completed 2009

Source: Stadt Zürich, Amt für Hochbauten, Foto: Hannes Henz

ABBREVIATIONS

CED cumulative energy demand
GHG greenhouse gases
GWP global warming potential
LCA life cycle assessment
nr non renewable

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings: 60 years
Calculation of total env. impact: Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy: Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP: GWP 100 years (IPCC 2007, TS 2)
Databases used: ecoinvent data v2.2

REFERENCES

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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

School F

The building F is a school property built in 2009. It is a tower-like steel construction glazed all around. The rooms are lying upon another. 22 class rooms, a double sports hall, media center, library, auditorium, canteen, kindergarten and studios build the second largest school building in Zurich.

The heat and hot water demand are covered by district heat. The heat is distributed by radiators. The building is equipped with an automatic ventilation.

CHARACTERISTIC FACTORS OPERATION

Floor area	9'582
Energy reference area	9'279 m^2
Energy demand room heating	53 MJ/m^2a
Energy demand hot water	20 MJm^2a
Energy demand electrical power	45 MJ/m^2a
- Energy demand ventilation:	7 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	Agglomeration
Public transport	grade B
Parking spots	0.74 parking spots per employee
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL F, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school F in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²a	kg CO2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	9.64	578	578	-	-	0.1	7.0	7.0	-	-	0.01	0.46	0.46	-	-
	backfill	1	86	86	-	-	0.0	1.0	1.0	-	-	0.00	0.07	0.07	-	-
	fundament	2'604	156'238	138'266	-	17'972	16.9	1'013.2	890.1	-	123.1	1.85	111.14	101.75	-	9.38
	ceiling	4'942	296'543	270'355	-	26'189	39.2	2'351.3	2'152.2	-	199.1	3.57	213.98	203.45	-	10.53
	roof	2'290	137'382	86'291	40'425	10'667	23.7	1'420.6	861.7	549.1	9.8	1.65	99.02	51.40	32.37	15.25
	pillars	4'293	257'597	257'597	-	-	24.5	1'470.9	1'470.9	-	-	1.44	86.36	86.36	-	-
	outer walls basement	493	29'555	25'402	-	4'153	3.7	224.8	207.7	-	17.0	0.41	24.78	20.89	-	3.88
	outer walls upper floors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	windows	1'335	80'127	38'681	38'681	2'764	18.5	1'109.5	546.7	546.7	16.1	1.39	83.12	40.16	40.16	2.80
	inner walls raw	715	42'874	40'068	-	2'805	7.2	432.2	408.1	-	24.1	0.62	37.36	36.14	-	1.22
	separation walls/inner doors	129	7'722	3'651	3'651	421	1.2	69.8	33.8	33.8	2.2	0.07	4.29	2.09	2.09	0.12
	flooring	1'914	114'830	44'012	44'012	26'807	22.3	1'336.0	631.5	631.5	73.1	1.96	117.73	46.16	46.16	25.41
	wall cover	35	2'120	1'046	1'046	29	0.6	36.1	18.0	18.0	0.2	0.03	1.68	0.84	0.84	0.01
	ceiling cover	136	8'143	3'655	3'655	832	1.7	103.4	50.5	50.5	2.3	0.09	5.59	2.74	2.74	0.11
	infrastructure	4'337	260'192	124'333	127'633	8'226	25.8	1'545.8	753.5	779.8	12.5	1.60	96.21	41.45	43.06	11.70
	sum building	**23'233**	**1'393'988**	**1'034'021**	**259'103**	**100'865**	**185.4**	**11'121.6**	**8'032.7**	**2'609.4**	**479.5**	**14.70**	**881.81**	**633.98**	**167.41**	**80.41**
Operation	room heating	1'379	82'770				44.2	2'654.4				2.48	148.62			
	hot water	761	45'650				24.4	1'464.0				1.37	81.97			
	ventilation	876	52'569				18.4	1'106.6				0.29	17.31			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	**7'773**	**466'355**				**187.2**	**11'231.9**				**5.70**	**341.89**			
Building induced mobility	**sum mobility**	**4'941**	**296'439**				**70.0**	**4'200.4**				**3.90**	**233.85**			
sum total	**construction, operation und building induced mobility**	**35'946**					**442.6**					**24.29**				
target							**350.0**					**14.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school F per m² energy reference area and 60 years lifespan.

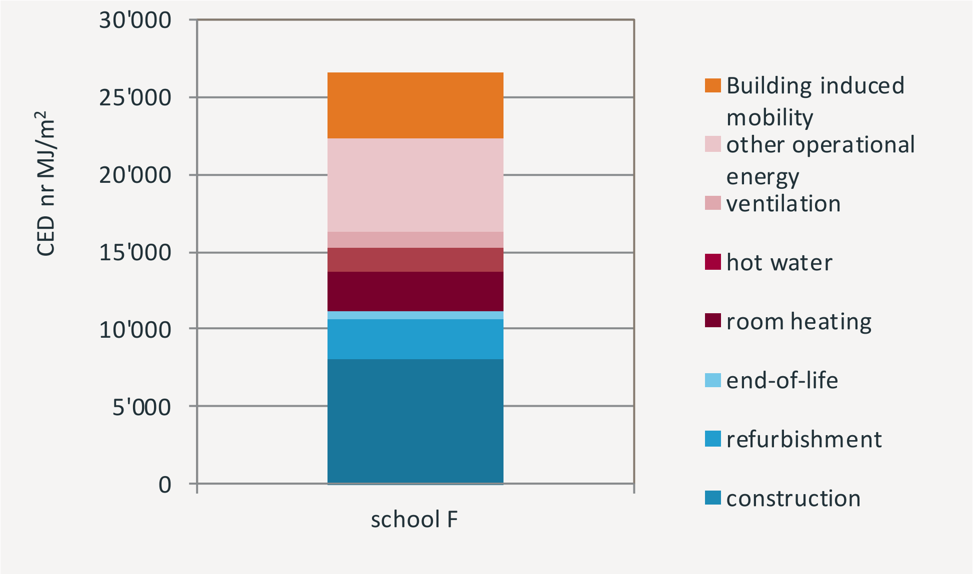


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school F.

Total construction (construction, renewal and deconstruction): The total construction as well as the operation each have a share of 42 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 72 % to this. The main impacts come from the ceiling, the roof, pillars as well as the infrastructure. The renewal phase contributes to 23 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 4 %.
The Swiss reference value regarding primary energy demand (non renew.) is exceeded by 70 %.

Operation: The operational energy demand is dominating the environmental impacts of the use stage (53 %), followed by the room heating (24 %). The Swiss reference level for new school buildings is slightly exceeded.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 16 % and lies 17 % above the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the newly constructed school building does not meet the Swiss target value. Similar impact are caused by the construction and the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school F per m² energy reference area and 60 years lifespan.

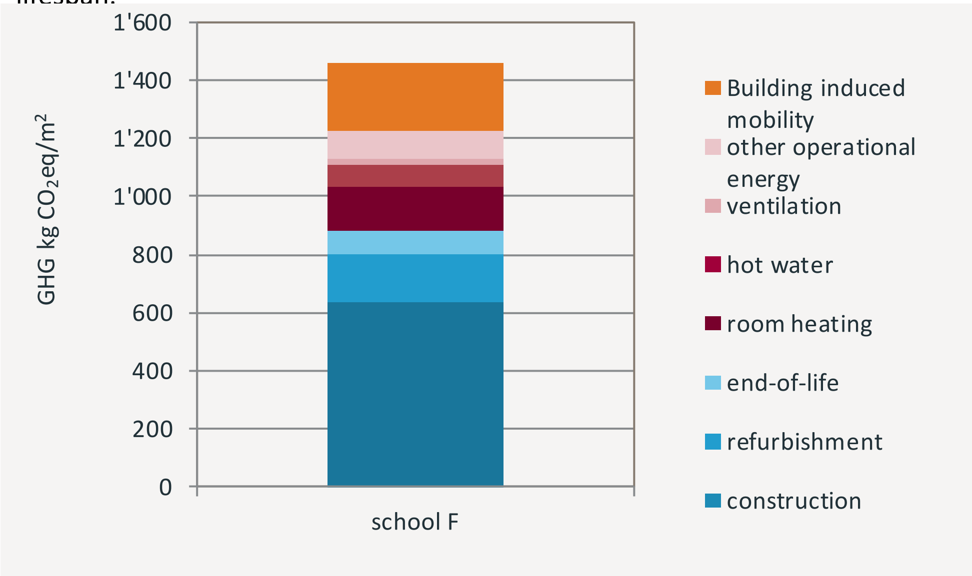


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school F.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 60 %. Within the construction phase the materialization is dominating the GWP (72 %). The main impacts come from the fundament, the ceilings and the roof. The renewal per year contributes about 19 % to the GWP of the total construction. The deconstruction has a share of 9 %.

Operation: In the building's use phase the GWP (23 %) is mainly influenced by the room heating and the electricity demand (43% resp. 27%). The property school F is heated with district heat. The reference level is exceeded by 128 %.

Induced mobility: The global warming potential of the induced mobility has a share of 16 % and it lies 30 % above the reference value.

Conclusion: The impacts of the construction stage on the GWP are dominating the results. The construction has the main impact. Overall the GWP of the building school F exceeds the target level for new school buildings by 70 %.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School F, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	9’582 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 9’279 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (glass/steel)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating:district heat, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 7 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 53 MJ/m^2a (per energy reference area) Hot water 20 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Building pit Backfill Foundation plate Ceilings Roof Pillars External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

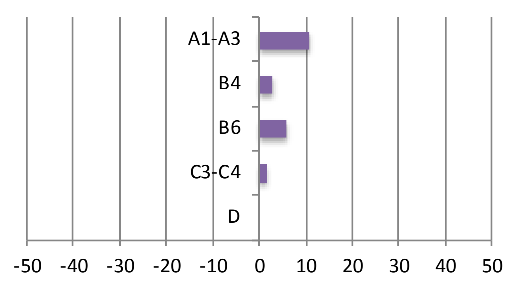
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH6	School F

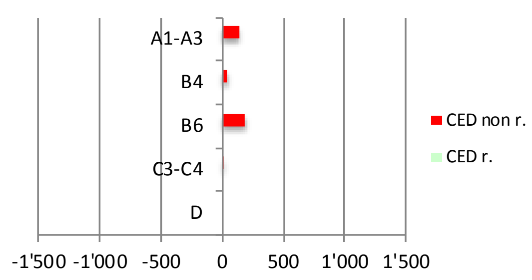
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	1.06E+01	2.79E+00	5.70E+00	1.34E+00	0.00E+00
CED non r.	MJ/m²a	1.34E+02	4.35E+01	1.87E+02	7.99E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH7

The total environmental impacts of buildings

KEY OBSERVATIONS

The school building (newly constructed school building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The school G has a total env. impact of 24’000 eco-points/m^{2}a, primary energy demand (non renew.) of 350 MJ/m^{2}a and a GWP of 12 kg CO_2/m^{2}a. The building meets the target values for newly constructed schools regarding global warming potential and for primary energy demand (non renew). The indicator CED is dominated by the use stage, while the construction stage is most important for the greenhouse gas emissions.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This school G is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: School

Size: gross floor area not known, 504 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed 2013

Source: Stadt Zürich, Foto: Amt für Städtebau

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distribution, hot water generation as well as ventilation are considered.
The replacements of building materials and components during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

School G

30 school pavilions of this type are used in the city of Zurich actually. These help to mitigate school shortage until proper school buildings are built. Pavilions like school G fulfill the criteria of Minergie. Windows are automatized for ventilation.
The heat and hot water demand is covered by an electric heat pump equipped with a borehole heat exchanger. The heat distribution works with radiators.

CHARACTERISTIC FACTORS OPERATION

Floor area	n/a
Energy reference area	504 m^2
Energy demand room heating	53 MJ/m^2a
Energy demand hot water	20 MJm^2a
Energy demand electrical power	45 MJ/m^2a
- Energy demand ventilation:	7 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	-
Public transport	-
Parking spots	0.74 parking spots per employee (Swiss average)
Public transport subscriptions	0.22 permanent public transport subscriptions (Swiss average)
Bicycle parking	1 (available)

DETAILED RESULTS OF SCHOOL G, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the school G in Zurich, referring to 1 m^2 energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^{2}a	UBP/m^2				MJ/m^{2}a	MJ/m^2				kg CO_2/m	kg CO2/m^2			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0.51	30	30	-	-	0.0	0.4	0.4	-	-	0.00	0.02	0.02	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	254	15'261	13'209	-	2'052	1.6	94.8	79.2	-	15.6	0.19	11.16	10.32	-	0.84
	ceiling	1'931	115'883	56'068	29'719	30'096	20.8	1'245.0	801.7	430.8	12.5	1.04	62.56	34.51	18.51	9.55
	roof	1'112	66'714	34'196	21'830	10'688	13.9	836.0	513.9	316.8	5.3	0.74	44.20	24.56	16.69	2.95
	pillars	445	26'721	18'053	-	8'667	3.4	204.2	201.1	-	3.0	0.21	12.67	10.51	-	2.16
	outer walls basement	697	41'842	17'405	17'405	7'032	7.8	466.0	230.3	230.3	5.4	0.51	30.86	14.26	14.26	2.33
	outer walls upper floors	1'481	88'863	41'760	26'177	20'927	16.9	1'016.5	633.0	373.8	9.7	0.78	47.06	25.91	15.88	5.28
	windows	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	inner walls raw	371	22'264	7'215	7'215	7'834	3.4	201.5	99.4	99.4	2.6	0.17	10.42	4.49	4.49	1.43
	separation walls/inner doors	479	28'731	9'012	9'950	9'769	4.4	263.2	121.2	137.9	4.0	0.27	15.94	5.92	6.62	3.41
	flooring	355	21'289	8'339	8'339	4'612	3.0	180.8	89.7	89.7	1.3	0.19	11.51	5.39	5.39	0.73
	wall cover	528	31'673	9'577	11'676	10'421	4.3	259.7	109.6	146.9	3.2	0.30	17.76	5.62	7.17	4.97
	ceiling cover	514	30'856	8'890	11'596	10'370	4.3	257.2	103.0	151.2	3.0	0.30	18.14	5.24	7.25	5.65
	infrastructure	3'211	192'668	90'569	93'870	8'229	21.7	1'301.7	631.4	657.8	12.5	1.36	81.66	34.17	35.78	11.70
	sum building	**11'380**	**682'796**	**314'323**	**237'776**	**130'697**	**105.4**	**6'326.8**	**3'613.9**	**2'634.7**	**78.2**	**6.07**	**363.96**	**180.93**	**132.04**	**51.00**
Operation	room heating	2'051	123'049				42.3	2'538.8				0.66	39.72			
	hot water	1'400	84'030				29.3	1'756.4				0.46	27.48			
	ventilation	876	52'569				18.4	1'106.6				0.29	17.31			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	**9'084**	**545'014**				**190.1**	**11'408.7**				**2.97**	**178.50**			
Building induced mobility	**sum mobility**	**3'742**	**224'544**				**55.5**	**3'329.1**				**3.03**	**181.54**			
sum total	**construction, operation und building induced mobility**	**24'206**					**351.1**					**12.07**				
target							**350.0**					**14.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the building school G per m^2 energy reference area and 60 years lifespan.

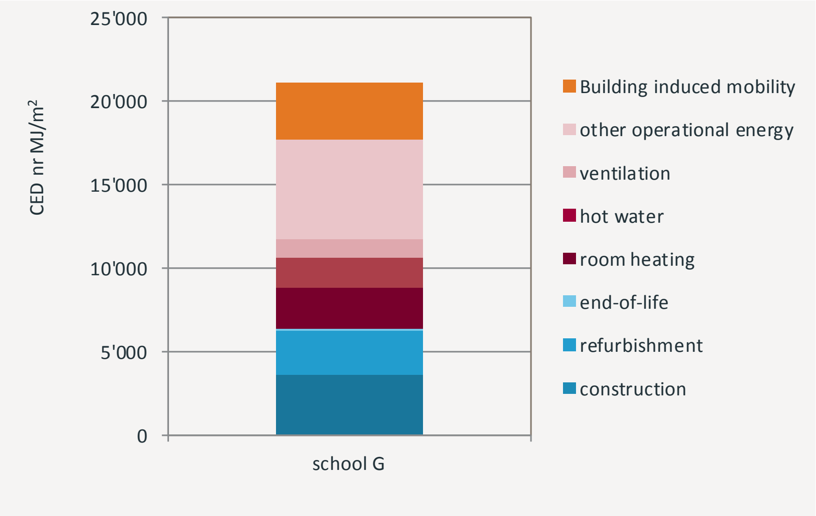


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the building school G.

Total construction (construction, renewal and decon-struction): The total construction has a share of 30 % to the overall primary energy demand (non renew.).
The construction phase itself contributes to 57 % to this. The main impacts come from the fundament, the outer walls, the roof as well as the infrastructure. The renewal phase contributes to 42 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 1 %.
The Swiss reference value regarding primary energy demand (non renew.) is met.

Operation: With 54 % the total operation has the main impact on the primary energy demand. The room heating has a share of 22 % and the residual electricity demand causes 53 % of the impacts. The Swiss reference level for new school buildings is slightly exceeded.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 16 % to the CED and lies 8 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the new school meets the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the building school G per m² energy reference area and 60 years lifespan.

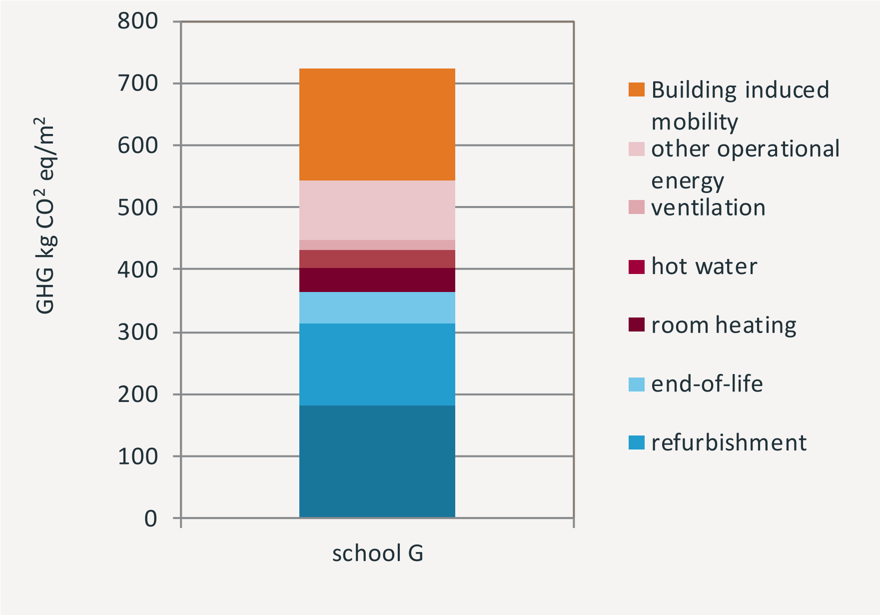


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the building school G.

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 50 %. Within the construction phase the materialization is dominating the GWP (50 %). The main impacts come from the fundament, walls, the roof as well as the infrastructure. The renewal per year contributes about 36 % to the GWP of the total construction. The deconstruction has a share of 14 %. The reference level regarding GWP for new schools is not exceeded.

Operation: In the building's use phase (25 %) the GWP is mainly influenced by the additional electricity demand (53 %). The property school G is heated with a borehole heat exchanger. The reference level is exceeded by 20 %.

Induced mobility: The global warming potential of the induced mobility has a share of 25 % on the total GHG emissions and meets the reference value.

Conclusion: The impacts of the construction stage on the GWP are most dominant. The construction itself has the main impact. Overall the GWP of the building school G holds the target level for new school buildings.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	school building – School G, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 504 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Modular concept (mixed construction: wood, glass)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 7 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 53 MJ/m^2a (per energy reference area) Hot water 20 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	Minergie
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Building pit Backfill Foundation plate Ceilings Roof External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

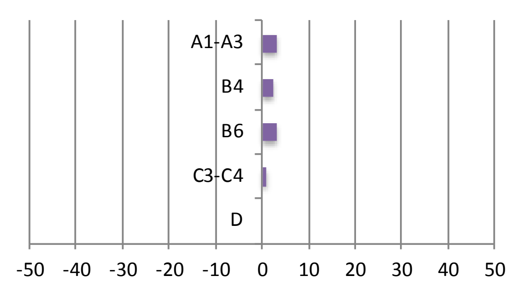
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		Annex 57
CH7	School G	

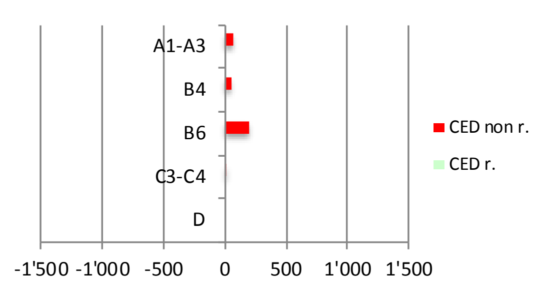
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3.02E+00	2.20E+00	2.97E+00	8.50E-01	0.00E+00
CED non r.	MJ/m²a	6.02E+01	4.39E+01	1.90E+02	1.30E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH8
The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The residential building A (refurbished building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The residential building A has a total env. impact of 27'000 eco-points/m²a, primary energy demand (non renew.) of 490 MJ/m²a and a GWP of 17 kg CO_2/m²a. The building does not meet the target values for refurbished residential buildings regarding global warming potential nor for primary energy demand (non renew). All indicators are dominated by the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This residential building A is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Residential home

Size: 5'259 m² gross floor area, 4'097 m² energy reference area

Location: Zurich, Switzerland

Building year: Completed 2013

Source: Stadt Zürich, Foto: Amt für Hochbauten

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
- Frischknecht R., Steiner R. and Jungbluth N. (2008) Methode der ökologischen Knappheit - Ökofaktoren 2006. Umwelt-Wissen Nr. 0906. Bundesamt für Umwelt (BAFU), Bern, retrieved from: www.bafu.admin.ch/publikationen/publikation/01031/index.html?lang=de.
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- SIA D 0236 (2011), SIA-Effizienzpfad Energie – Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building are calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

Residential building A

The residential property A consists of building with five upper floors, a ground floor and a basement. It's 42 years old. The building is brick-built with a flat roof. Within the refurbishment the façade, the technical installations and the interior are renewed. The energy demand of the use phase should be reduced by 75 % by the renewal of the façade.

The heat and hot water demand is covered by an electric heat pump equipped with a borehole heat exchanger. A gas-fueled boiler covers the peak demand.

CHARACTERISTIC FACTORS OPERATION

Floor area	5'259 m^2
Energy reference area	4'097 m^2
Energy demand room heating	135 MJ/m^2a
- Heat pump	67 %
- Gas	34 %
Energy demand hot water	50 MJm^2a
- Heat pump	80 %
- Gas	20 %
Energy demand electrical power	49 MJ/m^2a
- Energy demand ventilation:	10 MJ/m^2a
- Energy demand residual operation:	39 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Parking spots	0.33 parking spots per household
Public transport subscriptions	0.25 permanent public transport subscriptions (Swiss average)
Private cars per person	0.36 cars per person

DETAILED RESULTS OF THE RESIDENTIAL BUILDING A, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the residential building A in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^2a	UBP/m^2				MJ/m^2a	MJ/m^2				kg CO_2/m^2a	kg $CO2/m^2$			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0	0	0	-	-	0.0	0.0	0.0	-	-	0.00	0.00	0.00	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ceiling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	roof	312	18'747	6'297	3'149	9'301	5.0	300.5	192.5	96.3	11.7	0.35	20.95	5.52	2.76	12.68
	pillars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls basement	42	2'526	2'190	-	336	0.3	15.7	13.2	-	2.5	0.03	1.83	1.69	-	0.14
	outer walls upper floors	554	33'267	12'096	10'469	10'702	9.6	577.6	289.2	279.3	9.1	0.74	44.45	15.00	13.82	15.63
	windows	1'178	70'692	31'631	31'631	7'430	14.5	869.5	431.1	431.1	7.2	0.99	59.52	28.45	28.45	2.62
	inner walls raw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	separation walls/inner doors	144	8'625	3'187	3'187	2'251	1.3	79.9	39.1	39.1	1.7	0.08	4.86	2.07	2.07	0.71
	flooring	198	11'871	5'793	5'793	286	1.2	72.4	35.1	35.1	2.2	0.08	4.84	2.36	2.36	0.11
	wall cover	257	15'394	6'871	6'871	1'653	1.9	111.1	54.6	54.6	2.0	0.13	7.96	3.07	3.07	1.83
	ceiling cover	187	11'204	4'698	4'698	1'808	2.2	131.6	63.9	63.9	3.7	0.13	7.58	2.95	2.95	1.68
	infrastructure	3'153	189'205	89'408	92'708	7'089	18.7	1'121.8	541.3	567.6	13.0	1.18	70.60	29.53	31.14	9.93
	sum building	**6'025.5**	**361'532**	**162'172**	**158'505**	**40'856**	**54.7**	**3'280.1**	**1'660.1**	**1'567.1**	**53.0**	**3.71**	**222.58**	**90.64**	**86.62**	**45.32**
Operation	room heating	5'277	316'619				134.2	8'053.5				4.79	287.69			
	hot water	3'337	200'219				77.3	4'635.2				2.02	121.29			
	ventilation	1'252	75'098				26.3	1'580.8				0.41	24.73			
	other operational energy	4'881	292'877				102.7	6'165.0				1.61	96.45			
	sum operation	**14'747**	**884'814**				**340.6**	**20'434.5**				**8.84**	**530.17**			
Building induced mobility	**sum mobility**	**6'096**	**365'750**				**93.0**	**5'580.0**				**4.83**	**290.00**			
sum total	**construction, operation und building induced mobility**	**26'868**					**488.2**					**17.38**				
target							**440.0**					**15.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building A per m^2 energy reference area and 60 years lifespan.

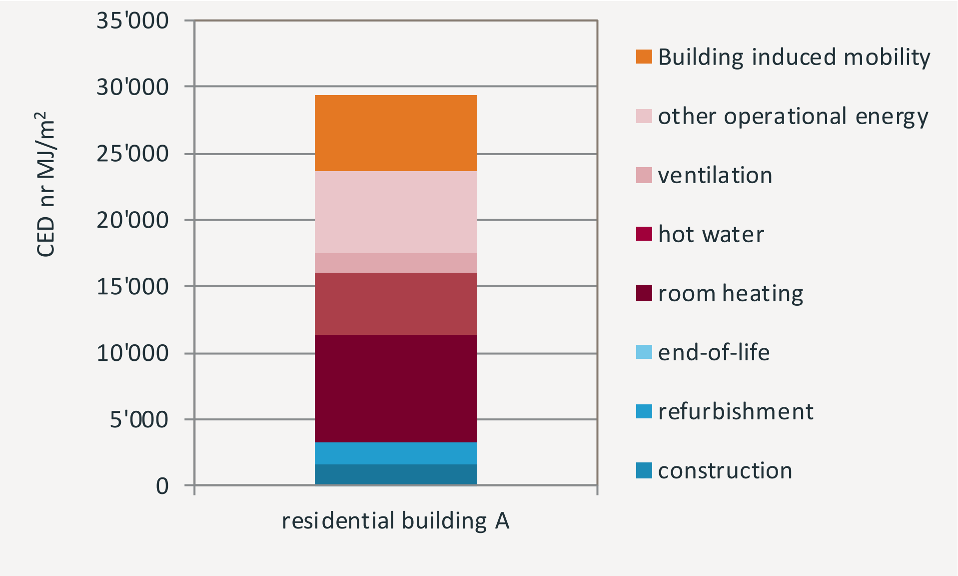


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building A .

Total construction (construction, renewal and deconstruction): The total construction has a share of 11 % to the overall primary energy demand (non renew.).
The construction itself contributes to 51 % to this. The main impacts come from the windows, the walls as well as from the infrastructure. The renewal phase contributes to 48 % to the primary energy demand of the total construction. In comparison the deconstruction has only an impact of 1 %.
The Swiss reference value regarding primary energy demand (non renew.) is met.

Operation: With 70 % the total operation has the main impact on the primary energy demand. The room heating has a share of 39 % and the residual electricity demand causes 30 % of the impacts. The Swiss reference level for refurbished residential buildings is exceeded by 36 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 19 % to the CED and lies
28 % lower than the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished residential property exceeds the target value by 11 %. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the residential building A per m² energy reference area and 60 years lifespan.

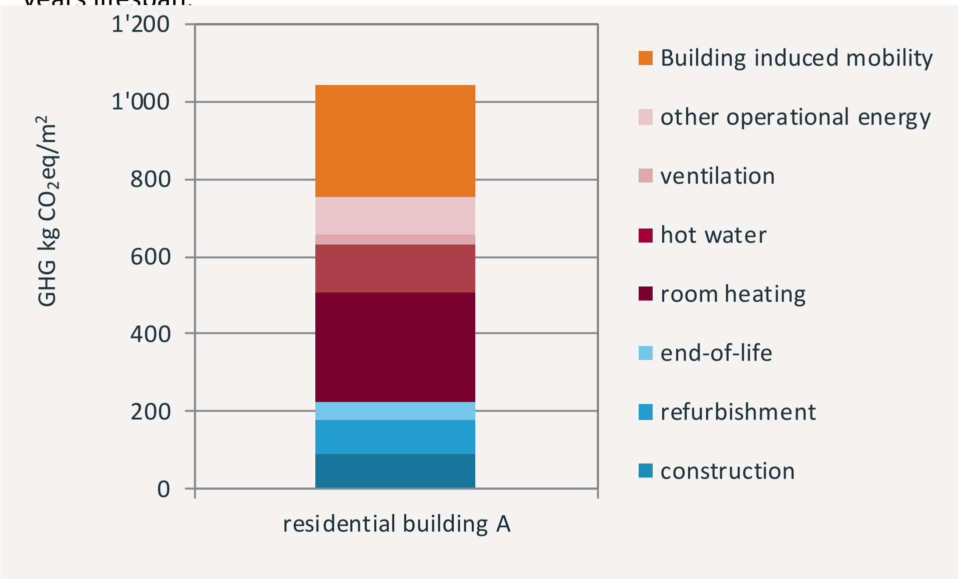


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the residential building A .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 21 %. Within the construction phase the materialization is dominating the GWP (41 %). The main impacts come from the walls, windows as well as from the infrastructure. The renewal per year contributes about 39 % to the GWP of the total construction. The deconstruction has a share of 20 %. The reference level regarding GWP for refurbished residential buildings is not exceeded.

Operation: In the building's use phase (51 %) the GWP is mainly influenced by the room heating (54 %), followed by the hot water provision (23 %). The residential building A is heated with a borehole heat exchanger. Peak demands are covered by a gas-fueled boiler. The reference level is exceeded by 77 %.

Induced mobility: The global warming potential of the induced mobility has a share of 28 % on the total GHG emissions and meets the reference value.

Conclusion: The impacts of the use stage on the GWP are most dominant. The room heating has the main impact. Overall the GWP of the residential building A exceeds the target level for refurbished residential buildings.

DOCUMENTATION REQUIREMENTS RESIDENTIAL BUILDING A

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Residential A, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	5’259 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 4’097 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, a gas-fueled boiler covers the peak demand. heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 10 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 135 MJ/m^2a (per energy reference area) - Heat pump 67 % - Gas 34 % Hot water 50 MJ/m^2a (per energy reference area) - Heat pump 80 % - Gas 20 %
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Roof External walls (underground and above ground) Windows, doors Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	-
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

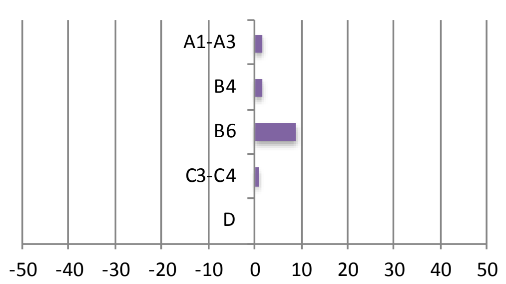
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		Annex 57
CH8	Residential building A	

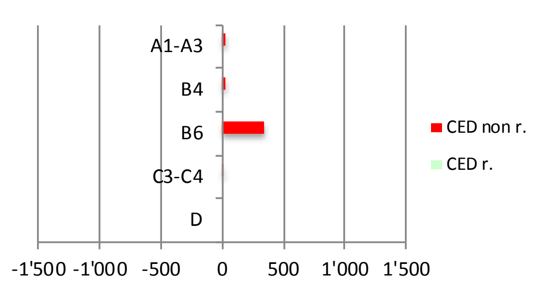
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	1.51E+00	1.44E+00	8.84E+00	7.55E-01	0.00E+00
CED non r.	MJ/m²a	2.77E+01	2.61E+01	3.41E+02	8.83E-01	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH9

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The residential building B (refurbished building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The residential building B has a total env. impact of 27'000 eco-points/m^2a, primary energy demand (non renew.) of 430 MJ/m^2a and a GWP of 14 kg CO_2/m^2a. The building meets the target values for refurbished residential buildings regarding global warming potential and for primary energy demand (non renew). The CED is dominated by the use stage whereas the GHG emissionas are dominated by the construction stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This residential building B is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Residential home

Size: gross floor area not known, 2'894 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completion in 2016

Visualisation: raumgleiter
Source: Galli Rudolf Architekten AG ETH BSA

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building Bre calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

Residential building B

The residential building B was constructed 1970-1972 from the architect Erwin Müller. The property consists of several buildings with total 220 flats. The 40 years old buildings are now renewed, in which small flats are reconstructed to larger, family-friendly apartments. The refurbishment covers the façade, the interior as well as the infrastructure.

The heat and hot water demand is covered by an electric heat pump equipped with a borehole heat exchanger.

CHARACTERISTIC FACTORS OPERATION

Floor area	n/a
Energy reference area	2’894 m^2
Energy demand room heating	77 MJ/m^2a
Energy demand hot water	50 MJm^2a
Energy demand electrical power	49 MJ/m^2a
- Energy demand ventilation:	10 MJ/m^2a
- Energy demand residual operation:	39 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade C
Distance for groceries	0.1 km
Parking spots	0.4 parking spots per household
Public transport subscriptions	0.25 permanent public transport subscriptions (Swiss average)
Private cars per person	0.36 cars per person (average city of Zurich)

DETAILED RESULTS OF THE RESIDENTIAL BUILDNG B, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the residential building B in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²	kg CO2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	0.34	21	21	-	-	0.0	0.2	0.2	-	-	0.00	0.02	0.02	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	13	793	581	-	212	0.1	5.5	4.3	-	1.2	0.01	0.53	0.39	-	0.14
	ceiling	21	1'232	911	-	321	0.3	16.3	14.2	-	2.1	0.01	0.77	0.54	-	0.22
	roof	365	21'881	11'950	8'562	1'368	2.3	140.7	84.4	54.3	1.9	0.14	8.61	4.25	2.85	1.51
	pillars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls basement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls upper floors	441	26'444	12'255	7'275	6'914	6.5	389.6	241.7	140.6	7.3	0.56	33.90	16.02	8.84	9.03
	windows	3'959	237'560	103'985	103'985	29'591	43.1	2'583.3	1'283.4	1'283.4	16.4	2.96	177.35	82.53	82.53	12.28
	inner walls raw	14	819	702	-	118	0.1	6.9	6.0	-	0.9	0.01	0.76	0.71	-	0.05
	separation walls/inner doors	506	30'362	14'402	14'402	1'558	3.6	214.9	106.1	106.1	2.6	0.20	11.88	5.69	5.69	0.51
	flooring	385	23'116	9'329	9'781	4'005	3.0	181.3	85.7	93.5	2.1	0.17	10.41	4.32	4.65	1.45
	wall cover	590	35'382	9'726	17'622	8'034	5.1	306.6	83.4	219.8	3.4	0.39	23.68	4.14	9.88	9.66
	ceiling cover	273	16'406	4'840	7'819	3'746	2.4	142.8	42.3	93.8	6.6	0.17	10.47	2.21	4.37	3.89
	infrastructure	1'674	100'462	46'900	50'200	3'361	11.0	660.9	314.8	341.1	5.0	0.70	41.71	17.68	19.28	4.75
	sum building	**8'241**	**494'478**	**215'602**	**219'647**	**59'229**	**77.5**	**4'649.1**	**2'266.8**	**2'332.8**	**49.6**	**5.33**	**320.09**	**138.50**	**138.11**	**43.48**
Operation	room heating	2'534	152'047				52.0	3'121.0				0.81	48.83			
	hot water	3'157	189'393				65.9	3'951.9				1.03	61.83			
	ventilation	1'252	75'098				26.3	1'580.8				0.41	24.73			
	other operational energy	4'881	292'877				102.7	6'165.0				1.61	96.45			
	sum operation	**11'824**	**709'416**				**247.0**	**14'818.7**				**3.86**	**231.85**			
Building induced	**sum mobility**	**6'618**	**397'050**				**101.2**	**6'070.0**				**5.17**	**310.00**			
sum total	**construction, operation und building induced mobility**	**26'682**					**425.6**					**14.37**				
target							**440.0**					**15.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building B per m² energy reference area and 60 years lifespan.

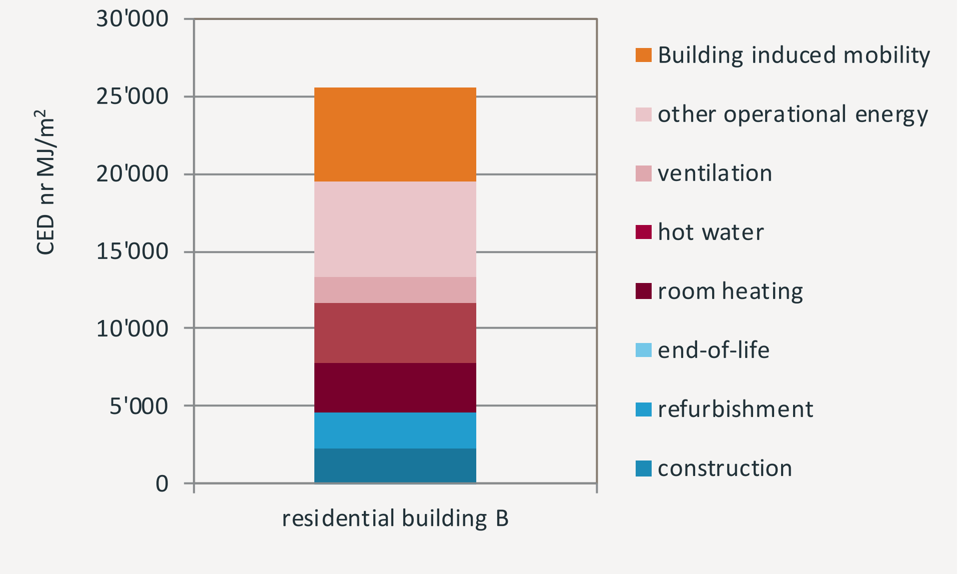


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building B .

Total construction (construction, renewal and deconstruction): The total construction has a share of 18 % to the overall primary energy demand (non renew.).
The construction itself contributes to 49 % to this. The main impacts come from the windows (aluminium-wood frames), the walls, wall covers as well as from the infrastructure. The renewal phase contributes to 50 % to the primary energy demand of the total construction and is influenced by the same materials. In comparison the deconstruction has only an impact of 1 %. The Swiss reference value regarding primary energy demand (non renew.) is met.

Operation: With 58 % the total operation has the main impact on the primary energy demand. The largest impact is caused by the electricity demand (42 %), followed by the hot water provision (27 %). The Swiss reference level for refurbished residential buildings is exceeded by 23 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 24 % to the CED and holds the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished residential property meets the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the residential building B per m² energy reference area and 60 years lifespan.

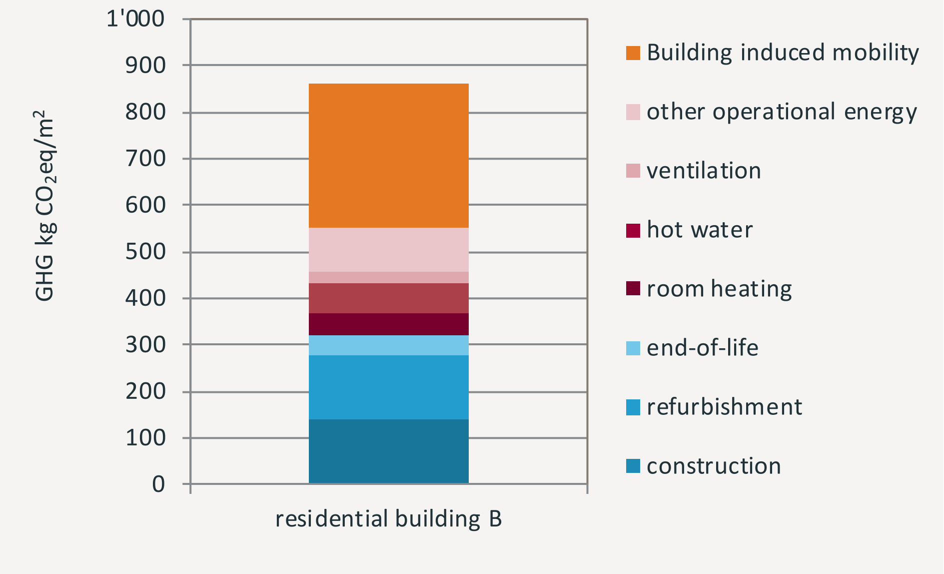


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the residential building B .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 37 %. Within the construction phase the materialization is dominating the GWP (43 %). The main impacts come from the walls, windows as well as from the infrastructure. Especially the windows with aluminium-wood frames dominate the GHG emissions. The renewal per year contributes about 43 % to the GWP of the total construction. The aluminium-wood framed windows have the main impact as well. The deconstruction has a share of 14 %. The reference level regarding GWP for refurbished residential buildings is not exceeded.

Operation: In the building's use phase (27 %) the GWP is mainly influenced by electricity demand (42 %), followed by the hot water provision (27 %). The residential building B is heated with a borehole heat exchanger. The reference level is exceeded by 55 %.

Induced mobility: The global warming potential of the induced mobility has a share of 36 % on the total GHG emissions and meets the reference value.

Conclusion: The impacts of the construction stage on the GWP are most dominant. The construction and the refurbishment have similar impacts and dominate the results. Overall the GWP of the residential building B meets the target level for refurbished residential buildings.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Residential B, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 2'894 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, heat distribution with radiators Cooling: n/a
Final energy demand electricity	Ventilation 10 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 77 MJ/m^2a (per energy reference area) Hot water 50 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Building pit Backfill Foundation plate Ceilings Roof Pillars External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

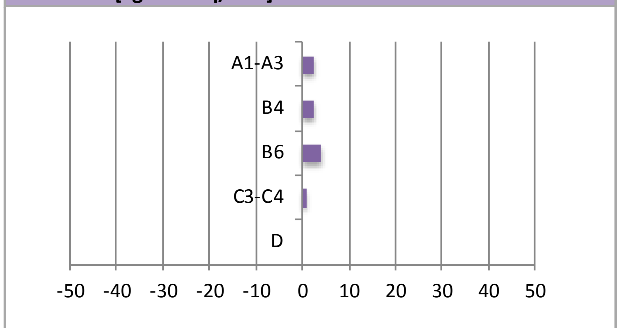
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH9	Residential building B

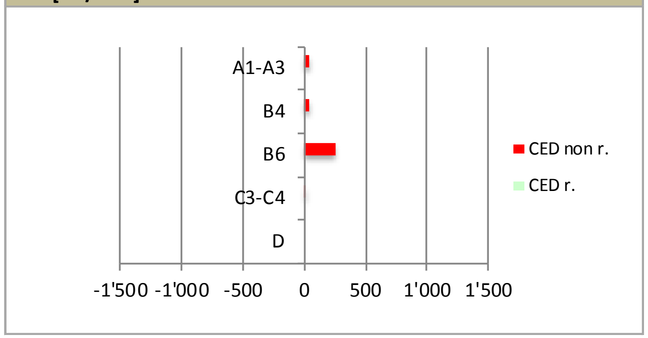
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO_2/m²a	2.31E+00	2.30E+00	3.86E+00	7.25E-01	0.00E+00
CED non r.	MJ/m²a	3.78E+01	3.89E+01	2.47E+02	8.26E-01	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH10

The total environmental impacts of buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The residential building E (new building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The residential building E has a total env. impact of 31'000 eco-points/m^{2}a, primary energy demand (non renew.) of 440 MJ/m^{2}a and a GWP of 18 kg CO_2/m^{2}a. The building meets the target values for new residential buildings regarding CED nr but not for the greenhouse gas emissions. The CED is dominated by the use stage whereas the GHG emissions are dominated by the construction stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building and the type of energy source for the provision of heat and hot water.

treeze fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This residential building E is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

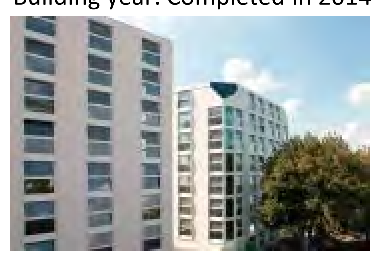
BUILDING KEY FACTS

Intended use: Residential home

Size: 2'478 m^2 gross floor area, 2'156 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed in 2014



Source: Stadt Zürich, Amt für Hochbauten, Foto: Giorgio von Arb

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

- Wyss et al. (2014) Zielwert Gesamtumweltbelastung Gebäude, Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten
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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distribution, hot water generation as well as ventilation are considered.
The replacements of building materials and components during the service life of the building Ere calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

DETAILED RESULTS OF THE RESIDENTIAL BUILDING E, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the residential building E in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²	kg CO2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	12.59	756	756	-	-	0.2	9.1	9.1	-	-	0.01	0.61	0.61	-	-
	backfill	4	257	257	-	-	0.1	3.1	3.1	-	-	0.00	0.21	0.21	-	-
	fundament	744	44'639	38'141	-	6'498	4.7	279.4	230.4	-	49.0	0.42	25.08	22.47	-	2.61
	ceiling	1'855	111'301	97'739	-	13'562	11.4	684.9	585.7	-	99.2	1.27	76.07	70.62	-	5.45
	roof	1'028	61'699	46'930	2'941	11'828	8.7	521.2	399.2	77.0	45.0	0.76	45.70	31.97	2.41	11.31
	pillars	34	2'032	1'878	-	155	0.2	12.0	10.9	-	1.2	0.02	1.11	1.04	-	0.06
	outer walls basement	258	15'454	12'205	1'077	2'173	1.8	110.2	82.6	16.0	11.5	0.22	13.28	9.87	1.82	1.59
	outer walls upper floors	513	30'777	24'299	-	6'479	7.4	443.3	422.7	-	20.6	0.62	37.31	30.35	-	6.95
	windows	1'545	92'695	40'429	40'429	11'838	18.6	1'114.8	552.8	552.8	9.2	1.26	75.86	35.41	35.41	5.05
	inner walls raw	701	42'062	37'184	-	4'878	4.6	277.2	244.0	-	33.2	0.47	28.21	26.16	-	2.05
	separation walls/inner doors	1'088	65'292	28'861	28'861	7'569	10.2	612.6	299.5	299.5	13.5	0.64	38.42	17.95	17.95	2.53
	flooring	941	56'435	21'962	21'962	12'510	9.9	593.5	277.7	277.7	38.1	0.89	53.24	22.44	22.44	8.36
	wall cover	378	22'666	10'094	10'094	2'478	3.1	185.2	88.8	88.8	7.6	0.24	14.49	6.29	6.29	1.91
	ceiling cover	109	6'570	2'553	2'553	1'464	1.1	68.5	32.7	32.7	3.0	0.08	4.51	1.58	1.58	1.34
	infrastructure	4'088	245'285	110'898	127'298	7'089	33.2	1'994.0	874.5	1'106.6	13.0	2.03	121.99	49.52	62.54	9.93
	sum building	**13'299**	**797'921**	**474'185**	**235'215**	**88'521**	**115.2**	**6'909.0**	**4'113.8**	**2'451.1**	**344.1**	**8.93**	**536.07**	**326.49**	**150.44**	**59.14**
Operation	room heating	1'876	112'554				38.5	2'310.3				0.60	36.15			
	hot water	3'157	189'393				65.9	3'951.9				1.03	61.83			
	ventilation	751	45'058				15.8	948.5				0.25	14.84			
	other operational energy	4'881	292'877				102.7	6'165.0				1.61	96.45			
	sum operation	**10'665**	**639'883**				**222.9**	**13'375.7**				**3.49**	**209.27**			
Building induced	**sum mobility**	**6'759**	**405'550**				**103.2**	**6'190.0**				**5.33**	**320.00**			
sum total	**construction, operation und building induced mobility**	**30'723**					**441.2**					**17.76**				
target							**440.0**					**16.50**				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building E per m^2 energy reference area and 60 years lifespan.

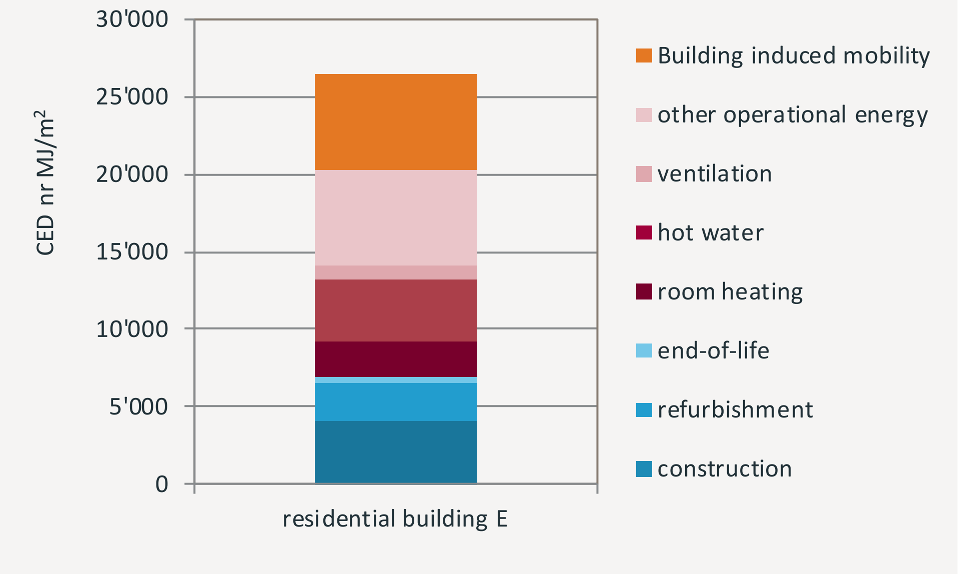


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the residential building E .

Total construction (construction, renewal and deconstruction): The total construction has a share of 26 % to the overall primary energy demand (non renew.).
The construction itself contributes to 60 % to this. The main impacts come from the ceiling, the windows, the walls, the flooring as well as from the infrastructure. The renewal phase contributes to 35 % to the primary energy demand of the total construction. In comparison the deconstruction has an impact of 5 %. The Swiss reference value regarding primary energy demand (non renew.) is slightly exceeded.

Operation: With 51 % the total operation has the main impact on the primary energy demand. The largest impact is caused by the electricity demand (46 %), followed by the hot water provision (30 %). The Swiss reference level for refurbished residential buildings is exceeded by 11 %.

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 23 % to the CED and holds the Swiss reference value.

Conclusion: The primary energy demand (non renewable) of the refurbished residential property meets the target value. The main impact is caused by the operation phase.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the residential building E per m^2 energy reference area and 60 years lifespan.

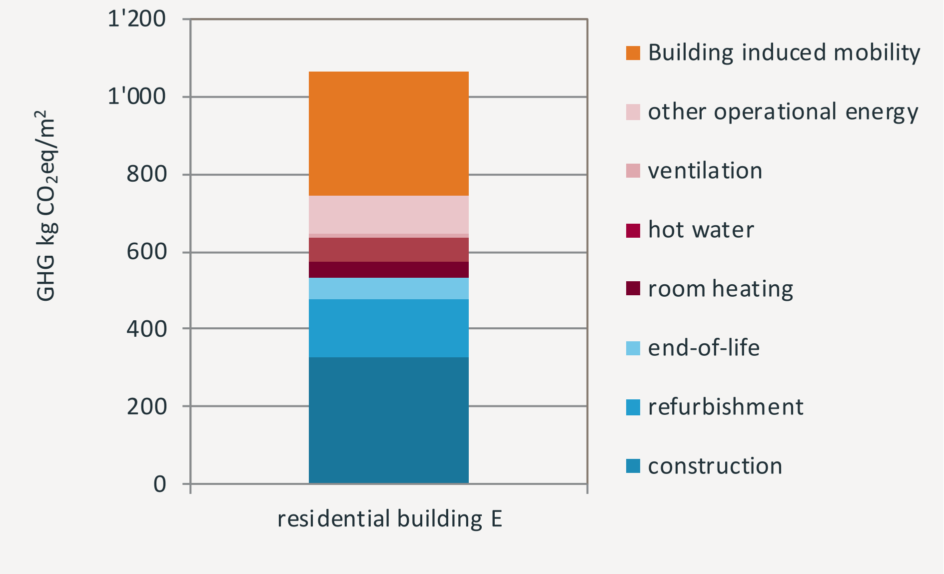


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the residential building E .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 50 %. Within the construction phase the materialization is dominating the GWP (61 %). The main impacts come from the ceilings, windows as well as from the infrastructure. The renewal per year contributes about 28 % to the GWP of the total construction. The deconstruction has a share of 11 %. The reference level regarding GWP for new residential buildings is slightly exceeded.

Operation: In the building's use phase (20 %) the GWP is mainly influenced by electricity demand (46 %), followed by the hot water provision (30 %). The residential building E is heated with a borehole heat exchanger. The reference level is exceeded by 40 %.

Induced mobility: The global warming potential of the induced mobility has a share of 30 % on the total GHG emissions and meets the reference value.

Conclusion: The impacts of the construction stage on the GWP are most dominant. The construction itself dominates the results. Overall the GWP of the residential building E slightly exceeds the target level for new residential buildings.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Residential E, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	2’487 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 2’156 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 6 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 57 MJ/m^2a (per energy reference area) Hot water 50 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Building pit Backfill Foundation plate Ceilings Roof Pillars External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

DOCUMENTATION REQUIREMENTS RESIDENTIAL BUILDING E (III)

Annex 57

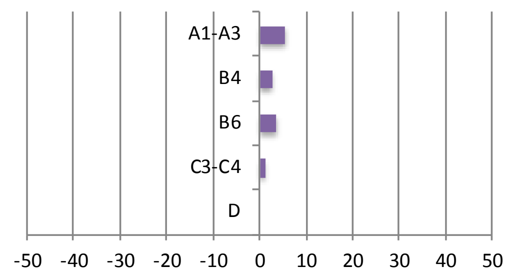
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH10	Residential building E

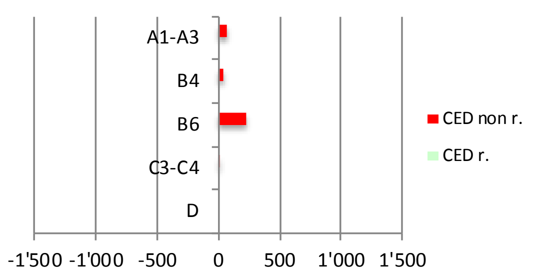
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	5.44E+00	2.51E+00	3.49E+00	9.86E-01	0.00E+00
CED non r.	MJ/m²a	6.86E+01	4.09E+01	2.23E+02	5.73E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH11
The total environmental impacts of buildings

KEY OBSERVATIONS

The retirement home A (refurbished building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The retirement home A has a total env. impact of 22'000 eco-points/m^2a, primary energy demand (non renew.) of 390 MJ/m^2a and a GWP of 17 kg CO_2/m^2a. All indicators are dominated by the use stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building End the type of energy source for the provision of heat and hot water.

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This retirement home A is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Retirement home

Size: 10'532 m^2 gross floor area, 9'843 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed in 2011

Source: Stadt Zürich, Amt für Hochbauten, Foto: Georg Aerni

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

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Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building Ere calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

Retirement home A

The property was built in 1976 and serves multifunctional purposes: retirement home, social center, coffee shops, shops and public parking. The new concept still encompasses all these functions. The retirement home was refurbished completely. Today there are 120 apartments of various size. The pensioners have different social services to make demand of.

All buildings are energetically refurbished and fulfill now the criteria of Minergie. Heating is covered by district heat.

CHARACTERISTIC FACTORS OPERATION

Floor area	10’532 m^2
Energy reference area	9’843 m^2
Energy demand room heating	68 MJ/m^2a
Energy demand hot water	50 MJm^2a
Energy demand electrical power	48 MJ/m^2a
- Energy demand ventilation:	10 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade A
Distance for groceries	0.1 km
Parking spots	0.07 parking spots per pensioner and employee
Public transport subscriptions	0.25 permanent public transport subscriptions (Swiss average)

DETAILED RESULTS OF THE RETIREMENT HOME A, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the retirement home A in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m²a	UBP/m²				MJ/m²a	MJ/m²				kg CO_2/m²a	kg CO_2/m²			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	backfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	fundament	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ceiling	45	2'713	2'137	168	408	0.3	19.8	14.2	2.4	3.2	0.03	1.93	1.66	0.09	0.18
	roof	735	44'084	12'005	12'005	20'075	15.6	935.0	460.0	460.0	15.0	0.96	57.73	14.28	14.28	29.16
	pillars	2	137	119	-	19	0.0	0.9	0.7	-	0.1	0.00	0.12	0.11	-	0.01
	outer walls basement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	outer walls upper floors	124	7'461	4'344	1'752	1'364	1.2	71.9	41.9	23.6	6.4	0.14	8.56	5.18	2.39	0.99
	windows	509	30'550	13'178	13'178	4'194	5.9	353.8	175.4	175.4	3.1	0.40	24.11	11.18	11.18	1.74
	inner walls raw	132	7'926	6'801	-	1'125	1.1	68.6	60.0	-	8.5	0.13	7.51	7.06	-	0.45
	separation walls/inner doors	680	40'815	18'878	18'878	3'060	9.7	584.1	285.7	285.7	12.7	0.64	38.50	18.78	18.78	0.95
	flooring	191	11'444	4'260	4'260	2'923	2.4	141.3	68.9	68.9	3.4	0.15	9.06	3.27	3.27	2.52
	wall cover	754	45'249	14'855	21'892	8'502	6.7	402.0	134.7	256.3	11.1	0.51	30.61	8.24	13.36	9.01
	ceiling cover	96	5'775	2'168	2'744	862	1.3	77.6	32.8	42.7	2.1	0.08	4.99	1.89	2.31	0.79
	infrastructure	3'433	205'985	97'798	101'098	7'089	22.9	1'376.9	668.8	695.1	13.0	1.46	87.73	38.10	39.70	9.93
	sum building	**6'702**	**402'139**	**176'542**	**175'975**	**49'623**	**67.2**	**4'031.9**	**1'943.2**	**2'010.2**	**78.5**	**4.51**	**270.84**	**109.75**	**105.36**	**55.73**
Operation	room heating	1'770	106'193				56.8	3'405.6				3.18	190.68			
	hot water	1'902	114'123				61.0	3'659.9				3.42	204.92			
	ventilation	1'252	75'098				26.3	1'580.8				0.41	24.73			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	9'680	**580'780**				244.2	**14'653.2**				8.57	**514.32**			
Building induced mobility	**sum mobility**	**5'366**	**321'970**				**82.0**	**4'920.0**				**4.17**	**250.00**			
sum total	**construction, operation und building induced mobility**	**21'748**					**393.4**					**17.25**				
target							-					-				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the retirement home A per m^2 energy reference area and 60 years lifespan.

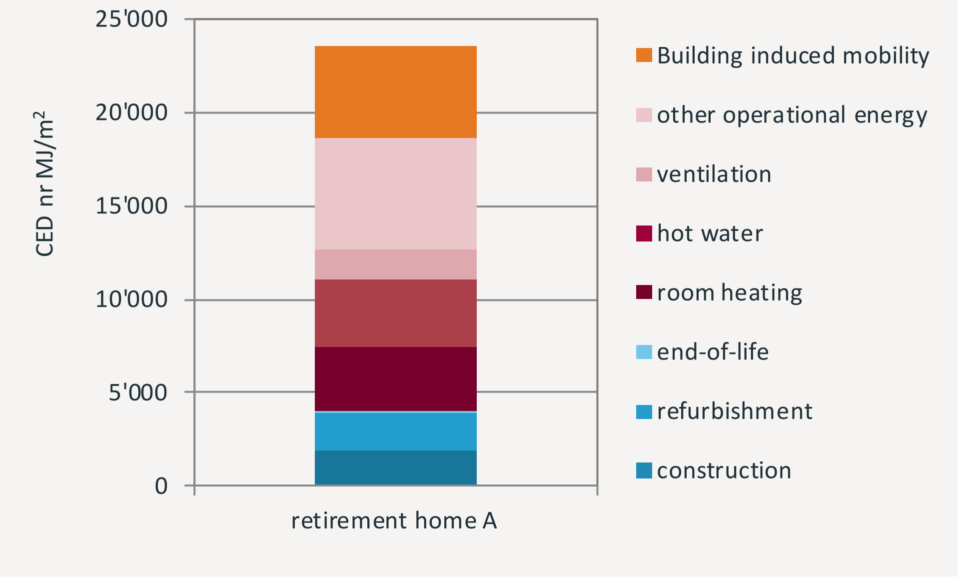


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the retirement home A .

Total construction (construction, renewal and deconstruction): The total construction has a share of 17 % to the overall primary energy demand (non renew.).
The construction itself contributes to 48 % to this. The main impacts come from the roof, the windows, the walls, the wall covers as well as from the infrastructure. The renewal phase contributes to 50 % to the primary energy demand of the total construction. In comparison the deconstruction has an impact of 2 %.

Operation: With 62 % the total operation has the main impact on the primary energy demand. The largest impact is caused by the electricity demand (41 %), followed by the hot water provision (25 %).

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 21 % to the CED.

Conclusion: The primary energy demand (non renewable) of the retirement home A is dominated by the use stage.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the retirement home A per m² energy reference area and 60 years lifespan.

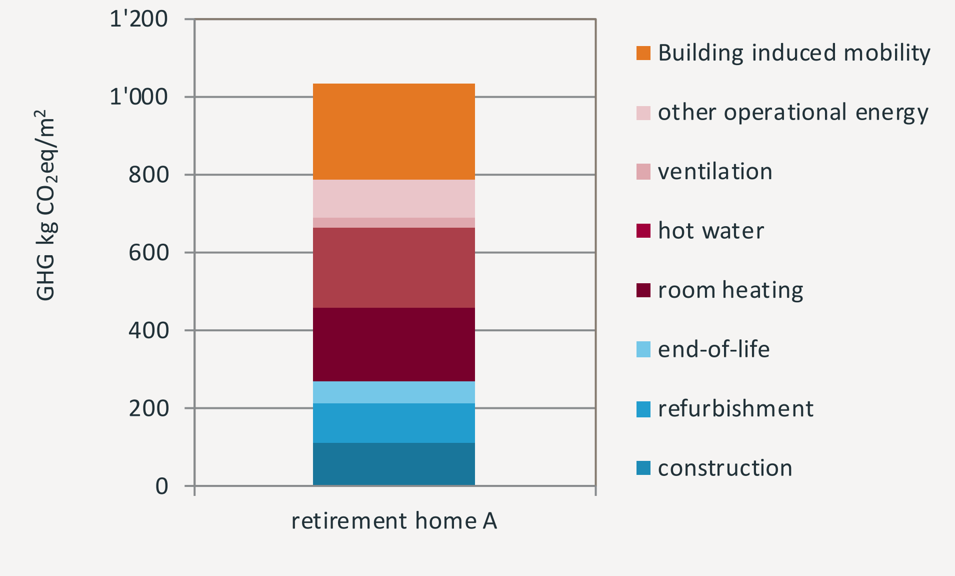


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the retirement home A .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 26 %. Within the construction phase the materialization is dominating the GWP (41 %). The main impacts come from the roof, the inner walls, windows as well as from the infrastructure. The renewal per year contributes about 39 % to the GWP of the total construction. The deconstruction has a share of 21 %.

Operation: In the building's use phase (50 %) the GWP is mainly influenced by the hot water provision (40 %), followed by the room heating (37 %). The retirement home A is heated with a district heat.

Induced mobility: The global warming potential of the induced mobility has a share of 24 % on the total GHG emissions.

Conclusion: The impacts of the use stage on the GWP are most dominant. The hot water provision dominates the results.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Retirement home A, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	10’532 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 9’843 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: district heat, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 10 MJ/m^{2}a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^{2}a (per energy reference area)
Final energy demand for heating and hot water	Room heating 68 MJ/m^{2}a (per energy reference area) Hot water 50 MJ/m^{2}a (per energy reference area)
Final energy demand for cooling	0 MJ/m^{2}a
Benchmark	Minergie
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Ceilings Roof Pillars External walls (above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

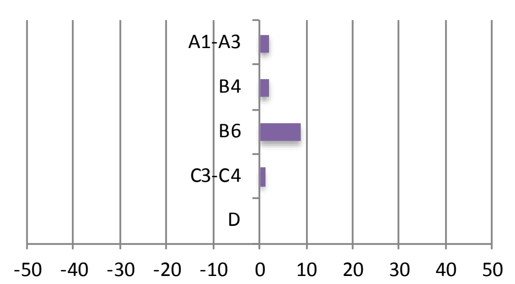
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		Annex 57
CH11	Retirement home A	

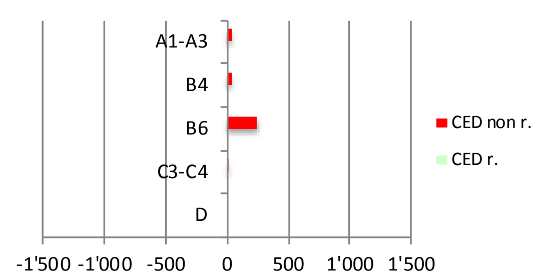
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	1.83E+00	1.76E+00	8.57E+00	9.29E-01	0.00E+00
CED non r.	MJ/m²a	3.24E+01	3.35E+01	2.44E+02	1.31E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH12

The total environmental impacts of buildings

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The rest home B (refurbished building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The rest home B has a total env. impact of 31'000 eco-points/m^{2}a, primary energy demand (non renew.) of 470 MJ/m^{2}a and a GWP of 17 kg CO_2/m^{2}a. The indicator CED is dominated by the use stage, while the GWP is mostly influenced by the construction stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building End the type of energy source for the provision of heat and hot water.

treeze
fair life cycle thinking

OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This rest home B is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Retirement/Rest home

Size: 14'479 m^2 gross floor area, 11'186 m^2 energy reference area

Location: Zurich, Switzerland

Building year: Completed in 2010

Source: Stadt Zürich, Amt für Hochbauten, Foto: Georg Aerni

ABBREVIATIONS

CED cumulative energy demand

GHG greenhouse gases

GWP global warming potential

LCA life cycle assessment

nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

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- SIA D 0236 (2011), SIA-Effizienzpfad Energie – Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building Ere calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

Rest home B

The rest home B was constructed in 1983 and it corresponds to the zeitgeist of the 70ies. In encompassing work the building was renewed optically and energetically. The façade, the roof, the interior and the technical equipment was refurbished. The building consists of six upper floors, ground floor and basement and a green flat roof.

The buildings meet the requirements of Minergie standard. Hot water and room heating are covered by an electrical heat pump equipped with a borehole heat exchanger and floor heating. Peak demand is covered with a gas-fueled boiler. The rest home has automatic ventilation.

CHARACTERISTIC FACTORS OPERATION

Floor area	14’479 m^2
Energy reference area	11’186 m^2
Energy demand room heating	98 MJ/m^2a
- Heat pump	95 %
- Gas	5 %
Energy demand hot water	50 MJm^2a
- Heat pump	80 %
- Gas	20 %
Energy demand electrical power	53 MJ/m^2a
- Energy demand ventilation:	15 MJ/m^2a
- Energy demand residual operation:	38 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade B
Distance for groceries	0.8 km
Parking spots	0.06 parking spots per pensioner and employee
Public transport subscriptions	0.25 permanent public transport subscriptions (Swiss average)

DETAILED RESULTS OF THE REST HOME B, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the rest home B in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^2a	UBP/m^2				MJ/m^2a	MJ/m^2				$kg\ CO_2/m^2a$	$kg\ CO_2/m^2$			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	2.44	146	146	-	-	0.0	1.8	1.8	0.0	0.0	0.00	0.12	0.12	-	-
	backfill	1	77	76	-	1	0.0	0.9	0.9	0.0	0.0	0.00	0.06	0.06	-	0.00
	fundament	177	10'620	8'897	-	1'723	1.2	69.1	57.2	0.0	11.9	0.11	6.77	5.93	-	0.84
	ceiling	1'033	61'978	53'174	2'001	6'804	6.5	391.3	321.8	18.2	51.3	0.70	41.91	37.97	1.16	2.77
	roof	838	50'257	24'222	7'488	18'547	9.0	541.2	345.1	148.0	48.1	0.61	36.57	11.64	4.37	20.56
	pillars	41	2'442	2'413	-	29	0.2	13.2	13.0	0.0	0.2	0.01	0.86	0.85	-	0.01
	outer walls basement	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-
	outer walls upper floors	1'773	106'401	64'023	41'386	993	13.9	832.7	481.4	344.6	6.7	1.02	61.26	38.61	22.29	0.36
	windows	611	36'639	16'507	16'507	3'625	7.8	465.9	231.4	231.4	3.1	0.53	31.66	15.05	15.05	1.56
	inner walls raw	182	10'914	9'359	-	1'555	2.8	166.4	155.5	0.0	10.9	0.25	14.86	14.30	-	0.57
	separation walls/inner doors	389	23'356	8'473	8'473	6'410	4.2	254.0	123.4	123.4	7.1	0.26	15.82	6.85	6.85	2.12
	flooring	942	56'497	23'284	23'284	9'930	6.9	414.3	184.6	184.6	45.1	0.84	50.10	23.32	23.32	3.46
	wall cover	1'050	63'014	27'256	27'256	8'502	8.4	504.2	243.6	243.6	16.9	0.67	40.25	17.53	17.53	5.19
	ceiling cover	512	30'734	14'646	14'646	1'441	3.7	221.1	108.8	108.8	3.5	0.21	12.84	5.89	5.89	1.07
	infrastructure	4'143	248'592	118'567	122'936	7'089	27.8	1'667.7	793.1	861.7	13.0	1.74	104.50	45.38	49.19	9.93
	sum building	**11'694**	**701'669**	**371'043**	**263'977**	**66'649**	**92.4**	**5'543.8**	**3'061.6**	**2'264.3**	**217.9**	**6.96**	**417.58**	**223.50**	**145.65**	**48.43**
Operation	room heating	3'902	234'093				83.3	4'996.3				1.59	95.43			
	hot water	2'836	170'144				66.6	3'996.5				1.86	111.30			
	ventilation	1'877	112'645				39.5	2'371.1				0.62	37.10			
	other operational energy	4'756	285'366				100.1	6'006.9				1.57	93.98			
	sum operation	13'371	**802'248**				289.5	**17'370.8**				5.63	**337.81**			
Building induced mobility	**sum mobility**	**5'733**	**344'000**				**87.7**	**5'260.0**				**4.50**	**270.00**			
sum total	**construction, operation und building induced mobility**	**30'799**					**469.6**					**17.09**				
target							-					-				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the rest home B per m^2 energy reference area and 60 years lifespan.

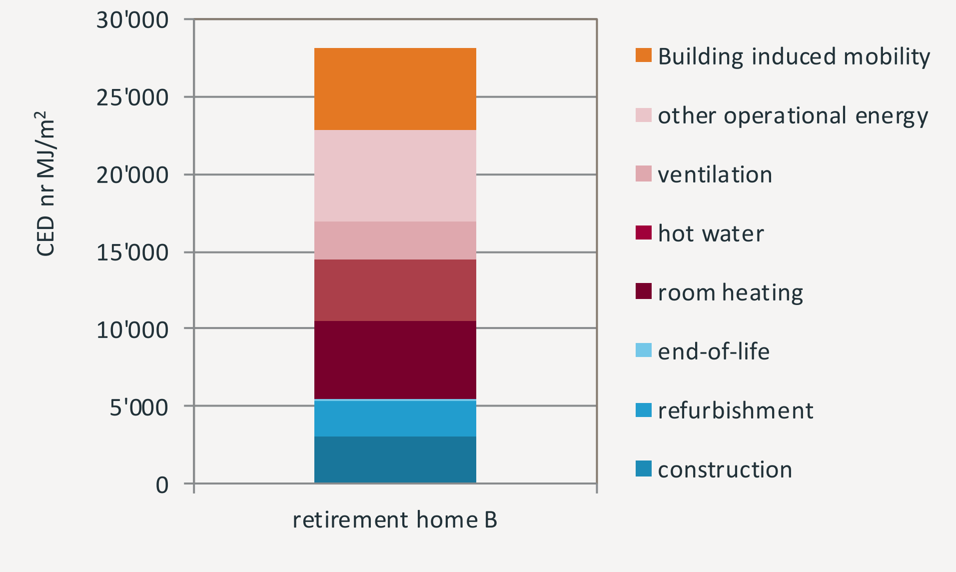


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the rest home B .

Total construction (construction, renewal and decon-struction): The total construction has a share of 20 % to the overall primary energy demand (non renew.).
The construction itself contributes to 55 % to this. The main impacts come from the roof, ceiling, inner walls, windows, wall covers, flooring as well as from the infrastructure. The renewal phase contributes to 41 % to the primary energy demand of the total construction. In comparison the deconstruction has an impact of 4 %.

Operation: With 62 % the total operation has the main impact on the primary energy demand. The largest impact is caused by the electricity demand (35 %), followed by the room heating (29 %).

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 19 % to the CED.

Conclusion: The primary energy demand (non renewable) of the rest home B is dominated by the use stage, especially the operational electrical energy.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the rest home B per m² energy reference area and 60 years lifespan.

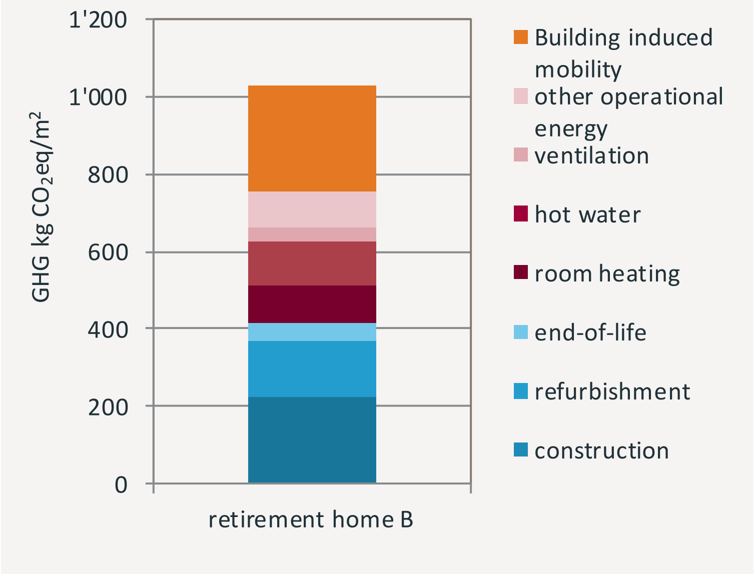


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the rest home B .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 41 %. Within the construction phase the materialization is dominating the GWP (54 %). The main impacts come from the roof, ceiling, the inner walls, windows, wall covers, flooring as well as from the infrastructure. The renewal per year contributes about 35 % to the GWP of the total construction. The deconstruction has a share of 12 %.

Operation: In the building's use phase (33 %) the GWP is mainly influenced by the hot water provision (33 %), followed by the room heating and electricity demand (28 % each). The rest home B is heated with an electric heat pump equipped with a borehole heat exchanger. Peak demand is covered with a gas-fueled boiler.

Induced mobility: The global warming potential of the induced mobility has a share of 26 % on the total GHG emissions.

Conclusion: The impacts of the construction stage on the GWP are most dominant.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Retirement home B, refurbishment
Energy-standard	net-positive
Gross floor area/ Net floor area	14’479 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 11’186 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, peak demand is covered with a gas-fueled boiler, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 15 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 38 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 98 MJ/m^2a (per energy reference area) - Heat pump 95 % - Gas 5 % Hot water 50 MJ/m^2a (per energy reference area) - Heat pump 80 % - Gas 20 %
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life, operation and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

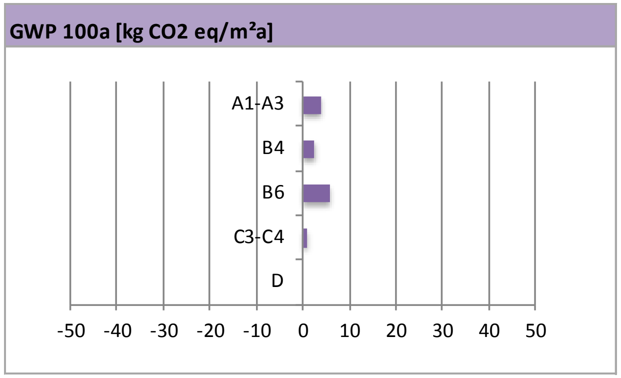
Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Only the materials used for the refurbishment were considered. Construction pit Backfilling Fundament plate Ceilings Roof Pillars External walls (above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

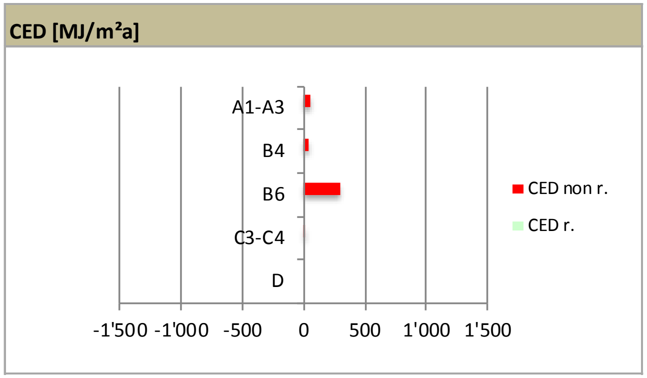
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment	
CH12	Retirement home B

Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	3.72E+00	2.43E+00	5.63E+00	8.07E-01	0.00E+00
CED non r.	MJ/m²a	5.10E+01	3.77E+01	2.90E+02	3.63E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)





Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH13
The total environmental impacts of buildings

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The retirement home C (refurbished building) was analyzed in terms of construction and operation of the buildings as well as the induced mobility. The env. impacts were assessed as total env. impact, non renewable primary energy demand and global warming potential (GWP). The latter two are shown in detail.

The retirement home C has a total env. impact of 29'000 eco-points/m^{2}a, primary energy demand (non renew.) of 380 MJ/m^{2}a and a GWP of 17 kg CO_2/m^{2}a. The indicator CED is dominated by the use stage, while the GWP is mostly influenced by the construction stage.

This example shows that the topic of env. impacts of buildings is not only very important but also very complex. The environmental impact depends largely on the materialization, the usage of the building End the type of energy source for the provision of heat and hot water.

treeze
fair life cycle thinking

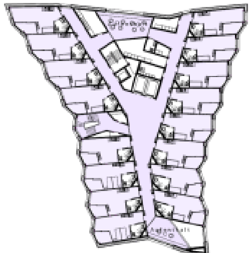
OBJECTIVES OF CASE STUDY

The main target is to perform a Life Cycle Assessment (LCA) to evaluate the total environmental (env.) impact of the building regarding construction, operation, end-of-life and induced mobility. This assessment is performed in the context of the discussion about reference and target values for env. impacts of buildings. 33 buildings located in Zurich, Switzerland, were analyzed. This retirement home C is one of the sample and is presented here. The study evaluates:

- The influence of the different life cycle stages: construction, renewal and deconstruction at the end-of-life
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The significance of the induced mobility
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Retirement home
Size: Gross floor area n/a, energy reference area 8'745 m^2
Location: Zurich, Switzerland
Building year: Not completed yet



Source: Enzmann + Fischer Architekten, Zürich

ABBREVIATIONS

CED cumulative energy demand
GHG greenhouse gases
GWP global warming potential
LCA life cycle assessment
nr non renewable

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

LCA BACKGROUND

Average life time of buildings:	60 years
Calculation of total env. impact:	Ecological scarcity 2006 (Frischknecht et al. 2008)
Calculation of Energy:	Cumulative energy demand, differing non-renewable and renewable primary energy (Frischknecht et al. 2007)
Calculation of GWP:	GWP 100 years (IPCC 2007, TS 2)
Databases used:	ecoinvent data v2.2

REFERENCES

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- SIA D 0236 (2011), SIA-Effizienzpfad Energie – Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. Transport to the building site is not considered, neither are the impacts of the construction phase itself. The datasets base on data of the Swiss public coordination conference of construction and property services of the public building owners (KBOB).

Operation stage modeling: In the building's use phase the energy consumption of space heating, heat distri-bution, hot water generation as well as ventilation are considered.
The replacements of building materials and compo-nents during the service life of the building Ere calculated based on the average lifetime of the component and the building; p. ex. a certain material with a life time of 30 years is accounted for twice because it is installed two times in the building's service life of 60 years.

End of life stage and next product system modeling: The EoL is modelled according to the current average Swiss disposal routes. Recycled materials cause no waste management impacts, nor are any credits accounted for. Other materials are landfilled or incinerated. The environmental impacts caused by waste management are accounted for.

Retirement home C

In Zurich-Wipkingen a new modern retirement home is planned. The existing retirement home does not meet the requirements of modern living no more. The new building shall fulfill the criteria of Minergie-P.

CHARACTERISTIC FACTORS OPERATION

Floor area	n/a
Energy reference area	9’843 m^2
Energy demand room heating	20 MJ/m^2a
Energy demand hot water	50 MJm^2a
Energy demand electrical power	45 MJ/m^2a
- Energy demand ventilation:	6 MJ/m^2a
- Energy demand residual operation:	39 MJ/m^2a

CHARACTERISTIC FACTORS INDUCED MOBILITY

Type	City center
Public transport	grade B
Distance for groceries	0.7 km
Parking spots	0.06 parking spots per pensioner and employee
Public transport subscriptions	0.25 permanent public transport subscriptions (Swiss average)

DETAILED RESULTS OF THE RETIREMENT HOME C, ZURICH

Total environmental impact, non renewable primary energy demand and global warming potential of the retirement home C in Zurich, referring to 1 m² energy reference area and 60 years service life.

	indicator	sum environmental impact					primary energy demand non renewable					greenhouse gas emissions				
	unit	UBP/m^2a	UBP/m^2				MJ/m^2a	MJ/m^2				$kg\ CO_2/m^2a$	$kg\ CO2/m^2$			
	EKG-number	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life	sum amortized	sum	construction	refurbishment	end-of-life
Building's construction	construction pit	21.99	1'319	1'319	-	-	0.3	15.9	15.9	0.0	0.0	0.02	1.06	1.06	-	-
	backfill	5	327	327	-	-	0.1	4.0	4.0	0.0	0.0	0.00	0.26	0.26	-	-
	fundament	1'197	71'842	58'778	-	13'064	7.8	465.1	378.8	0.0	86.3	0.87	52.42	45.54	-	6.88
	ceiling	2'474	148'469	126'834	332	21'303	17.2	1'030.5	871.4	4.8	154.2	1.79	107.16	96.95	0.22	9.99
	roof	1'287	77'210	55'678	9'611	11'920	11.5	688.6	500.2	141.2	47.2	0.98	58.84	41.07	6.39	11.38
	pillars	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-
	outer walls basement	615	36'903	27'179	2'022	7'702	5.1	305.4	229.5	45.0	30.9	0.60	35.71	25.44	2.99	7.28
	outer walls upper floors	1'433	85'982	61'568	19'774	4'640	11.2	670.9	467.2	167.2	36.4	0.89	53.13	40.34	10.91	1.88
	windows	645	38'680	16'689	16'689	5'302	7.5	452.5	224.4	224.4	3.8	0.51	30.82	14.29	14.29	2.24
	inner walls raw	1'064	63'844	54'587	-	9'257	6.7	404.3	333.8	0.0	70.5	0.83	50.02	46.24	-	3.78
	separation walls/inner doors	891	53'480	24'046	24'046	5'387	10.0	600.9	294.1	294.1	12.6	0.57	34.42	16.26	16.26	1.90
	flooring	245	14'728	5'582	4'055	5'092	3.2	194.7	122.5	69.1	3.0	0.24	14.25	4.74	3.60	5.92
	wall cover	385	23'108	10'841	10'841	1'425	2.7	161.4	78.9	78.9	3.7	0.16	9.48	4.17	4.17	1.14
	ceiling cover	177	10'609	4'282	4'668	1'659	2.2	133.9	62.4	69.2	2.3	0.16	9.43	3.84	4.12	1.48
	infrastructure	3'433	205'985	97'798	101'098	7'089	22.9	1'376.9	668.8	695.1	13.0	1.46	87.73	38.10	39.70	9.93
	sum building	**13'875**	**832'485**	**545'509**	**193'136**	**93'840**	**108.4**	**6'504.8**	**4'251.9**	**1'789.1**	**463.8**	**9.08**	**544.74**	**378.31**	**102.65**	**63.79**
Operation	room heating	861	51'649				6.5	391.5				0.33	19.76			
	hot water	2'875	172'475				59.9	3'592.7				0.94	56.21			
	ventilation	751	45'058				15.8	948.5				0.25	14.84			
	other operational energy	4'881	292'877				102.7	6'165.0				1.61	96.45			
	sum operation	**9'368**	**562'060**				**185.0**	**11'097.6**				**3.12**	**187.26**			
Building induced mobility	**sum mobility**	**5'709**	**342'510**				**87.3**	**5'240.0**				**4.50**	**270.00**			
sum total	**construction, operation und building induced mobility**	**28'951**					**380.7**					**16.70**				
target							-					-				

PRIMARY ENERGY DEMAND, NON RENEWABLE

Primary energy demand, non renewable, from the construction, operation and induced mobility for the retirement home C per m^2 energy reference area and 60 years lifespan.

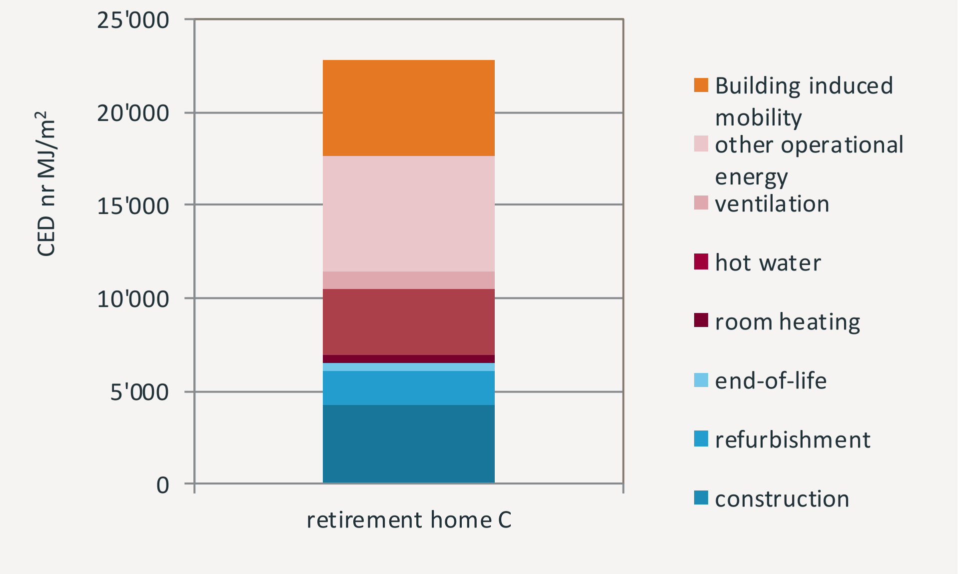


Figure 1: Contribution to the primary energy demand, non renewable, from the construction, operation and induced mobility for the retirement home C .

Total construction (construction, renewal and decon-struction): The total construction has a share of 28 % to the overall primary energy demand (non renew.).
The construction itself contributes to 65 % to this. The main impacts come from the fundament, ceilings, the roof, the windows, the walls as well as from the infrastructure. The renewal phase contributes to 28 % to the primary energy demand of the total construction. In comparison the deconstruction has an impact of 7 %.

Operation: With 49 % the total operation has the main impact on the primary energy demand. The largest impact is caused by the electricity demand (56 %), followed by the hot water provision (32 %).

Induced mobility: The primary energy demand (non renew.) of the induced mobility has a share of 23 % to the CED.

Conclusion: The primary energy demand (non renewable) of the retirement home C is dominated by the use stage, especially the electricity demand.

GLOBAL WARMING POTENTIAL (GWP)

Global warming potential from the construction, operation and induced mobility for the retirement home C per m² energy reference area and 60 years lifespan.

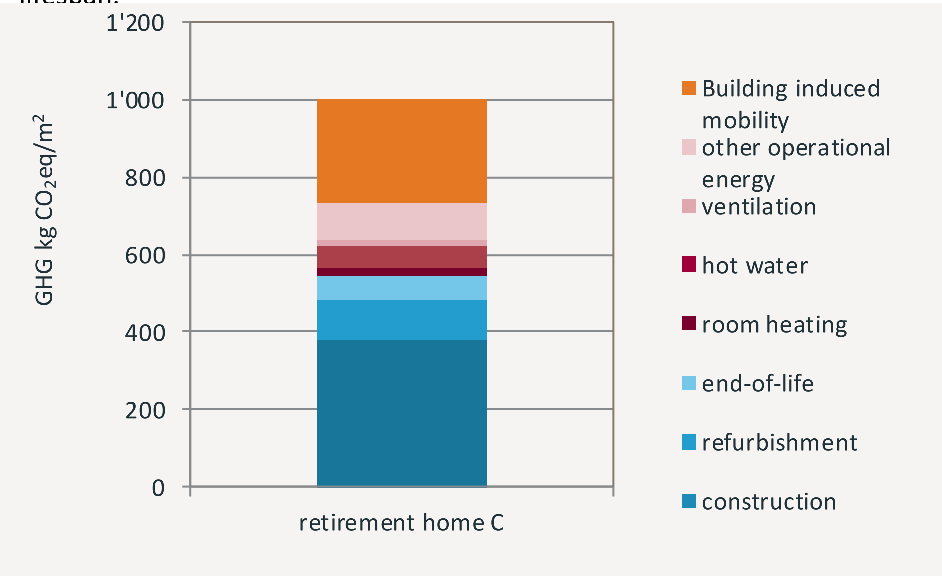


Figure 2: Contribution to the global warming potential from the construction, operation and induced mobility for the retirement home C .

Total construction (construction, renewal and deconstruction): The construction phase contributes to the total global warming potential by 54 %. Within the construction phase the materialization is dominating the GWP (69 %). The main impacts come from the fundament, ceilings, the roof, walls as well as from the infrastructure. The renewal per year contributes about 19 % to the GWP of the total construction. The deconstruction has a share of 12 %.

Operation: In the building's use phase (19 %) the GWP is mainly influenced by the electricity demand (52 %) followed by the hot water provision (30 %). The retirement home C is heated with a heat pump.

Induced mobility: The global warming potential of the induced mobility has a share of 27 % on the total GHG emissions.

Conclusion: The impacts of the construction stage on the GWP are most dominant. The construction itself dominates the results.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Retirement home C, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	n/a
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 8'745 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, brick)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump equipped with a borehole heat exchanger, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 6 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 20 MJ/m^2a (per energy reference area) Hot water 50 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	Minergie-P-eco
Purpose of assessment	to determine CED and GHG emissions as well as total environmental impact for construction, use, end-of-life and the induced mobility of the building
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - use stage - end-of-life stage - induces mobility No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Construction pit Backfilling Fundament plate Ceilings Roof Pillars External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Infrastructure (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Recycling at the end-of-life
Accounting of electricity mix	static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GHG emissions (according to IPCC 2007 and 2013) total environmental impact (according to the method of ecological scarcity 2006 and 2013)

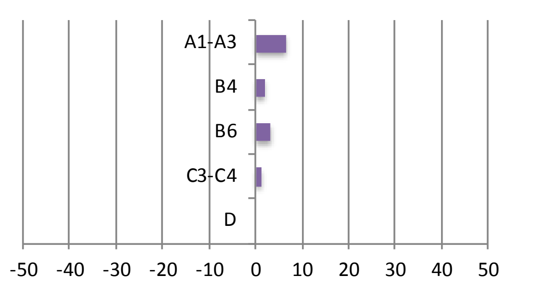
MINIMUM DOCUMENTATION REQUIREMENTS - RESULTS

Life Cycle Assessment		Annex 57
CH13	Retirement home C	

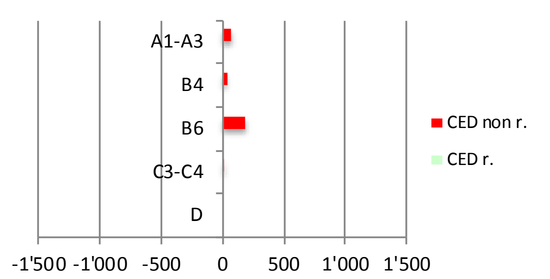
Indicator	Unit	Product stage	Use stage		End-of-Life	Next product system
		A1-A3: Product stage	B4: Replacement	B6: Operational energy use	C3-C4: End-of-Life	D: Reuse, recovery or recycling potential
GWP	kgCO2/m²a	6.31E+00	1.71E+00	3.12E+00	1.06E+00	0.00E+00
CED non r.	MJ/m²a	7.09E+01	2.98E+01	1.85E+02	7.73E+00	0.00E+00
CED r.	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED complete	MJ/m²a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* GWP (Global Warming Potential for a 100-year time horizon)

GWP 100a [kg CO2 eq/m²a]



CED [MJ/m²a]



Project: Richtwert Gesamtumweltbelastung Gebäude
Carried out by: treeze Ltd, Architekturbüro Preisig Pfäffli, ETH Zürich
Database: KBOB, ecoinvent

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH14
LCA of newly built Swiss apartment buildings

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The newly built Swiss residential building mfh08 was analyzed in terms of construction, replacement and disposal as well as operation. The environmental impacts were assessed regarding the non renewable primary energy demand (CEDnr) and global warming potential (GWP 100a).

Looking at construction, replacement and disposal, the residential building mfh08 has a CEDnr of about 108 MJ/m^2a and a GWP of about 8.3 kg CO_2eq./m^2a. During operation, it has a CEDnr of about 238 MJ/m^2a and a GWP of about 3.7 kg CO_2eq./m^2a.

The most relevant building elements are external walls (wall coverings included), ceilings (floorings included) and windows.

The most influential life cycle stages are the building construction and the operational phase.

ETH zürich DBAUG

OBJECTIVES OF CASE STUDY

Determine the most influential building parameters and life phases regarding EE and EG as well as operative energy and emissions of newly built Swiss apartment buildings over their life cycle.

The study evaluates:

- The influence of the different life cycle stages: construction, replacement and deconstruction at the end-of-life as well as building operation
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The impacts related to different building elements

Indicators: CEDnr and GWP 100a

CASE STUDY KEY FACTS

Intended use: Residential home
Size: 1’442 m^2 gross floor area, 1’121.9 m^2 energy reference area
Location: Switzerland
Year of construction: 2011
Building data: John, V. (2012). Derivation of reliable simplification strategies for the comparative LCA of Individual and Typical newly built Swiss Apartment buildings. Dissertation ETH Zurich, Zurich.

mfh08

ABBREVIATIONS

CED cumulative energy demand
CEDnr non renewable primary energy demand
GWP global warming potential
LCA life cycle assessment

Building life cycle stages included in the study, according to EN15978

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						X		X			X		X	

LCA BACKGROUND

Average life time of buildings:
60 years, according to the Swiss information leaflet SIA 2032 "Graue Energie von Gebäuden"

Calculation of Energy:
Annual energy demand, calculated according to the Swiss standard SIA 380/1 "Thermische Energie im Gebäude"; Modelling of energy systems according to the Swiss SIA information leaflet 2040 „SIA-Effizienzpfad Energie"; Primary energy demand calculated according to CEDnr.

Calculation of GWP:
GWP 100a (IPCC) with characterization factors as implemented in Simapro 7.3.0

Databases used:
Ecoinvent database version 2.2 and KBOB 2009/1 data (updated version from 2012)

Standards/guidelines:
LCA according to ISO regulations

REFERENCES

John, V. (2012). Derivation of reliable simplification strategies for the comparative LCA of Individual and Typical newly built Swiss Apartment buildings. Dissertation ETH Zurich, Zurich. «mfh08». DOI: http://dx.doi.org/10.3929/ethz-a-007607252

Wyss, F., Frischknecht, R., Pfäffli, K., John, V. (2014) Zielwert Gesamtumweltbelastung Gebäude, Report for the Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten. «Wohnliegenschaft P».

Production and construction stage modelling:
Environmental impact information related to raw material extraction and manufacturing of building materials are taken from the Swiss LCI database Ecoinvent version 2.2 and modelled with the LCA software SimaPro version 7.3.0.
Transportation to the manufacturer is already included in these Ecoinvent processes.
For environmental impact information concerning building services (installations for heating and ventilation system, electrical and sanitary installations), data from the Swiss KBOB list 2009/1 (updated version from 2012) by the Swiss public coordination conference of construction and property services of the public building owners was utilized.

Operation stage modelling: For the modelling of building operation, the annual energy demands for space heating, domestic hot water, ventilation, and other operational energy demands are considered. The calculations take into account the energy demand and the coverage and efficiency of the utilized energy systems. For the determination of the annual operational energy demands for heating and domestic hot water of the building, the Swiss standard SIA 380/1 was followed. For the ventilation energy demand and the other operational energy demands, the default values from the Swiss information leaflet SIA 2040 were utilized. LCI data from the Swiss KBOB list 2009/1 (updated version from 2012) was utilized for the assessment and the Swiss consumer mix was chosen as electricity mix during operation.
The replacement of building materials and components in the operation stage is also considered in the use stage.

End of life stage and next product system modelling: The final disposal of the building materials at their end-of-life is modelled, using data from the Ecoinvent database.
Transportation to the disposal site is already included in the Ecoinvent processes.

Residential building mfh08

The building was constructed in 2011 and offers 6 accommodation units. There are one basement floor and three floors over ground. In mfh08, regional Swiss wood products have been utilized in order to allow for reduced transportation to the building site. This building is a hybrid construction (mainly made of wood, with concrete elements as thermal mass) and has therefore comparably low embodied energy and emissions. The table below shows the quantities for the main construction materials as well as the insulation materials (for construction and replacement during the building's assumed service life of 60 years).

mfh08

Construction material	886.11	t	13.163	kg/m²a	Reinforced concrete
	51.38	t	0.763	kg/m²a	Timber and derived timber products
	48.56	t	0.721	kg/m²a	Sand-lime brick and cement mortar
Insulation material	20.61	t	0.306	kg/m²a	Recycled glass foam fill
	18.70	t	0.278	kg/m²a	Mineral wool
	5.77	t	0.086	kg/m²a	Expanded polystyrene (EPS)
	4.14	t	0.061	kg/m²a	Extruded polystyrene (XPS)

CHARACTERISTIC FACTORS OPERATION

Floor area	1'442 m²
Energy reference area	1'121.9 m²
Energy demand room heating	78 MJ/m²a
Energy demand hot water	50 MJm²a
Energy demand electrical power	45 MJ/m²a
- Energy demand ventilation:	6 MJ/m²a
- Energy demand residual operation:	39 MJ/m²a

The building meets the very high Swiss energy standard MINERGIE-P-ECO. In order to meet the MINERGIE-P-ECO requirements, various measures must be taken: The building envelope has to be air tight and well insulated with about 25-35 cm of insulation material. Heat bridges have to be avoided and additionally, a comfort ventilation system is applied. Furthermore, certain ecological requirements need to be fulfilled (e.g. concerning indoor air quality, recyclability of materials, noise protection and others). In this building, the heating energy demand is generated by an electric water brine heat pump, but there is no energy produced directly on site. The heat pump uses the Swiss energy mix.

DETAILED RESULTS OF THE RESIDENTIAL BUILDING mfh08

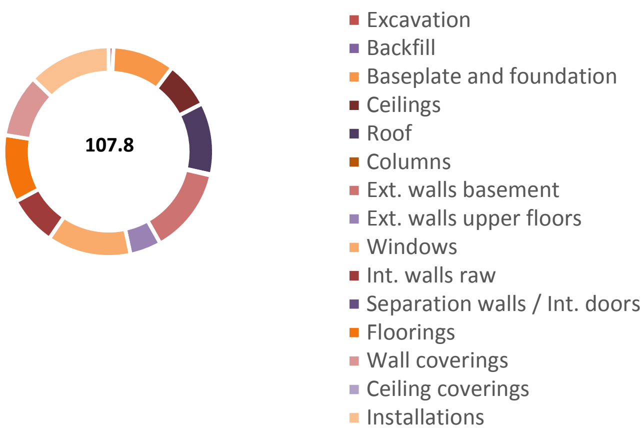
Non renewable primary energy demand CEDnr and global warming potential GWP 100a of the residential building mfh08, referring to 1 m² energy reference area and 1 year within the assumed service life of 60 years.

	Indicator	CEDnr					GWP 100a				
	Unit	MJ//m²a	MJ/m²				kg CO_2/m²a	kg CO_2/m²			
		Sum amortized	Sum	Construction	Replacement	Deconstruction	Sum amortized	Sum	Construction	Replacement	Deconstruction
Building's construction	Excavation	0.8	47.2	47.2	-	-	0.05	3.13	3.13	-	-
	Backfill	0	2.9	-	-	-	0	0.19	-	-	-
	Baseplate and foundation	10.3	616.9	558.1	-	58.8	0.71	42.71	39.97	-	2.74
	Ceilings	7.7	461.2	378	-	83.2	0.69	41.44	37.5	-	3.95
	Roof	11.9	712.3	352.6	333.7	25.9	0.61	36.9	15.85	14.81	6.23
	Columns	0.2	13.5	12.5	-	1	0.01	0.79	0.73	-	0.07
	Ext. walls basement	14.2	851.4	473.2	335.4	42.8	1.92	115.22	54.92	37.28	23.02
	Ext. walls upper floors	5.2	313.8	174.1	128.9	10.8	0.23	13.5	8.74	4.23	0.53
	Windows	13.9	831.8	412.2	412.2	7.3	0.94	56.33	26.22	26.22	3.89
	Int. walls raw	8.2	492.4	401.9	45.2	45.2	0.85	51.27	45.09	1.48	4.69
	Separation walls / Int. doors	-	-	-	-	-	-	-	-	-	-
	Floorings	11.2	670.1	287.4	287.4	95.4	0.91	54.6	24.14	24.14	6.33
	Wall coverings	10.4	626.7	305.1	305.1	16.5	0.51	30.67	13.91	13.91	2.86
	Ceiling coverings	-	-	-	-	-	-	-	-	-	-
	Installations	13.8	830.4				0.86	51.37			
	Sum building	**107.8**	**6'470.50**	**3'402.20**	**1'847.90**	**387.1**	**8.31**	**498.13**	**270.18**	**122.08**	**54.31**
Operation	Heating	52.8	3'168.80				0.82	49.20			
	Domestic hot water heating	66.0	3'960.0				1.03	61.50			
	Ventilation	15.8	950.4				0.25	14.76			
	Other operational energy	103.0	6177.6				1.6	95.94			
	Sum operation	**237.6**	**14'256.0**				**3.69**	**221.40**			

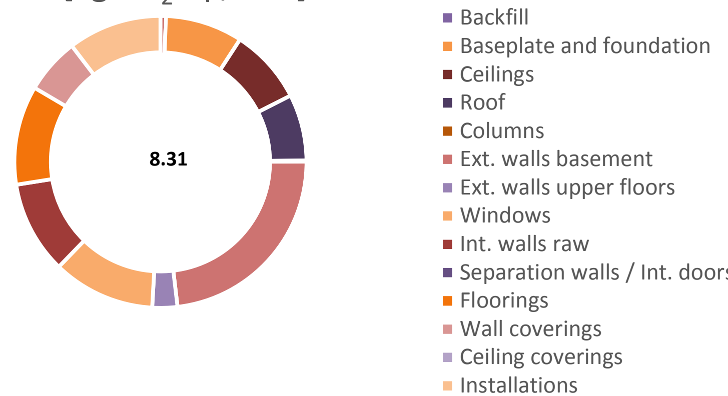
DETAILED RESULTS OF THE RESIDENTIAL BUILDING mfh08

Non renewable primary energy demand CEDnr and global warming potential GWP 100a of the residential building mfh08, referring to 1 m² energy reference area and 1 year within the assumed service life of 60 years.

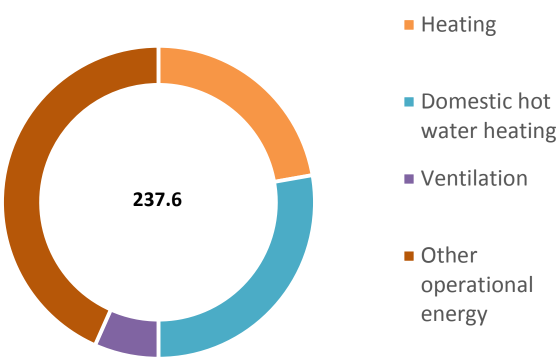
CEDnr building's construction [MJ/m²a]



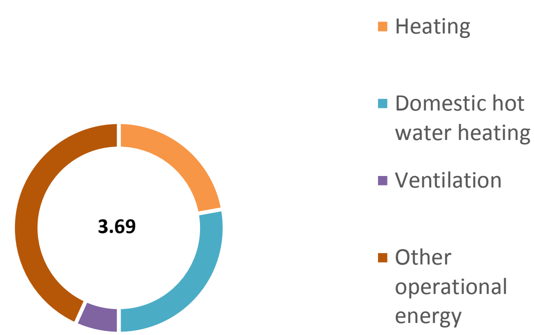
GWP 100a building's construction [kg CO_2eq./m²a]



CEDnr building operation [MJ/m²a]



GWP 100a building operation [kg CO_2eq./m²a]



MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Residential mfh08, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	1’442 m²
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 1’121.9 m²
Surface/Volume ratio (m-1)	n/a
Construction method	Hybrid construction (reinforced concrete, wood and sand-lime brick)
Thermal insulation	Insulation of floor, walls and roof
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump (water/brine) equipped with a borehole heat exchanger, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 6 MJ/m²a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m²a (per energy reference area)
Final energy demand for heating and hot water	Room heating 78 MJ/m²a (per energy reference area) Hot water 50 MJ/m²a (per energy reference area)
Final energy demand for cooling	0 MJ/m²a
Benchmark	-
Purpose of assessment	to determine CEDnr and GWP 100a for construction, replacement, deconstruction, operation
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Excavation Backfill Baseplate and foundation Ceilings Ext. walls (underground and above ground) Int. walls Columns Roof Ext. doors Floorings Wall coverings Ceiling coverings Installations (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Final disposal at the end-of-life
Accounting of electricity mix	Static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GWP 100a (according to IPCC 2007 and 2013)

Key issues related to Annex 57:
2.1 Which stages in the life cycle of the building are most important?
2.2 Which elements in the building?

Case study CH15

LCA of newly built Swiss apartment buildings

KEY OBSERVATIONS

The newly built Swiss residential building mfh11 was analyzed in terms of construction, replacement and disposal as well as operation. The environmental impacts were assessed regarding the non renewable primary energy demand (CEDnr) and global warming potential (GWP 100a).

Looking at construction, replacement and disposal, the residential building mfh11 has a CEDnr of about 105 MJ/m^{2}a and a GWP of about 7.8 kg CO_2eq./m^{2}a. During operation, it has a CEDnr of about 200 MJ/m^{2}a and a GWP of about 3.1 kg CO_2eq./m^{2}a.

The most relevant building elements are ceilings, external walls (wall coverings included) and baseplate (floorings included).

The most influential life cycle stages are the building construction and the operational phase.

OBJECTIVES OF CASE STUDY

Determine the most influential building parameters and life phases regarding EE and EC as well as operative energy and emissions of newly built Swiss apartment buildings over their life cycle.

The study evaluates:

- The influence of the different life cycle stages: construction, replacement and deconstruction at the end-of-life as well as building operation
- The importance of the annual operational energy demand: heating, hot water, ventilation, and residual operational energy demand
- The impacts related to different building elements

Indicators: CEDnr and GWP 100a

CASE STUDY KEY FACTS

Intended use: Residential home
Size: 3’064 m^2 gross floor area, 2’966 m^2 energy reference area
Location: Switzerland
Year of construction: 2012
Building data: John, V. (2012). Derivation of reliable simplification strategies for the comparative LCA of Individual and Typical newly built Swiss Apartment buildings. Dissertation ETH Zurich, Zurich.

ABBREVIATIONS

CED cumulative energy demand
CEDnr non renewable primary energy demand
GWP global warming potential
LCA life cycle assessment

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X			X		X	

LCA BACKGROUND

Average life time of buildings:
60 years, according to the Swiss information leaflet SIA 2032 "Graue Energie von Gebäuden"

Calculation of Energy:
Annual energy demand, calculated according to the Swiss standard SIA 380/1 "Thermische Energie im Gebäude"; Modelling of energy systems according to the Swiss SIA information leaflet 2040 „SIA-Effizienzpfad Energie"; Primary energy demand calculated according to CEDnr.

Calculation of GWP:
GWP 100a (IPCC) with characterization factors as implemented in Simapro 7.3.0

Databases used:
Ecoinvent database version 2.2 and KBOB 2009/1 data (updated version from 2012)

Standards/guidelines:
LCA according to ISO regulations

REFERENCES

John, V. (2012). Derivation of reliable simplification strategies for the comparative LCA of Individual and Typical newly built Swiss Apartment buildings. Dissertation ETH Zurich, Zurich. «mfh11». DOI: http://dx.doi.org/10.3929/ethz-a-007607252

Wyss, F., Frischknecht, R., Pfäffli, K., John, V. (2014) Zielwert Gesamtumweltbelastung Gebäude, Report for the Bundesamt für Energie (BfE), Bundesamt für Umwelt (Bafu), Stadt Zürich Amt für Hochbauten. «Wohnliegenschaft S».

Production and construction stage modelling:
Environmental impact information related to raw material extraction and manufacturing of building materials are taken from the Swiss LCI database Ecoinvent version 2.2 and modelled with the LCA software SimaPro version 7.3.0. Transportation to the manufacturer is already included in these Ecoinvent processes.
For environmental impact information concerning building services (installations for heating and ventilation system, electrical and sanitary installations), data from the Swiss KBOB list 2009/1 (updated version from 2012) by the Swiss public coordination conference of construction and property services of the public building owners was utilized.

Operation stage modelling: For the modelling of building operation, the annual energy demands for space heating, domestic hot water, ventilation, and other operational energy demands are considered. The calculations take into account the energy demand and the coverage and efficiency of the utilized energy systems. For the determination of the annual operational energy demands for heating and domestic hot water of the building, the Swiss standard SIA 380/1 was followed. For the ventilation energy demand and the other operational energy demands, the default values from the Swiss information leaflet SIA 2040 were utilized. LCI data from the Swiss KBOB list 2009/1 (updated version from 2012) was utilized for the assessment and the Swiss consumer mix was chosen as electricity mix during operation.
The replacement of building materials and components in the operation stage is also considered in the use stage.

End of life stage and next product system modelling: The final disposal of the building materials at their end-of-life is modelled, using data from the Ecoinvent database. Transportation to the disposal site is already included in the Ecoinvent processes.

Residential building mfh11

The building was constructed in 2012 and offers 22 accommodation units. There are one basement floor and three floors over ground. The building mfh11 has a compact design, which reduces material amounts for the building envelope. This building does not have any underground parking spaces which reduces the underground volume and thus improves the embodied energy and emissions balance of the building. The material choice follows the ecological requirements of the Swiss MINERGIE-P-ECO standard. The table below shows the quantities for the main construction materials as well as the insulation materials (for construction and replacement during the building's assumed service life of 60 years).

mfh11

Construction material	2798.83	t	15.727	kg/m²a	Reinforced concrete
	182.84	t	1.027	kg/m²a	Masonry + cement mortar
	6.17	t	0.035	kg/m²a	Steel
Insulation material	42.46	t	0.239	kg/m²a	Recycled glass foam fill
	13.06	t	0.073	kg/m²a	Expanded polystyrene (EPS)
	11.23	t	0.063	kg/m²a	Polyurethane foam (PU)
	11.12	t	0.062	kg/m²a	Extruded polystyrene (XPS)
	8.44	t	0.047	kg/m²a	Mineral wool

CHARACTERISTIC FACTORS OPERATION

Floor area	3'064 m²
Energy reference area	2'966 m²
Energy demand room heating	23 MJ/m²a
Energy demand hot water	50 MJm²a
Energy demand electrical power	45 MJ/m²a
- Energy demand ventilation:	6 MJ/m²a
- Energy demand residual operation:	39 MJ/m²a

The building meets the very high Swiss energy standard MINERGIE-P-ECO. In order to meet the MINERGIE-P-ECO requirements, various measures must be taken: The building envelope has to be air tight and well insulated with about 25-35 cm of insulation material. Heat bridges have to be avoided and additionally, a comfort ventilation system is applied. Furthermore, certain ecological requirements need to be fulfilled (e.g. concerning indoor air quality, recyclability of materials, noise protection and others). In this building, the heating energy demand is generated by an electric water brine heat pump, but there is no energy produced directly on site. The heat pump uses the Swiss energy mix.

DETAILED RESULTS OF THE RESIDENTIAL BUILDING mfh11

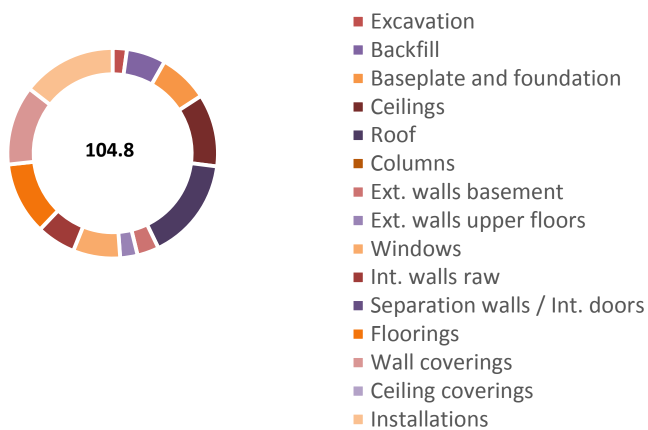
Non renewable primary energy demand CEDnr and global warming potential GWP 100a of the residential building mfh11, referring to 1 m² energy reference area and 1 year within the assumed service life of 60 years.

	Indicator	CEDnr					GWP 100a				
	Unit	MJ//m²a	MJ/m²				kg CO_2/m²a	kg CO_2/m²			
		Sum amortized	Sum	Construction	Replacement	Deconstruction	**Sum amortized**	Sum	Construction	Replacement	Deconstruction
Building's construction	**Excavation**	2.3	136.8	136.8	0.0	0.0	0.14	8.10	8.10	-	-
	Backfill	6.3	380.4	0.0	0.0	0.0	0.29	17.52	-	-	-
	Baseplate and foundation	8.0	480.7	434.9	0.0	45.8	0.55	33.29	31.15	-	2.14
	Ceilings	11.7	704.8	561.2	0.0	143.6	1.23	73.52	66.72	-	6.80
	Roof	16.6	996.7	548.0	381.0	67.7	1.24	74.59	32.81	12.95	28.83
	Columns	-	-	-	-	-	-	-	-	-	-
	Ext. walls basement	3.5	209.0	186.0	0.0	23.0	0.52	31.43	16.85	-	14.57
	Ext. walls upper floors	2.8	165.3	146.4	0.0	18.8	0.25	15.06	14.20	-	0.86
	Windows	7.6	454.9	225.3	225.3	4.4	0.51	30.86	14.32	14.32	2.22
	Int. walls raw	6.3	377.1	260.4	54.4	62.3	0.60	35.96	29.68	3.33	2.95
	Separation walls / Int. doors	-	-	-	-	-	-	-	-	-	-
	Floorings	11.7	701.4	323.1	323.1	55.1	0.80	48.20	19.36	19.36	9.49
	Wall coverings	12.8	766.6	380.0	380.0	6.7	0.70	41.96	15.41	15.41	11.13
	Ceiling coverings	-	-	-	-	-	-	-	-	-	-
	Installations	15.2	912.4				0.94	56.48			
	Sum building	**104.8**	**6286.1**	**3202.2**	**1363.7**	**427.4**	**7.78**	**466.97**	**248.60**	**65.37**	**79.00**
Operation	**Heating**	**15.6**	934.2				**0.24**	14.51			
	Domestic hot water heating	**66.0**	3'960.0				**1.03**	61.50			
	Ventilation	**15.8**	950.4				**0.25**	14.76			
	Other operational energy	**103.0**	6177.6				**1.60**	95.94			
	Sum operation	**200.4**	**12'022.2**				**3.11**	**186.71**			

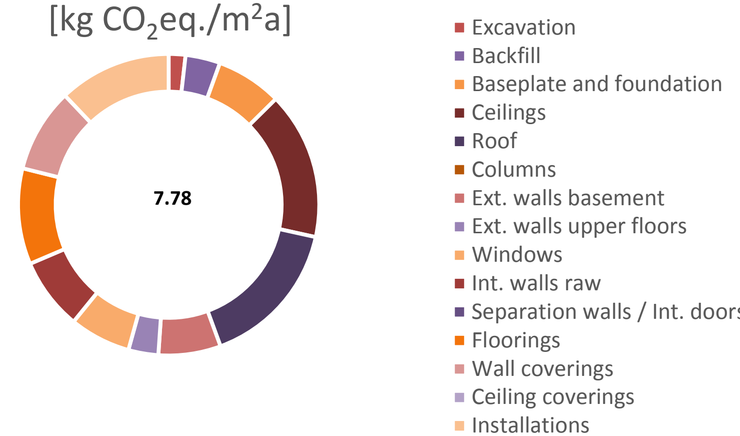
DETAILED RESULTS OF THE RESIDENTIAL BUILDING mfh11

Non renewable primary energy demand CEDnr and global warming potential GWP 100a of the residential building mfh11, referring to 1 m² energy reference area and 1 year within the assumed service life of 60 years.

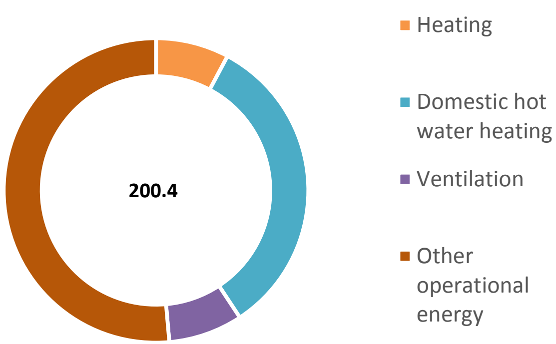
CEDne building's construction [MJ/m²a]



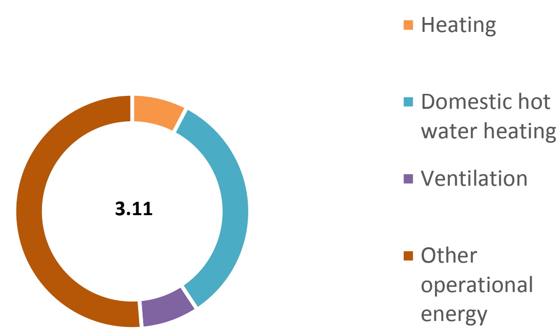
GWP 100a building's construction [kg CO_2eq./m²a]



CEDne building operation [MJ/m²a]



GWP 100a building operation [kg CO_2eq./m²a]



MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Switzerland / moderate climate
Building/ Usage type	Residential home – Residential mfh11, new construction
Energy-standard	net-positive
Gross floor area/ Net floor area	3'064 m^2
Gross volume/ Net volume	n/a
Reference area for EE/EC	energy reference area 2'966 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (reinforced concrete and masonry)
Thermal insulation	Insulation of floor, ext. walls and roof
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: electric heat pump (water/brine) equipped with a borehole heat exchanger, heat distribution with floor heating Cooling: n/a
Final energy demand electricity	Ventilation 6 MJ/m^2a (per energy reference area) Appliances, lighting, services, etc. 39 MJ/m^2a (per energy reference area)
Final energy demand for heating and hot water	Room heating 23 MJ/m^2a (per energy reference area) Hot water 50 MJ/m^2a (per energy reference area)
Final energy demand for cooling	0 MJ/m^2a
Benchmark	-
Purpose of assessment	to determine CEDnr and GWP 100a for construction, replacement, deconstruction, operation
Assessment methodology	According to the methodology of ecoinvent and to SIA 2032 guidance
Reference Study Period	60 years
Included life cycle stages	From cradle to grave - Construction stage - Use stage - End-of-life stage No benefits for potential recycling were considered

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Excavation Backfill Baseplate and foundation Ceilings Ext. walls (underground and above ground) Int. walls Columns Roof Ext. doors Floorings Wall coverings Ceiling coverings Installations (ventilation, heating, sanitary equipment, electrical equipment)
Scenarios and assumptions used	Final disposal at the end-of-life
Accounting of electricity mix	Static emissions factors, Swiss consumer mix
Databases used	Ecoinvent v2.2 and v2.2+
LCA Software used	Simapro 7.3.3
Method of materials quantification	LCI
Values and sources of primary energy and emission factors	KBOB-recommendation (www.kbob.ch) ecoinvent
Character of the indicator used	Optimum or modified (e.g. tables 9, 11 or 13 in ST1 draft report)
Indicators assessed	CED non renewable (according to Frischknecht et al, 2007) GWP 100a (according to IPCC 2007 and 2013)

Czech Republic

Key issues related to Annex 57:
1. Strategies for building design
4. EG and EE reduction strategies – Material/component level

Case study CZ1
Reused versus new materials

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Reuse of materials does not necessary mean reduction of environmental impact of house.

- If construction with reused materials does not allow to reach the same energy consumption level as completely new building, a little bit higher energy consumption can cancel the positive effect of reuse.
- Use of old materials can imply special solutions, which can be connected with higher environmental impact than usual solutions.
- For to obtain more relevant and accurate evaluation of benefits of reuse, more life cycle should be taken into account

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OBJECTIVES OF CASE STUDY

To quantify environmental impact of two scenario of life cycle for family house, which is constructed after demolition of the old one:

1. New house s constructed with reusing of certain materials from the demolition.

2. New house is constructed without reusing any materials.

To evaluate influence of reuse of materials to the overall environmental impact of the house.

To evaluate contribution of different building materials to the overall impact of the house.

BUILDING KEY FACTS

Intended use: Family house

Two house sizes: 142 m^2 floor area

Location: Plzeň – Doudlevce, Czech Republic

Building year: 2010

Source of information about building: Design phase of the project, photos

Structural material of walls: Bricks, concrete formwork blocks with steel reinforcement

Structural material of roof: Wooden beams

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Building life cycle stages included in the study, according to EN15978

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								x						

LCA BACKGROUND

Reference study period:	60 years
Functional equivalent:	House for family of four, average U value of building envelope $U_{average} \leq 0{,}3$ W/(m2.K)
Functional unit:	1 person
Calculation of Energy:	Non-renewable Primary Energy
Calculation of GWP:	GWP (100 years)
Databases used:	Envimat
Standards/guidelines:	EN 15978 standard, SBToolCZ – environmental part of assessment gives guidelines for evaluating impact of product stage and operational energy use of the building

REFERENCES

Vonka, Martin & kolektiv. *Metodika SBToolCZ - Manuál hodnocení bytových staveb ve fázi návrhu.* Praha : CIDEAS, Fakulta stavební ČVUT v Praze, 2010. 978-80-01-04664-7

Hodková, Julie, et al., Envimat.cz - Online database of environmental profiles of building materials and structures. *IFIP Advances in Information and Communication Technology.* 2011 йил, Vol. 2011, 359, pp. 272-279. ISSN 1868-4238

The case study consists of low-energy family house. **Two scenarios** are used – with and without reuse of old materials.

Production stage modeling:

The study includes the raw material extraction and the manufacturing of building materials according to the standard of SBToolCZ and to the available bill of materials. The calculation does not includes bbuilding services (heating, ventilation, water pipes, waste pipes), internal doors and fittings such as bathroom, lighting and kitchen. Generic data from Envimat database are used because except mineral wool, for which EPD is available.

Reused materials are considered to have no environmental impact within life cycle of the new house.

Operation stage:

In this stage, only part of operational energy use is taken into account.

Operational energy use is expressed by value of energy demand for heating. Others parts of overall energy consumption of the house are the same for both compared scenarios. Energy demand of heating is calculated according to Czech legislative documents.

For calculation of non-renewable primary energy consumption and global warming potential conversion factors from SBToolCZ guidelines are used. They correspond to Czech conditions.

BUILDING DESCRIPTION

THE BUILDING

The case study comprise low energy family house of two floors. House is founded on concrete strips. Vertical load structure is from bricks and concrete. Wooden structure is used for intermediate floor and roof. Ground floor and plinth are insulated by expanded polystyrene. Walls and roof are insulated by mineral wool. Wall insulation is supported by wooden grid, which also support wooden facade. Windows are plastic with triple glazing. House is heated by hot air and source of heat is natural gas and soar thermal panels.

Scenario 1

This scenario was developed according to how really the house was constructed. A small part of foundations and most of old full bricks from demolished house were reused. The brick wall has thickness of 150mm and is strengthen by reinforced concrete columns. On the interior surface there is stud cavity for pipes and cables and gypsum board supported by steel sections.

U value of this wall is 0,18 W/(m^{2}K)

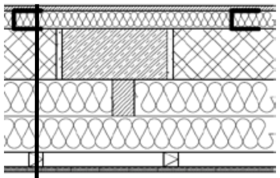
Scenario 2

In this scenario no reuse of materials is considered. The main difference from scenario 1 is in structure of wall. The criteria for design of this wall were, that it should be very usual structure used for family houses in Czech Republic, with the same exterior appearance and with same or lower U value as for scenario 1. Cavity bricks of thickness of 240 m were used. Strengthening by concrete columns is not needed, thus cables and pipes can be put into the wall and interior surface is covered by cement-lime mortar.

U value of wall is 0,18 W/(m^{2}K)

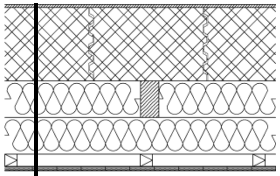
When using cavity bricks, very small difference in thickness of wall or insulation implies big difference in Uvalue.

SCENARIO 1



Gypsum board	12,5 mm
Steel frame with mineral wool	50 mm
Bricks - full (from original construction)	150 mm
Mineral wool in wooden grid	200 mm
Diffuse foil DEKTEN 135	
Ventilated cavity + diagonal wooden lathing (40/60mm)	40 mm
Vertical wooden cladding (larch)	14 mm

SCENARIO 2



Cement-lime mortar		10mm
Clay block Porotherm 24 P+D		240mm
Mineral wool in wooden grid		240mm
Diffuse foil DEKTEN 135		
Ventilated cavity + diagonal wooden lathing (40/60mm)	300	40mm
Vertical wooden cladding (larch)		14mm

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COMPARISON OF SCENARIOS

Although in scenario 1 quite big part of structure is from reused materials (all bricks for walls), the reduction of environmental impact in product stage thanks to the reuse is not very significant. Charts below show, that regarding non-renewable energy consumption of materials it is reduction of 1,6 % (51 MJ/(person.a)), regarding global warming potential it is 4,6 % (10 kg CO_2, eq./(person.a)). Reduction of operational impact is negative, because in scenario 2 (completely new building) the house has lower energy demand for heating thanks to lower U value of wall. The difference between U vales for scenario 1 and 2 is only 0,02 W/m^{2}K but it cause 3,4 % of reduction of non renewable energy, it is 354 MJ/(person.a). Regarding global warming potential it saves 2,6 % of impact, it mens 29 kg CO_2, eq./(person.a).

Primary Energy consumption:

Scenario 1: 13 953 MJ/(person.a)

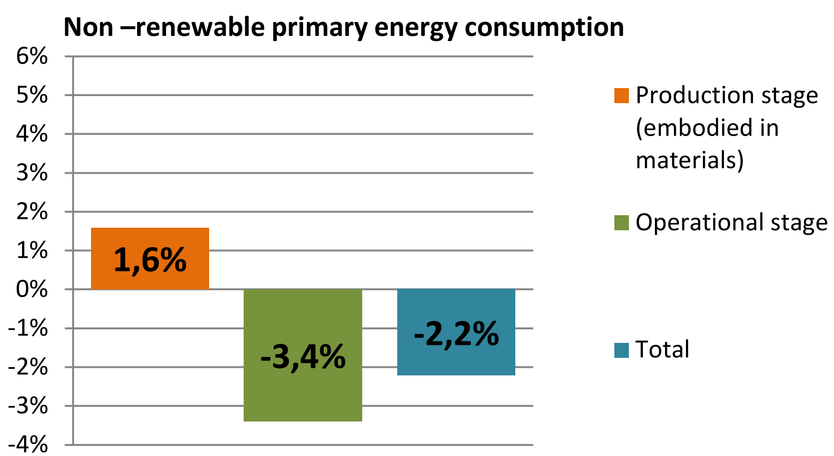
Scenario 2 : 13 651 MJ/(person.a)

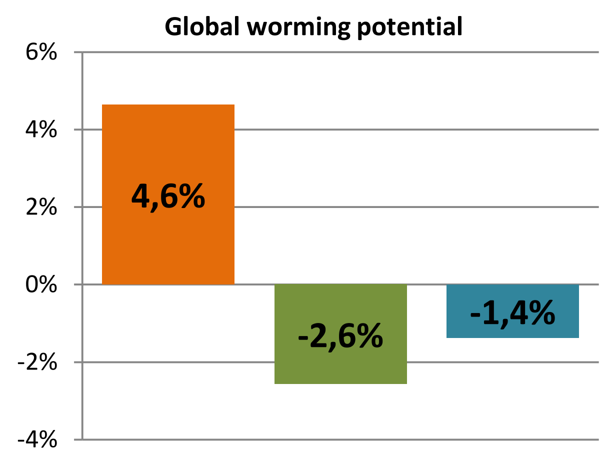
Global warming potential

Scenario 1 : 1370 kg CO_2, eq./(person.a)

Scenario 2 : 1351 kg CO_2, eq./(person.a)

RATE OF REDUCTION OF ENVIRONMENTAL PARAMETER THANKS TO MATERIAL REUSE* (SCENARIO 1)





* When reuse of materials reduce impact, percentage value is positive

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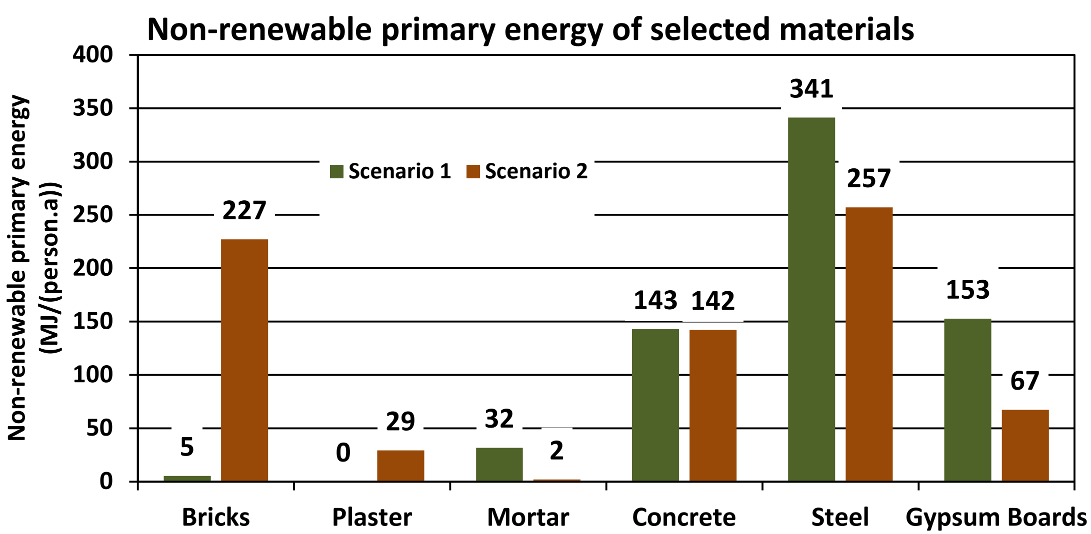
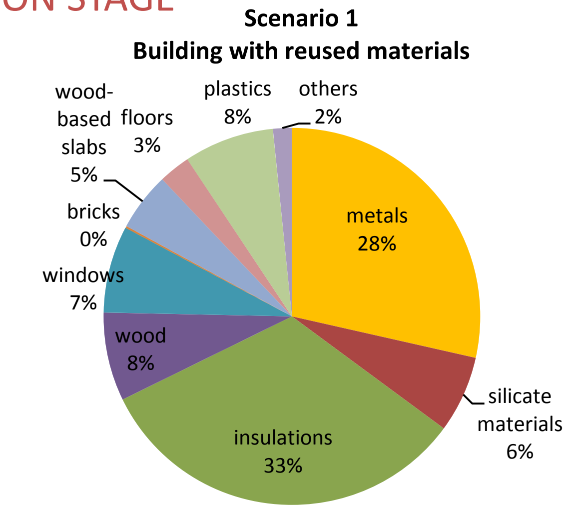
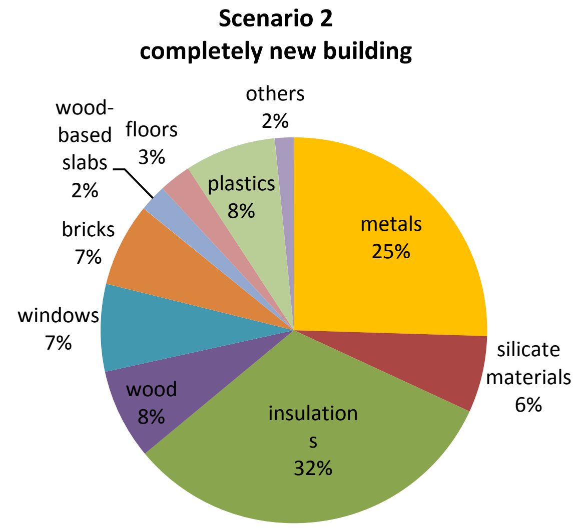
ANALYSE OF NON-RENEWABLE ENERGY CONSUMPTIONS IN PRODUCTION STAGE

Figures on the right side illustrates the non-renewable primary energy consumption of individual building parts on the complete building LC. In scenario 1, the reused materials (e.g. bricks) are considered as to have no environmental impact. But new bricks, used in scenario 2, have quiet small impact regarding the use of non renewable primary energy. Bigger amount of metals used in scenario 1 has big influence and is caused by steel sections supporting gypsum boards on the interior side of walls and by reinforcement in strengthening columns. These metal components are not needed in scenario 2.

The chart below shows the difference between non-renewable energy consumption of selected materials. In scenario 1 no bricks and no plaster are needed, but more of mortar, steel and gypsum boards are necessary, than in scenario 2.







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Key issues related to Annex 57:
1. Strategies for building design
4. EG and EE reduction strategies – Material/component level

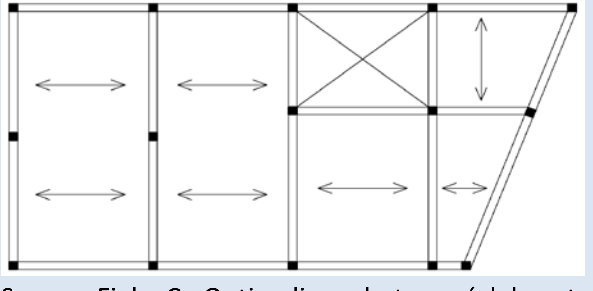
Case study CZ2
UHPC versus standard concrete frame

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Use of new composite silicate material for building frame – ultra high performance concrete (UHPC) can bring significant reduction of environmental impacts.

- **Optimization of construction elements** dimensions is of high importance - even if the new material (here **UHPC**) has higher environmental impacts per declared unit (e.g. 1kg), the total impacts of the structure are lower thanks to the smaller dimensions of elements and thus **lower material consumption**;
- It is possible to **reduce environmental impact in the range 10 to 54%** in comparison to common solution (cast in site RC frame structure) due to **excellent mechanical properties**;
- **Subtle elements bring material and energy savings** during production, transport, manipulation and construction on building site
- **Subtle structural elements can be integrated into building envelope** of energy efficient buildings, avoiding risk of thermal bridges;



Source: Fiala, C.: Optimalizace betonových konstrukcí v environmentálních souvislostech, Publisher of Czech Technical University, 2011, s. 102, ISBN 978-80-01-04663-0

OBJECTIVES OF CASE STUDY

A simple six-storey building with a ground plan of approx. 10 x 20 m was chosen for LCA study and comparison of three selected concrete frame structure alternatives

The main objective was to show the **potential for reduction of environmental impacts of the buildings using the advanced composite material - Ultra High Performance Concrete** for its frame structure, in comparison with the common solutions as monolithic reinforced concrete (RC) frame or precast RC frame.

BUILDING KEY FACTS

Intended use: Residential as well as office building

Two house sizes: 10 x 20 m

Location: Bustehrad, Czech Republic

Building year: Not yet built

Project phase studied: Design stage

Structural material of frame: Concrete

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Building life cycle stages included in the study, according to EN15978

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	X	X								X	X	X	X	

LCA BACKGROUND

Reference study period:	100 years
Functional equivalent:	Load-bearing frame for the given ground plan and the same load
Databases used:	Local environmental data collected within the inventory phase of the LCA procedure, GEMIS
Standards/guidelines:	ISO 14040, ISO 14041, ISO 14042, ISO 14043 - Environmental management – Life cycle assessment

REFERENCES

Aïtcin P.: „Vysokohodnotný beton“, ISBN 80-86769-39-9 ČKAIT, June 2005, Prague

Hájek, P., Fiala, C. & Kynčlová, M.. “Life Cycle Assessment of Concrete Structures - Step towards Environmental Savings”, Structural Concrete, Journal of the fib, Volume 12, Number 1, 2011, ISSN 1464-4177.

Fiala, C.: Optimalizace betonových konstrukcí v environmentálních souvislostech, Publisher of Czech Technical University, 2011, s. 102, ISBN 978-80-01-04663-0

The case study consists of **three concrete frame structures alternatives** for a 6 storey house.

Three scenarios:

(1) V1 reference monolithic RC frame structure from concrete C30/37

(2) V2 precast RC frame structure from concrete C30/37

(3) V3 subtle HPC frame structure from concrete C100/115

Production stage modeling:

The complex life cycle analysis (LCA) was performed for three various RC frame structures that were designed for afore mentioned building. This analysis focuses primarily on load-bearing structures and does not cover building envelope, partitions and surface finishes.

The analysis covers transport of the raw material to the concrete plant, concrete production, transport to the building site, pumping of fresh concrete, formwork, demolition and deposition of the concrete at the end of the structures lifespan.

Operation stage:

The case study does not include operation stage assessment.

THE BUILDING

The house is designed with a very universal layout enabling design of many feasible structural and material alternatives. The same ground plan can be used for residential as well as for office building.

The case study focuses only on the main load bearing frame – floors and columns.

Scenario 1

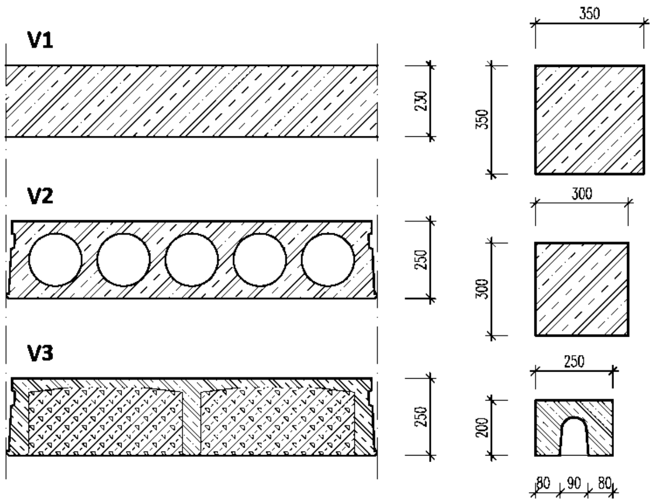
V1 Reference monolithic RC frame structure from concrete C30/37 with columns dimensions of 350 x 350 mm, girders 350 x 500 mm, monolithic floor slab with thickness of 230 mm, with main reinforcement in on direction.

Scenario 2

V2 Precast RC frame structure from concrete C30/37 with columns dimensions of 300 x 300 mm, precast girders 300 x 450 mm and hollow core panels with thickness of 250 mm

Scenario 3

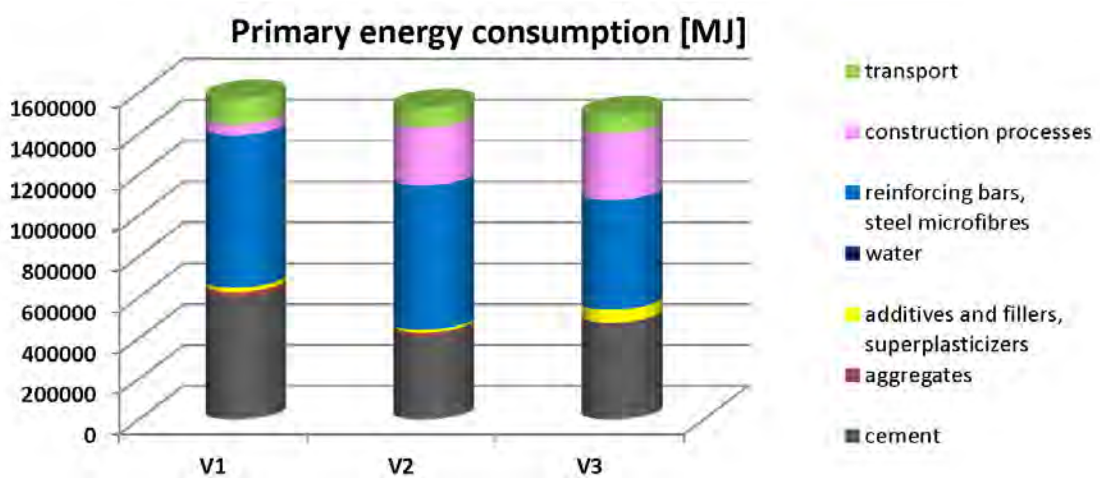
V3 Subtle HPC frame structure from concrete C100/115 with columns as shown in Fig. 1, girders dimensions of 200 x 400 mm and floor structure panels as described in chapter 2, Fig. 2. Floor panels are lightened by lightening elements from wood shavings concrete. HPC is reinforced by dispersed steel microfibers in amount of 80 kg per cubic meter of fresh concrete (1% vol.).



Source: Fiala, C.: Optimalizace betonových konstrukcí v environmentálních souvislostech, Publisher of Czech Technical University, 2011, s. 102, ISBN 978-80-01-04663-0

COMPARISON OF SCENARIOS

The figure shows the influence of individual components such as cement, aggregate, water, admixtures etc. on primary energy consumption. It is apparent that main environmental impact is due to cement and steel reinforcement. Transport, construction process, aggregates and admixtures cause minor effect.



Source: Fiala, C.: Optimalizace betonových konstrukcí v environmentálních souvislostech, Publisher of Czech Technical University, 2011, s. 102, ISBN 978-80-01-04663-0

Aggregated data – Primary energy consumption per unit area of all alternatives in MJ.

Primary Energy consumption:

Scenario 1: 1 759.6 GJ/floor area

Scenario 2 : 1 655.5 GJ/floor area

Scenario 3 : 1 581.1 GJ/floor area

Global warming potential

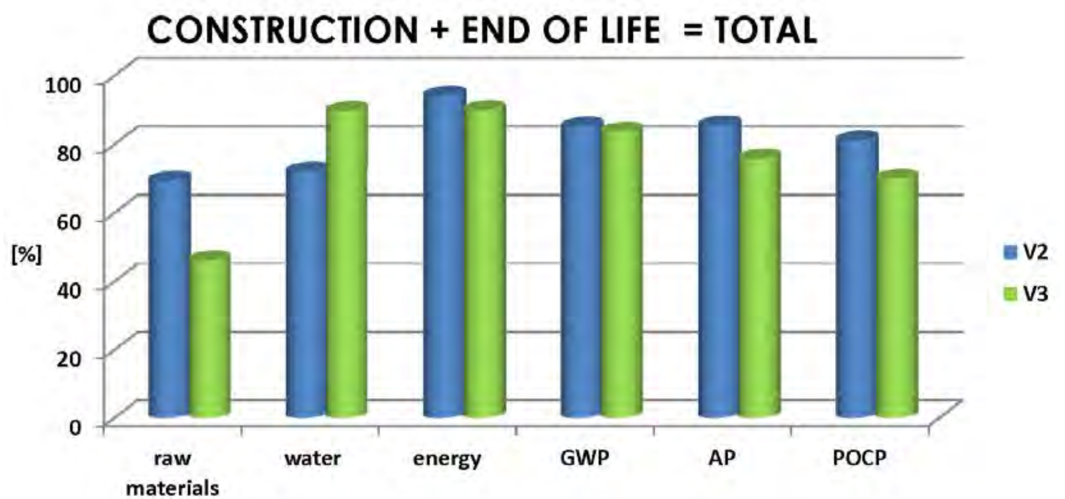
Scenario 1 : 204.2 t CO_2, eq./floor area

Scenario 2 : 173.8 t CO_2, eq./floor area

Scenario 3 : 170.9 t CO_2, eq./floor area

COMPARISON OF ASSESSED ALTERNATIVES

The figure presents the comparison of assessed alternatives. 100% is represented by V1 (monolithic RC frame structure from C30/37). V1 alternative has the highest environmental impact in all assessed criteria. More than 30% of raw material consumption can be saved by utilizing V2 alternative (precast RC frame with hollow core precast slabs) and further 24% by designing structure as subtle HPC frame (V3). V3 alternative shows the highest environmental savings in all assessed criteria (with exception of water consumption due to high water absorption of lightening elements from wood shavings concrete). Savings range from 10 to 54% when compared with V1, and from 2 to 24% in comparison with V2.



Source: Fiala, C.: Optimalizace betonových konstrukcí v environmentálních souvislostech, Publisher of Czech Technical University, 2011, s. 102, ISBN 978-80-01-04663-0

Three alternatives of RC frame structures have been analysed and compared. The results of analysis proved expectation that **subtle HPC frame structure is the most environmental friendly** alternative. The results show that the high quality of **mechanical and environmental performance** of new silicate composites creates the potential for wider application of High Performance Concrete in building construction. The further advantage of subtle HPC frame can appear in areas with **regulated size of built-up area** (e.g in dense inhabited town areas). With higher demands on thermal insulation parameters of building envelopes increases also their thickness. The **possible integration of subtle columns in building envelope** can thus save valued inner space.

Case study DE1

Energy Plus Primary School in Hohen Neuendorf

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 years. The study showed that the production of the photovoltaic equipment substitutes the electricity demand, so only the heating demand covered with wood pellets rests. Therefore the contribution of the operation energy to the Primary Energy non renewable is very small. A similar result is stated for Global Warming Potential (GWP) with RSP of **50 years.**

Embodied Energy (EE) and Embodied GHG Emissions (EG) were evaluated.

REFERENCE STUDY PERIOD

	50	years
EE	135	MJ/m^2_{GFA}/year
EG	8,4	kg CO_2 equiv. /m^2_{GFA}/year

The evaluation of different building parts shows the significance of the material used for the structural parts. In this case reinforced concrete. The total weight per m²GFA is 1.540 kg. Evaluation of the different building materials showed the following contributions:

the primary structure: concrete with 83,5%, metal with 3,3% , wood with 1,1%.

the secondary structure: sealings with 1,4%, floorings with 5,9%, insulation with 1,6%, walling with 2%, glass with 0,5% and technical equipment with 0,2%.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to the life cycle of a new primary school in Germany. The study evaluates:

- The significance of different life cycle stages and processes
- The Embodied Energy (EE) and Embodied GHG Emissions (EG)
- The impacts related to different building parts to determine the energy and GHG emissions offsetting, because a net positive concept is applied

Additionally the study evaluates:

- The aspect of Photovoltaic concerning production and harvest.

BUILDING KEY FACTS

Intended use: School building
Size: .7414 m² GFA 6.563m² NFA.
Heated area: 6.563m²
Reference area for EE/EG 7.414m²
Location: Stadt Hohen Neuendorf, Germany
Architect: Ibus Architects Berlin
Building year: Completed 2011

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ASCONA
Gesellschaft für ökologische Projekte

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	X

Production and construction stage modelling: All impacts from the raw material extraction and the manufacturing of the building materials are included. No cut-off-rules are applied. The technical equipment is included. System boundary is the building.

Operation stage modelling: The energy consumption during the building's operation stage is modelled by using the simulation tool Trensis, including the gains of the photovoltaic equipment located on the roof. Electricity is calculated considering the actual German grid.mix (2011). The replacements of building materials and components during the use stage are only allowed in integers, i.e. a component with a life time of 45 years is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span. The replacement cycles are calculated according to the rules of BNB-system. The CEN/TC 350 standards allow for an individual assessment of a product and the probability of its replacement, if the service life of this component is near the chosen required service life of the building. E.g. if the replacement of a component with a service life of 45 years in a building with a service life of 50 years is regarded as uncertain within the 50 years, this actual replacement can be disregarded (CEN/TC 350, 2011).

End of life stage and next product system modelling: The EoL modelling can be simplified into groups of materials. Metals and mineral-based building materials are recycled with some predefined recycling potentials, materials with a heating value (e.g. wood and plastics) are incinerated and other materials are land filled. Only metals with shares of primary manufacturing have recycling potentials. This means that e.g. reinforcement steel, which is made of 100% steel scrap, does not have a recycling potential (BNB International, 2010).

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Ökobau.dat 2011 (BMUB)
Energy supply: Thermal energy from wood pellets, electricity from German grid- mix, electricity with PV-modules (410 m²)
Standards/guidelines: EN 15978 standard and BNB guidelines

REFERENCES

König, Holger,; De Cristofaro Lisa; Benchmarks for life cycle costs and life cycle assessment of residential buildings, Building Research & Information Vol.40, Issue 5, 2012, pages 558-580 – ISSN: 0961-3218, doi: 10.1080/09613218.2012.702017,

CEN/TC 350 standards:
EN 15978 :2011 - Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method

BNB guidelines, 2010. BNB – German assessment system for sustainable construction for federal buildings

THE BUILDING

The structural components of the foundations, the floor slab, the outside walls, the column, the staircases, the ceilings and the roofs are made of reinforced concrete. The facade is covered with bricks, the translucent parts are composed of wood, glass, the sunscreen is made of aluminium lamellas. The roof is covered with a sealing membrane and a green surface. It is used for the photovoltaic equipment. 410 m² photovoltaic elements are installed. For the heating, a wood pellet burner is used. The planned cogeneration unit with a stirling motor could not be realized. The ventilation and cooling is supported by an adiabatic system. The lighting is done partly with the use of LED lights. Construction elements and material contents are calculated with the help of LEGEP database for building elements.

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MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 11.416 tons or 1.539,9 kg/m$^2_{GFA}$ (not including gravel).

Minerals: 9528 to (83,5%)
Wood, wood based products 130 to (1,1%)
Metal: 378 to (3,3%)
Plastics: 48 to (0,4%)
Sealing, Rooftiles: 154 to (1,4%)
Floorings: 671 to (5,9%)
Insulation materials: 178 to (1,6%)
Plaster, interior fittings: 234 to (2%)
Paints and primers: 13 to (0,1%)
Glass : 57 to (0.5%)
Technical Equipment: 25 to (0,2%)

Service life of materials, what is replaced ……………
Structural parts. None
Windows wood/plastic: 40 years
Paints: 15 years
Glass: 30 years
Roof elements: 25 years
Technical equipment:
Primary Structure: 50 years
Sanitation: 20 -25 ears
Heating and Air: 20-25 years
Electricity: 20 – 25 years
Photovoltaic: 25 years

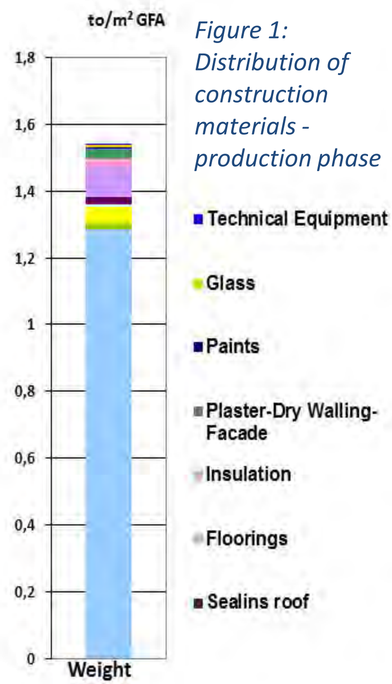


Figure 1: Distribution of construction materials - production phase

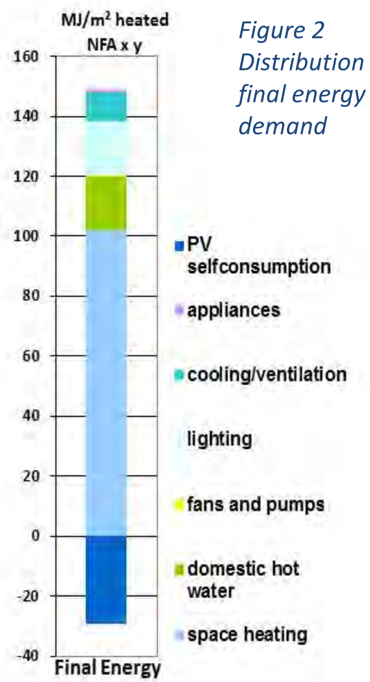
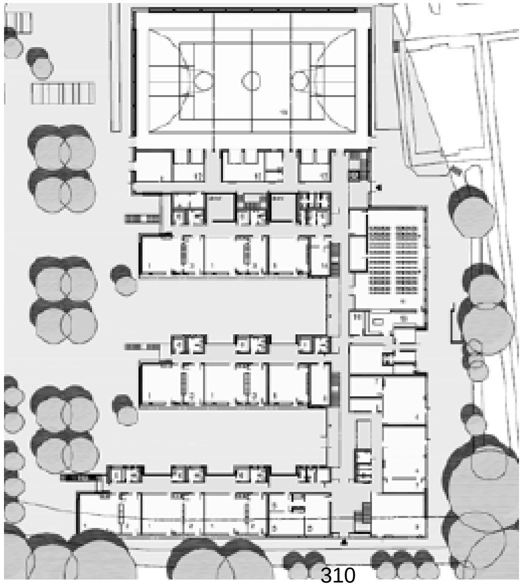


Figure 2 Distribution of final energy demand



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RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:
305 MJ/m$^2_{GFA}$/year
- construction materials: 44%
- operational energy: 56 %

Embodied Energy:
135 MJ/m$^2_{GFA}$/year

Global Warming Potential
9,58 kg CO_2 equiv. /m$^2_{GFA}$/year
- construction materials: 88%
- operational energy: 12%

Embodied GHG Emissions:
8,4 kg CO_2 equiv. /m$^2_{GFA}$/year

Impact categories evaluated
GWP: Global warming potential
$PE_{n,ren}$: Primary Energy, non-renewable
PE_{ren}: Primary Energy, renewable

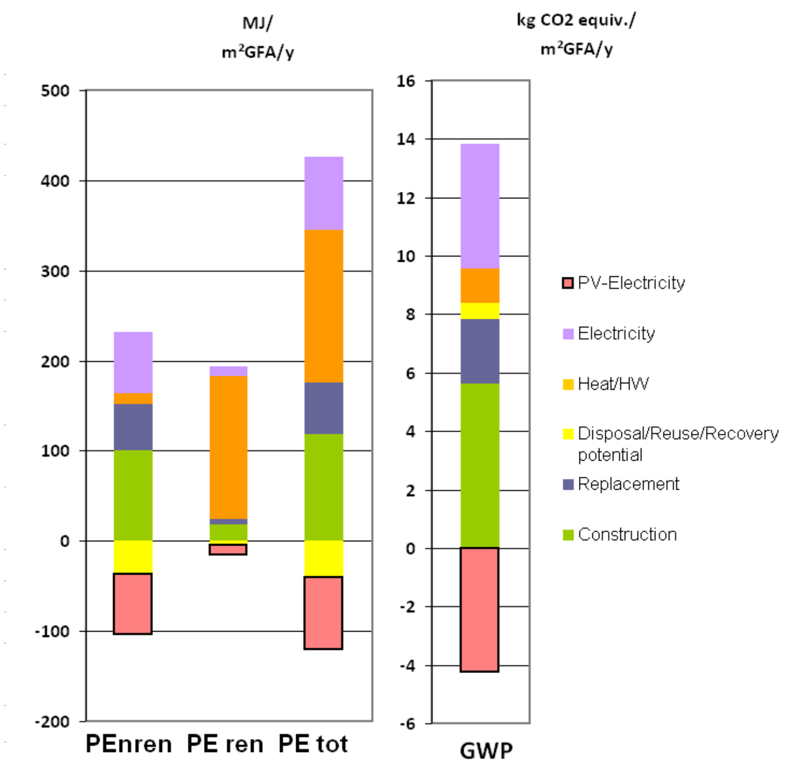


Figure 3: Distribution of shares between construction materials related impacts and operation related impacts considering the whole life cycle of the building.
The yellow column representing the disposal/reuse/recovery is in the "bonus" area (under 0) for PE due to recycling potentials of wood, plastic and metals.
The electricity produced by the photovoltaic system is highlighted and shown in the table with the red column also in the "bonus" area (under 0)

Input of construction elements (DIN 276 structure), full life cycle (A1-3;B1,4;C3-4;D)

Impact categories evaluated: *GWP: Global warming potential,* $PE_{n,ren}$*: Primary Energy, non-renewable,* PE_{ren}*: Primary Energy, renewable*

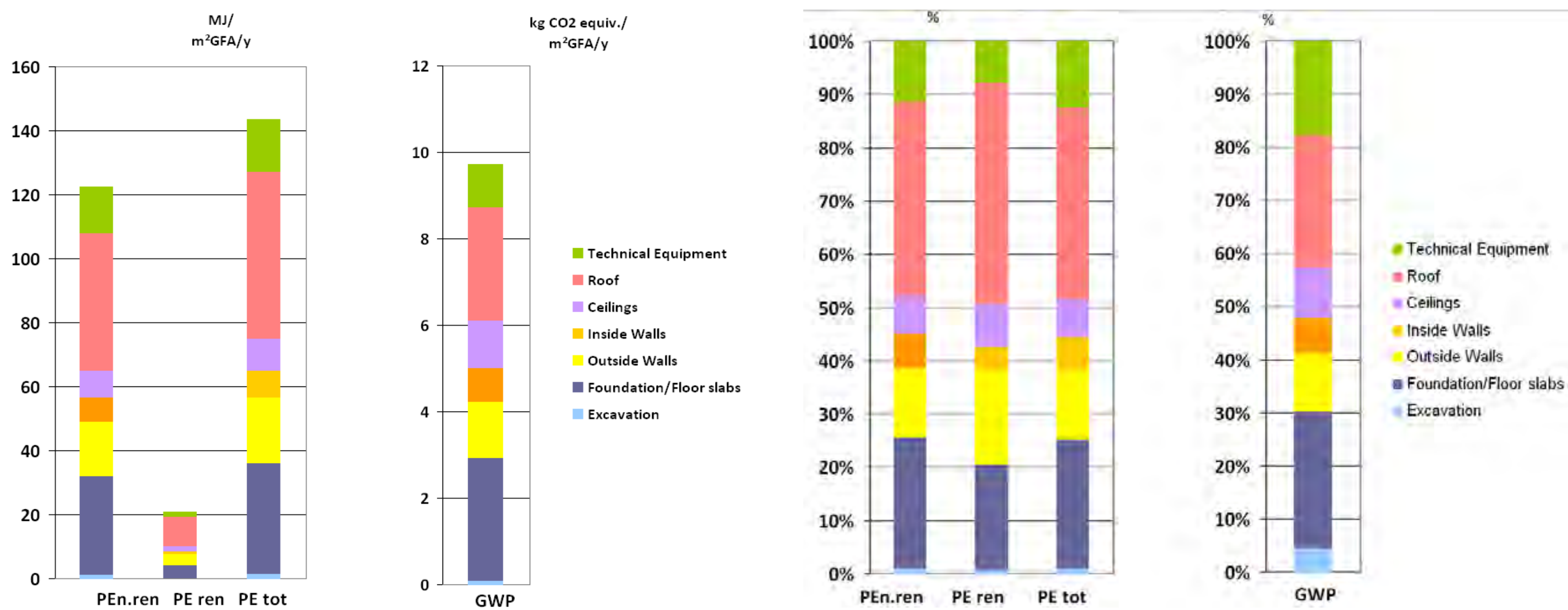


Figure 4: Contribution of the different construction elements divided into 7 different building cost groups to the primary energy and GWP related indicators covering the stages of production, replacement and end-of life treatment of the materials.

Results

The project design is marked by two specialities:

• The energy demand of the building is lower than the energy demand of a passive house.

• The 410 m² photovoltaic installation. The planned cogeneration unit with a stirling motor based on wood pellets could not be realized.

Both elements result in a low value of PE non renewable and a low value for the impact of GWP. The indicator total PE will almost never reach a net-zero-level, because the input of the necessary heating demand covered with wood pellets lifts up the value of PE. ren..

The weight of the building is comparable with buildings with mineral structure. The results of the LCA of the different building components (following the cost categories of the DIN 276) show the typical distribution between construction (85-90%) and technical equipment (10-15%) for all indicators .

The electricity demand of the building (including pumps, fans, lighting, cooling, ventilation and appliances) is covered by the PV-equipment. With the electricity production of the planned cogeneration unit, a net zero energy building could have been realized.

Germany

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials

Case study DE2
Schmuttertal Gymnasium Diedorf - Germany

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 years . The study showed that the energy production from the photovoltaic equipment, and therefore the bonus, is higher than the contribution of the energy demand to the indicator Primary Energy non renewable (PE n. ren.). A similar result is stated for Global Warming Potential (GWP) with RSP of **50 years.**

Embodied Energy (EE) and Embodied GHG Emissions (EG) were evaluated.

REFERENCE STUDY PERIOD

	50	years
EE	93	$MJ/m^2_{GFA}/year$
EG	4,71	kg CO_2 equiv. $/m^2_{GFA}/year$

Evaluation of different building parts showed the significance of the material used for the structural parts, in this case wood and wood based products. The values of the indicators PE n.ren and GWP per m²/y. are low. The total weight per m²GFA is 920 kg. Evaluation of the different building materials showed the following contributions:

the primary structure: concrete with 70,3% , metal with 3,9% , wood and wood based products with 7,2%.

the secondary structure: sealings with 0,7%, floorings with 10,4%, insulation with 3,2%, walling with 2,9%, glass with 0,7% and technical equipment with 0,4%.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to the life cycle of a new school building in Germany. The study evaluates:

-The significance of different life cycle stages and processes

-The Embodied Energy (EE) and Embodied GHG Emissions (EG)

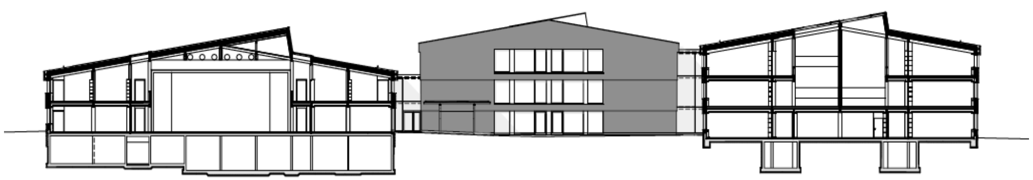
-The impacts related to different building parts to determine the energy and GHG emissions offsetting, because a net positive concept is applied

Additionally the study evaluates:

- The aspect of Photovoltaic concerning production and harvest.

BUILDING KEY FACTS

Intended use: School building
Size: 17292 m² GFA, 15711 m² NFA
Heated area: 13792 m² Reference area for EE/EG: 17292 m²
Location: Diedorf, Germany – moderate climate
Architect: Nagler – Kaufmann Architects Munich – Vorarlberg
Building year: Completed 2015



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Longitudinal section

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Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	X

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Ökobau.dat 2011 (BMUB)
Energy supply: Thermal energy from wood pellets, electricity from German grid- mix, PV-installation on the roof, selfconsumption and grid
Standards/guidelines: EN 15978 standard and BNB guidelines

REFERENCES

König, Holger,; De Cristofaro Lisa; Benchmarks for life cycle costs and life cycle assessment of residential buildings, Building Research & Information Vol.40, Issue 5, 2012, pages 558-580 – ISSN: 0961-3218, doi: 10.1080/09613218.2012.702017,

CEN/TC 350 standards:
EN 15978 :2011 - Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method

BNB guidelines, 2010. BNB – German assessment system for sustainable construction for federal buildings

Production and construction stage modelling: All impacts from the raw material extraction and the manufacturing of the building materials are included. No cut-off-rules are applied. The technical equipment is included. System boundary is the building.

Operation stage modelling: The energy consumption during the building's operation stage is modelled by using the simulation tool Trensis, including the gains of the photovoltaic equipment located on the roof. Electricity is calculated considering the actual German grid.mix (2011). The replacements of building materials and components during the use stage are only allowed in integers, i.e. a component with a life time of 45 years is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span. The replacement cycles are calculated according to the rules of BNB-system. The CEN/TC 350 standards allow for an individual assessment of a product and the probability of its replacement, if the service life of this component is near the chosen required service life of the building. E.g. if the replacement of a component with a service life of 45 years in a building with a service life of 50 years is regarded as uncertain within the 50 years, this actual replacement can be disregarded (CEN/TC 350, 2011).

End of life stage and next product system modelling: The EoL modelling can be simplified into groups of materials. Metals and mineral-based building materials are recycled with some predefined recycling potentials, materials with a heating value (e.g. wood and plastics) are incinerated and other materials are land filled. Only metals with shares of primary manufacturing have recycling potentials. This means that e.g. reinforcement steel, which is made of 100% steel scrap, does not have a recycling potential (BNB International, 2010).

THE BUILDING

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 composed of wood, glass, with aluminium lamellas for the sunscreen. The roof is covered with a sealing membrane and used for the photovoltaic equipment. 2600 m² photovoltaic elements are installed. For the heating a burner with wood pellets is used. The ventilation and cooling is supported by an adiabatic system. The lighting is done partly with the use of LED lights. Construction elements and material contents are calculated with the help of LEGEP database for building elements.

© Photo: Jakob Schoof/DETAIL

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 15.910 tons or 920,1 kg/m$^2_{GFA}$(not including gravel).

Minerals: 11.184 to (70,3%)
Wood, wood based products 1.150 to (7,2%)
Metal 622 to (3,9%)
Plastics 30 to (0,2%)
Sealing: 113 to (0,7%)
Floorings: 1652 to (10,4%)
Insulation materials: 513 to (3,2%)
Plaster, interior fittings 456 to (2,9%)
Paints and primers: 10 to (0,1%)
Glass : 107 to (0.7%)
Technical Equipment 72 to (0,4%)

Service life of materials, what is replaced ....
Structural parts. None
Windows wood or plastic 40 years
Paints: 15 years
Glass: 30 years
Roof elements: 25 years
Technical equipment:
Primary Structure : 50 years
Sanitation 20 -25 ears
Heating and Air 20-25 years
Electricity: 20 – 25 years
Photovoltaic: 25 years

Figure 1: Distribution of construction materials - production phase

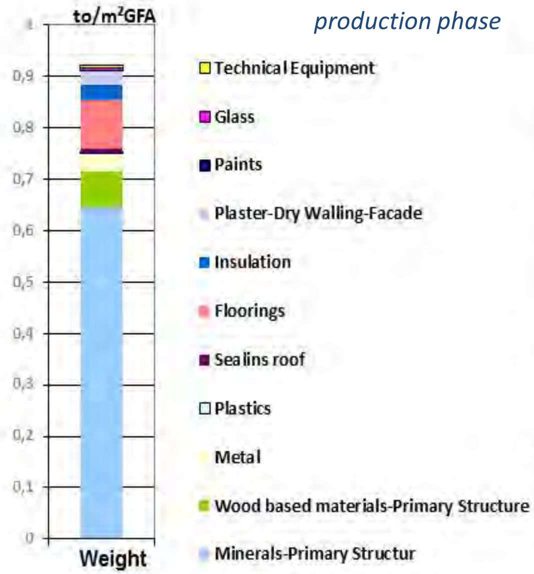
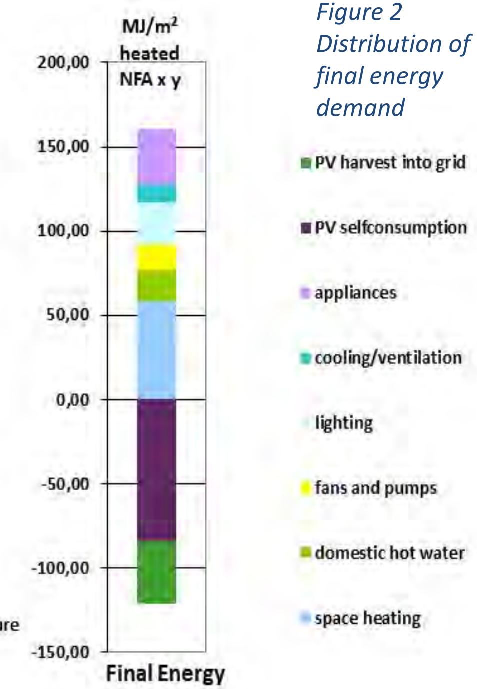
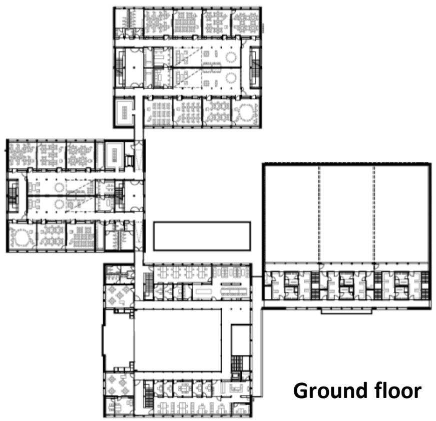


Figure 2 Distribution of final energy demand





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© Photos: Jakob Schoof/DETAIL

RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:
175,5 MJ/m²$_{GFA}$/year
- construction materials: 53%
- operational energy: 47%

-

94 MJ/m²$_{GFA}$/year Electricity into the grid:
Embodied Energy:
93 MJ/m²$_{GFA}$/year

Global Warming Potential:
5,49 kg CO_2 equiv. /m²$_{GFA}$/year
- construction materials: 86%
- operational energy: 14%

4,9 kg CO_2 equiv. /m²$_{GFA}$/year Electricity into the grid
Embodied GHG Emissions:
4,7 kg CO_2 equiv. /m²$_{GFA}$/year

Impact categories evaluated
GWP: Global warming potential
$PE_{n,ren}$: Primary Energy, non-renewable
PE_{ren}: Primary Energy, renewable

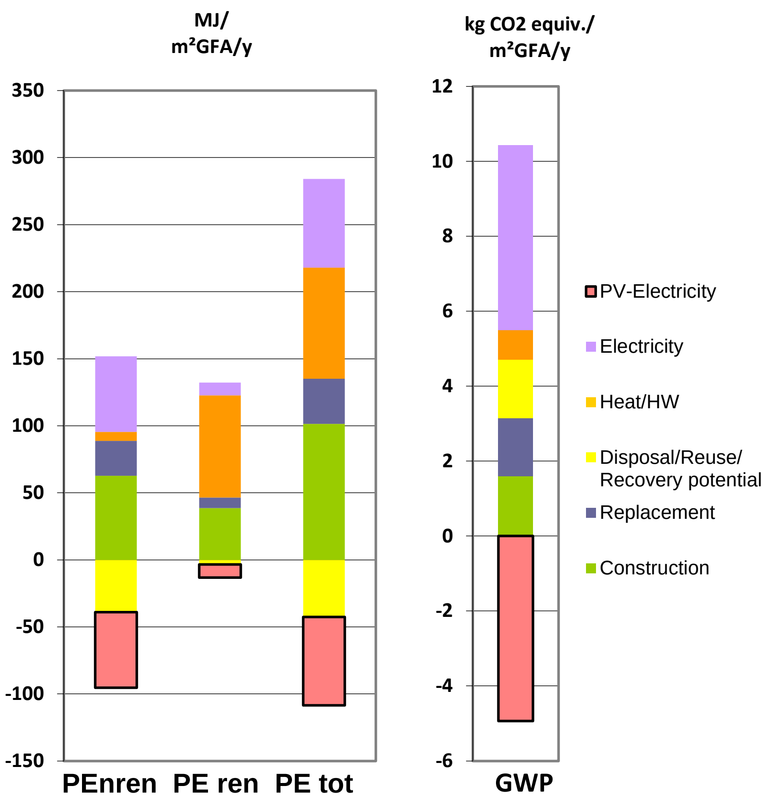

Figure 3: Distribution of shares between construction materials related impacts and operation related impacts considering the whole life cycle of the building. The yellow column representing the disposal/reuse/recovery is in the "bonus" area (under 0) for PE due to recycling potentials of wood, plastic and metals. The electricity produced by the photovoltaic system is highlighted and shown in the table with the red column also in the "bonus" area (under 0).

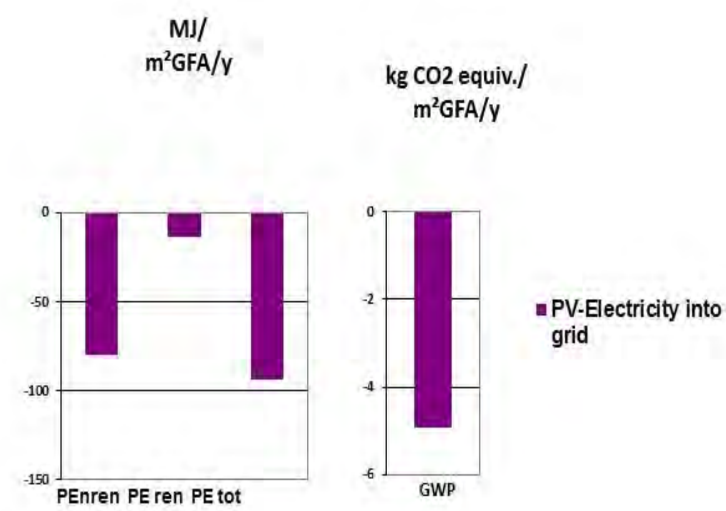

Figure 4: Environmental gains of the PV-electricity production given to the grid

Input of construction elements (DIN 276 structure) Full life cycle (A1-3;B1,4;C3-4;D)

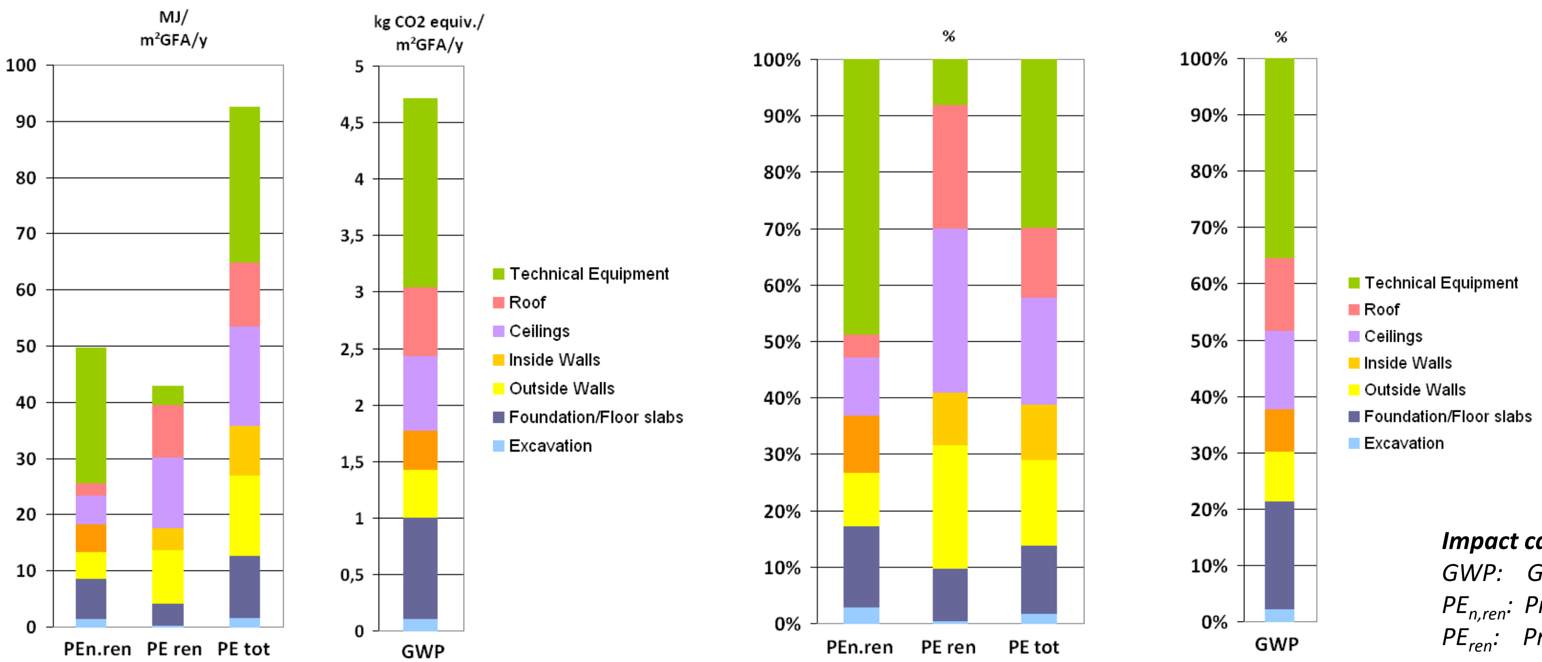

Figure 5: Contribution of the different construction elements divided into 7 different building cost groups to the primary energy and GWP related indicators covering the stages of production, replacement and end-of life treatment of the materials.

Impact categories evaluated

GWP: Global warming potential

$PE_{n,ren}$: Primary Energy, non-renewable

PE_{ren}: Primary Energy, renewable

Results

The project design is marked by two specialities:

•The structural parts composed of wood or wood based elements.

•The 2600 m² photovoltaic and the wood pellet burner.

Both elements result in a net zero value of PE non renewable, a high value for PE ren. and almost net zero value for the impact of GWP. The indicator total PE will almost never reach a net-zero-level, because the input of the necessary heating demand covered with wood pellets lifts up the value of PE. ren.

The weight of the building is only 2/3 of the weight of comparable buildings with mineral structure. The distribution between the building components (following the cost categories of the DIN 276) shows for PE n.ren. a balance between construction elements and technical equipment, for PE ren. a dominant share of construction elements (90%), for the total PE and for GWP a 2/3 for the construction elements and 1/3 for the technical equipment.

In buildings with wooden structural parts there is a stronger influence of the technical equipment than in buildings with mineral-based structure.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials

Case study DE3
Residential Building - Germany

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 years. The study showed that the energy production of the photovoltaic equipment, and therefore the bonus, is higher than the contribution of the energy demand to the indicator Primary Energy non renewable (PE n. ren.). A similar result is stated for Global Warming Potential (GWP) with RSP of **50 years.**

Embodied Energy (EE) and Embodied GHG emissions (EG) were evaluated.

REFERENCE STUDY PERIOD

	50	years
EE	97,3	$MJ/m^2_{GFA}/year$
EG	5,7	kg CO_2 equiv. $/m^2_{GFA}/year$

The evaluation of the different building parts showed the significance of the material used for the structural parts. In this case, mineral based and wood based products were used. The values of the indicators PE n.ren and GWP per m²/y are average. The total weight per m²GFA is 1.420,6 kg. The evaluation of the different building materials showed the following contributions:

the primary structure: concrete with 78,6%, metal with 4,4%, wood based products with 1.4%.

the secondary structure: sealings with 1.4%, floorings with 6,9%, insulation with 2%, walling with 3%, glass with 0,9% and technical equipment with 0,7%.

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OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to the life cycle of a new residential building in Germany. The study evaluates:

-The significance of different life cycle stages and processes

-The Embodied Energy (EE) and Embodied GHG emissions (EG)

-The impacts related to different building parts to determine the energy and GHG emissions offsetting, because a net positive concept is applied

Additionally the study evaluates:

- The aspect of Photovoltaic concerning production and harvest.

BUILDING KEY FACTS

Intended use: Residential building

Size: 2118 m² GFA, 1738 m² NFA

Heated area: 1448 m² Reference area for EE/EG: 2118 m²

Location: Berlin, Germany – moderate climate

Architect: Melder and Binker Architects Freiburg

Building year: Completed app. 2015/2016

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	X

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Ökobau.dat 2011 (BMUB)
Energy supply: Thermal energy from wood pellets, electricity from German grid- mix, PV-installation on the roof, selfconsumption and grid
Standards/guidelines: EN 15978 standard and BNB guidelines

REFERENCES

König, Holger,; De Cristofaro Lisa; Benchmarks for life cycle costs and life cycle assessment of residential buildings, Building Research & Information Vol.40, Issue 5, 2012, pages 558-580 – ISSN: 0961-3218, dok 10.1080/09613218.2012.702017,

CEN/TC 350 standards:

EN 15978 :2011 - Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method

BNB guidelines, 2010. BNB – German assessment system for sustainable construction for federal buildings

Production and construction stage modelling: All impacts from the raw material extraction and the manufacturing of the building materials are included. No cut-off-rules are applied. The technical equipment is included. System boundary is the building.

Operation stage modelling: The energy consumption during the building's operation stage is modelled by using the simulation tool Trensis, including the gains of the photovoltaic equipment located on the roof. Electricity is calculated considering the actual German grid.mix (2011). The replacements of building materials and components during the use stage are only allowed in integers, i.e. a component with a life time of 45 years is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span. The replacement cycles are calculated according to the rules of BNB-system. The CEN/TC 350 standards allow for an individual assessment of a product and the probability of its replacement, if the service life of this component is near the chosen required service life of the building. E.g. if the replacement of a component with a service life of 45 years in a building with a service life of 50 years is regarded as uncertain within the 50 years, this actual replacement can be disregarded (CEN/TC 350, 2011).

End of life stage and next product system modelling: The EoL modelling can be simplified into groups of materials. Metals and mineral-based building materials are recycled with some predefined recycling potentials, materials with a heating value (e.g. wood and plastics) are incinerated and other materials are land filled. Only metals with shares of primary manufacturing have recycling potentials. This means that e.g. reinforcement steel, which is made of 100% steel scrap, does not have a recycling potential (BNB International, 2010).

THE BUILDING

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 and is partly used for the photovoltaic equipment. 75 m² photovoltaic elements are installed. For the heating a burner with wood pellets is used. 45 m² solar panels support the production of hot water. The ventilation is equipped with a heat recovery system. The lighting is done partly with the use of LED lights. Construction elements and material contents are calculated with the help of LEGEP database for building elements.

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 3008 tons or 1420,6 kg/m$^2_{GFA}$ (not including gravel).

Minerals: 2366 to (78,6%)
Wood, wood based products 43 to (1.4%)
Metal 133 to (4,4 %)
Plastics 9,to (0,3%)
Sealing: 44 to (1,4%)
Floorings: 208 to (6,9%)
Insulation materials: 61 to (2%)
Plaster, interior fittings 91 to (3%)
Paints and primers: 10,to (0,4%)
Glass : 26 to (0.9 %)
Technical Equipment 17 to (0,7%)

Service life of materials, what is replaced ....
Structural parts. None
Windows wood or plastic 40 years
Paints: 15 years
Glass: 30 years
Roof elements: 25 years
Technical equipment:
Primary Structure : 50 years
Sanitation 20 -25 ears
Heating and Air 20-25 years
Electricity: 20 – 25 years
Photovoltaic: 25 years

Figure 1: Distribution of construction materials - production phase

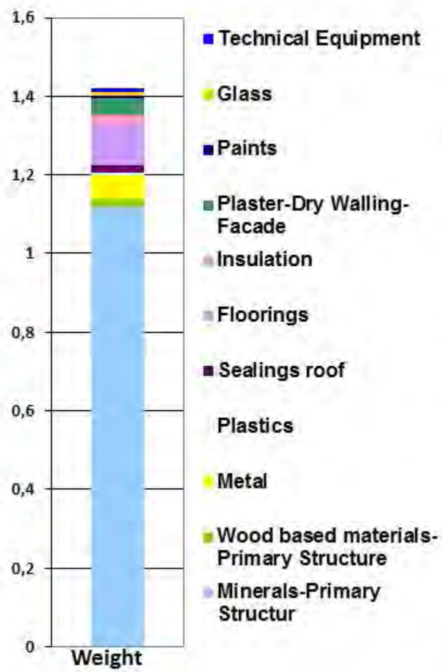
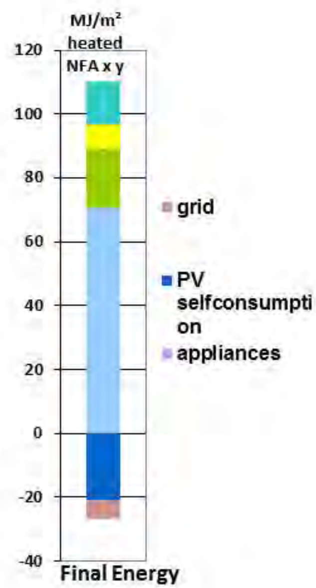


Figure 2: Distribution of final energy demand



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RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:	Global Warming Potential:
186,6 MJ/m²$_{GFA}$/year	**6,56** kg CO_2 equiv. /m²$_{GFA}$/year
- construction materials: 52%	- construction materials: 87%
- operational energy: 48%	- operational energy: 13%
-	
12,7 MJ/m²$_{GFA}$/year Electricity into the grid:	**0,67** kg CO_2 equiv. /m²$_{GFA}$/year Electricity into the grid
Embodied Energy:	**Embodied GHG Emissions:**
97,3 MJ/m²$_{GFA}$/year	**5,7** kg CO_2 equiv. /m²$_{GFA}$/year

Impact categories evaluated

GWP: Global warming potential

$PE_{n,ren}$: Primary Energy, non-renewable

PE_{ren}: Primary Energy, renewable

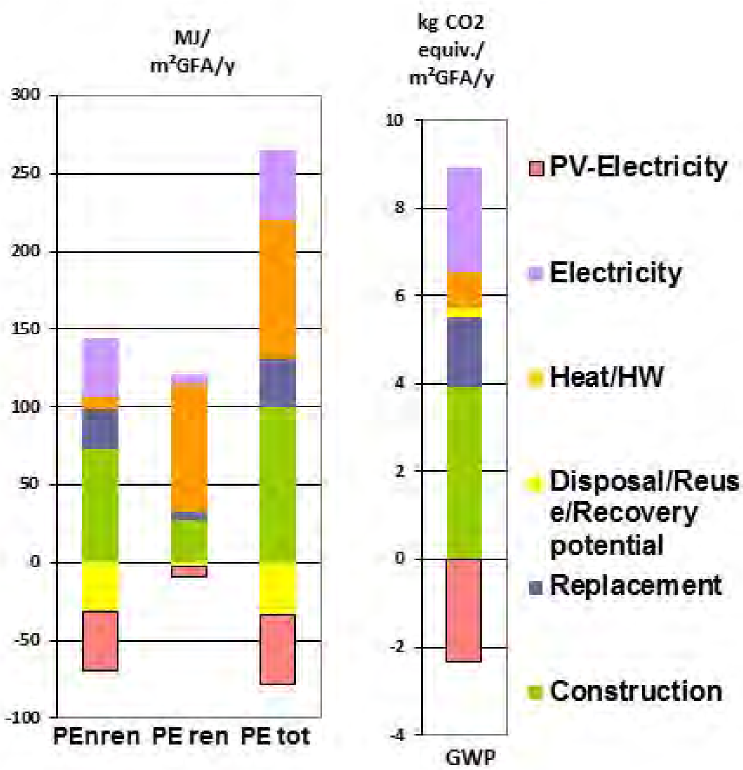


Figure 3: Distribution of shares between construction materials related impacts and operation related impacts considering the whole life cycle of the building. The yellow column representing the disposal/reuse/recovery is in the "bonus" area (under 0) for PE due to recycling potentials of wood, plastic and metals. The electricity produced by the photovoltaic system is highlighted and shown in the table with the red column also in the "bonus" area (under 0)

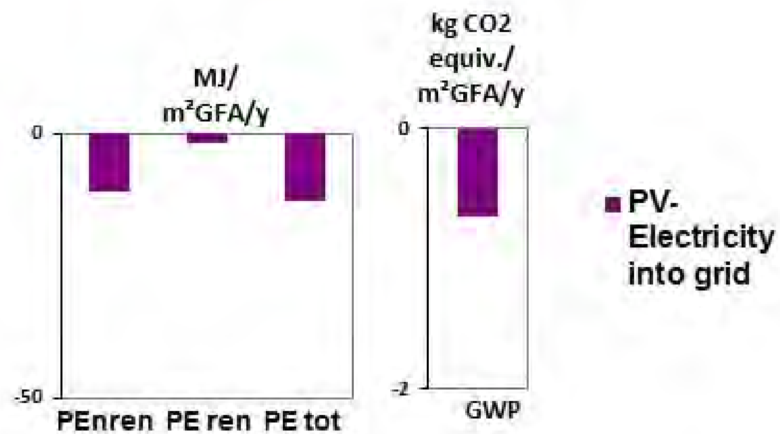
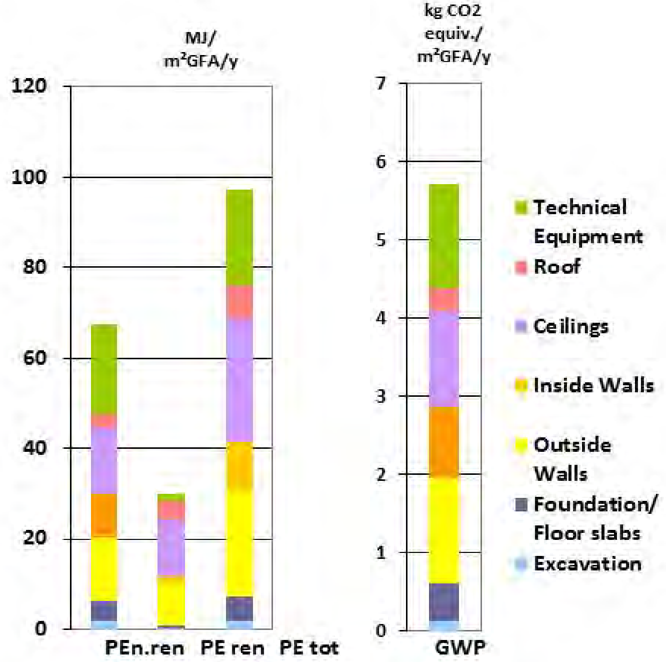


Figure 4: Environmental gains of the PV-electricity production given to the grid

Input of construction elements (DIN 276 structure) Full life cycle (A1-3;B1,4;C3-4;D)



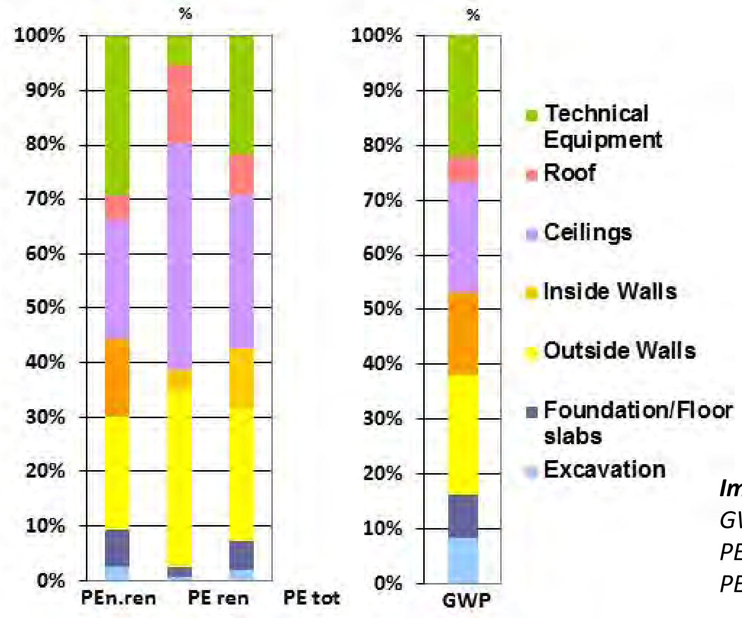


Figure 5: Contribution of the different construction elements divided into 7 different building cost groups to the primary energy and GWP related indicators covering the stages of production, replacement and end-of life treatment of the materials.

Impact categories evaluated

GWP: Global warming potential

$PE_{n,ren}$: Primary Energy, non-renewable

PE_{ren}: Primary Energy, renewable

Results

The project design is marked by two specialities:

- The use of wood or wood based elements for the building façade and for the floors.
- The 75 m² photovoltaic, the wood pellet burner, the 45 m² solar panels for hot water and the ventilation with heat recovery.

All these elements result in a net zero value of PE non renewable, a high value for PE ren. and a very low value for the impact of GWP. The indicator total PE will almost never reach a net-zero-level, because the input of the necessary heating demand covered with wood pellets lifts up the value of PE. ren.

The weight of the building is average for buildings with mineral structure. The distribution between the construction elements (following the cost categories of the DIN 276) shows for PE n.ren. and GWP about 20 % share of the technical equipment, due to all the equipment for solar gains and heat recovery. For the indicator PE ren. the construction (95%) is dominant. For the four-storey building the outside walls and the ceilings have the main influence on the result.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials

Case study DE4
Administration Building Germany

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 years . The study showed that the production of the photovoltaic equipment and therefore the bonus is higher than the contribution of the energy demand to the indicator Primary Energy non renewable (PE n. ren.). A similar result is stated for Global Warming Potential (GWP) with RSP of **50 years.**

Embodied Energy (EE) and Embodied GHG Emissions (EG) were evaluated.

REFERENCE STUDY PERIOD

	50	years
EE	217	$MJ/m^2_{GFA}/year$
EG	9,36	kg CO_2 equiv. $/m^2_{GFA}/year$

Evaluation of different building parts showed the significance of the material used for the structural parts, in this case wood and wood based products. The weight, the PE n.ren and the GWP per m²/y. are low. The total weight per m²GFA is 1114 kg. Evaluation of the different building materials showed following contributions:

the primary structure: concrete with 51,64 % , metal with 4,66% , wood and wood based products with 10,71%, plastic with 1,06%.

The secondary structure: sealings with 2,82%, floorings with 10,52%, insulation with 8,34%, walling with 8,8%, glass with 0,3%, paintings with 0,18% and technical equipment with 0,95%.

ASCONA
Gesellschaft für ökologische Projekte

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to the life cycle of a new administration building in Germany. The study evaluates:

-The significance of different life cycle stages and processes

-The Embodied Energy (EE) and Embodied GHG Emissions (EG)

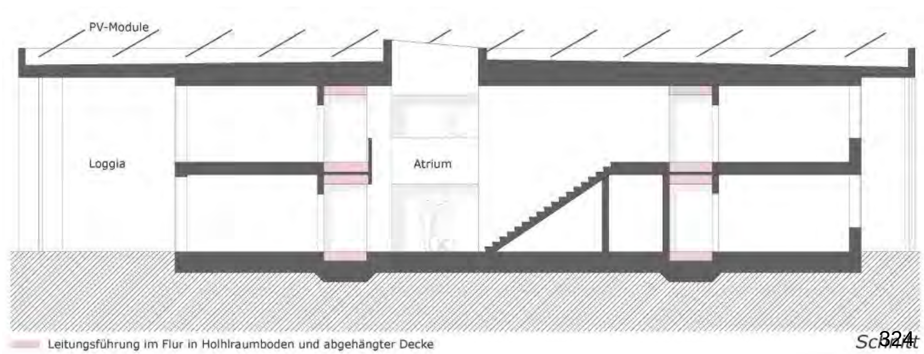
-The impacts related to different building parts to determine the energy and GHG emissions offsetting, because a net positive concept is applied

Additionally the study evaluates:

- The aspect of Photovoltaic concerning production and harvest.

BUILDING KEY FACTS

Intended use: Administration building
Size: 1264 m² GFA, 1035 m² NFA
Heated area: 1035 m² Reference area for EE/EG: 1035 m²
Location: Potsdam, Germany – moderate climate
Architect: Braun-Kerbl-Löffler Architects
Building year: Completed 2013



Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	X

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. No cut-off-rules are used. The technical equipment is included. System border is the building.

Operation stage modeling: The energy consumption in the building's operation stage is modeled by use of a simulation tool Trensis, including the gains of the photovoltaic equipment on the roof. Electricity is calculated with the actual German grid.mix (2011). The replacement of building materials and components in the operation stage are only allowed in integers, i.e. a component with a life time of 45 years is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span. The replacement cycles are calculated according the rules of BNB-system. The CEN/TC 350 standards allow for an individual assessment of a product and the probability of its replacement, if the service life of this component is near the chosen required service life of the building. E.g. if the replacement of a component with a life time of 45 years in a building with a life time of 50 years is regarded as uncertain within the 50 years, this actual replacement can be disregarded (CEN/TC 350, 2011).

End of life stage and next product system modeling: The EoL modeling can be simplified into groups of materials. Metals and mineral building materials are recycled with some predefined recycling potentials, materials with a heating value (e.g. wood and plastics) are incinerated and other materials are landfilled. Only metals with shares of primary manufacturing have recycling potentials. This means that e.g. reinforcement steel, which is made of 100% steel scrap, does not have a recycling potential (BNB International, 2010).

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Ökobau.dat 2011 (BMUB)
Energy supply: Thermal energy from wood pellets, electricity from German grid- mix, PV-installation on the roof, selfconsumption and grid
Standards/guidelines: EN 15978 standard and BNB guidelines

REFERENCES

König, Holger,; De Cristofaro Lisa; Benchmarks for life cycle costs and life cycle assessment of residential buildings, Building Research & Information Vol.40, Issue 5, 2012, pages 558-580 – ISSN: 0961-3218, doi: 10.1080/09613218.2012.702017,

CEN/TC 350 standards:
EN 15978 :2011 - Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method

BNB guidelines, 2010 . BNB – German assessment system for sustainable construction for federal buildings

Umweltbundesamt (UBA). https://www.umweltbundesamt.de/neubau-buerogebaeude-haus-2019-in-berlin

BUILDING DESCRIPTION - INVENTORY

THE BUILDING

The structural components of the fundament and the floor slab are armed concrete, all other structural parts are wood or wood based products. The facade is composed of wood, glass, with aluminium lamellas for the sunscreen. The roof is covered with a sealing membrane and used for the photovoltaic equipment. 370 m² photovoltaic elements are installed. For the heating a heatpump is used. The ventilation is equipped with a heat recovery system. The lightning is done partly with LED. Construction elements and material contents are calculated with the LEGEP database for building elements.

© **Andreas Meichsner** *photography*

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 1407 tons or 1114 kg/m$^2_{GFA}$(not including gravel).

Minerals: 727 to (51,64%)
Wood, wood based products 150,7 to (10,71%)
Metal 65,6 to (4,66%)
Plastics 14,9 to (1,06%)
Sealing: 39,7 to (2,82%)
Floorings: 148,2 to (10,52%)
Insulation materials: 117,4 to (8,34%)
Plaster, interior fittings 123,9 to (8,8%)
Paints and primers: 2,5to (0,3%)
Glass : 4,3 to (0.2%)
Technical Equipment 13 to (0,95%)

Service life of materials, what is replaced
....
Structural parts. None
Windows wood or plastic 40 years
Paints: 15 years
Glass: 30 years
Roof elements: 25 years
Technical equipment:
Primary Structure : 50 years
Sanitation 20 -25 ears
Heating and Air 20-25 years
Electricity: 20 – 25 years
Photovoltaic: 25 years

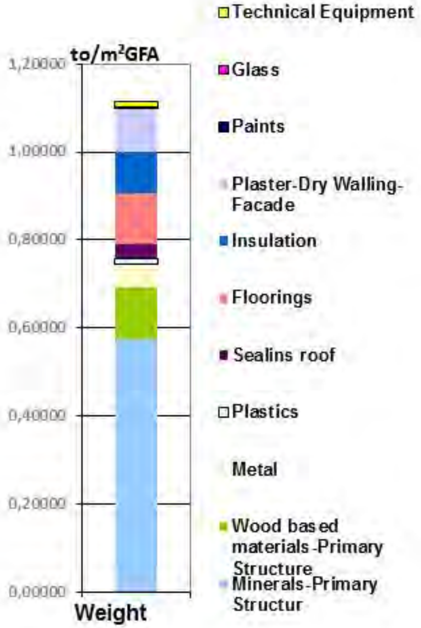


Figure 1: Distribution of construction materials - production phase

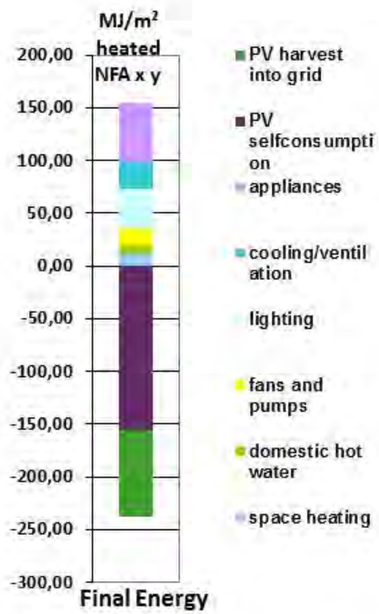
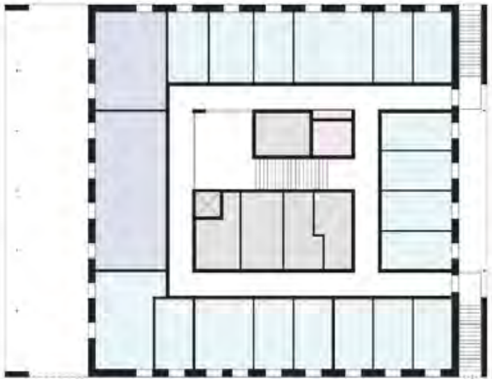


Figure 2 Distribution of final energy demand



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RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:
216,5 MJ/m$^2_{GFA}$/year
- construction materials: 100%
- operational energy: 0%

-
212 MJ/m$^2_{GFA}$/year Electricity into the grid:

Embodied Energy:
216,5 MJ/m$^2_{GFA}$/year

Global Warming Potential:
9,36 kg CO_2 equiv. /m$^2_{GFA}$/year
- construction materials: 100%
- operational energy: 0%

11,2 kg CO_2 equiv. /m$^2_{GFA}$/year Electricity into the grid

Embodied GHG Emissions:
9,36 kg CO_2 equiv. /m$^2_{GFA}$/year

Impact categories evaluated
GWP: Global warming potential
$PE_{n,ren}$: Primary Energy, non-renewable
PE_{ren}: Primary Energy, renewable

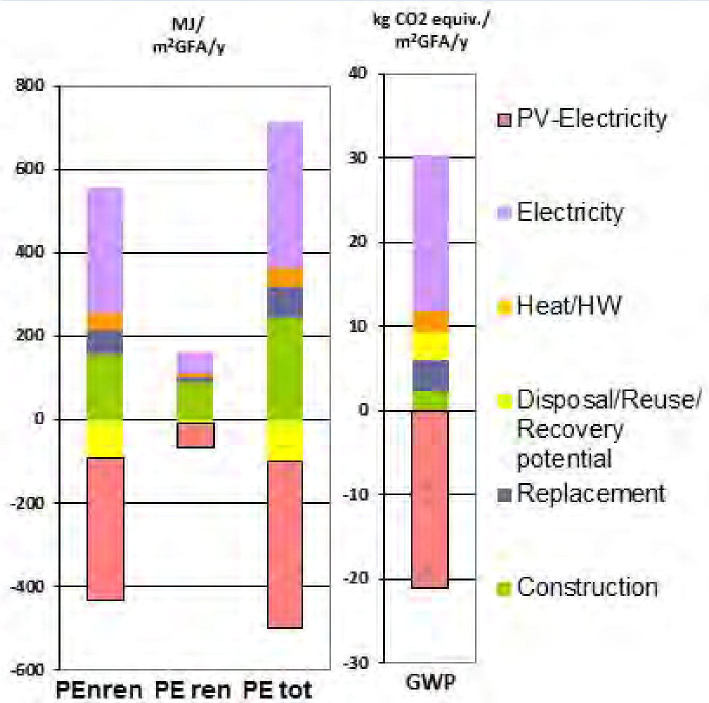


Figure 3: Distribution between construction materials and operational energy for the whole life cycle of the building .
The yellow column for the disposal/reuse/recovery is in the bonus area /under 0) for PE due to recycling potentials of wood, plastic and metals.
The electricity produced by photovoltaic is shown in the tabel with the red column also in the bonus area (under 0)

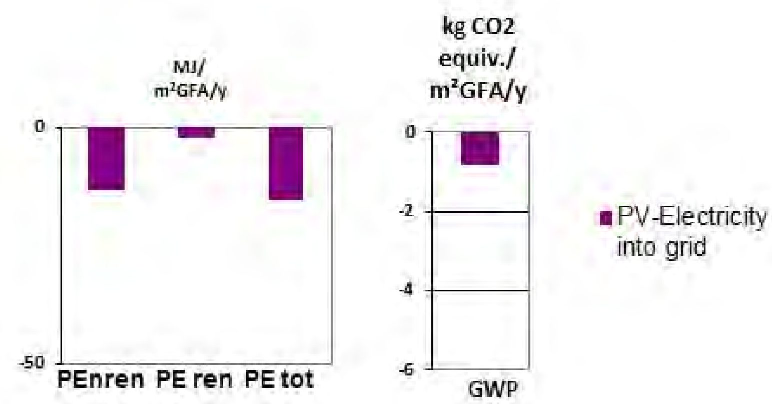


Figure 4: Environmental gains of the PV-electricity production given to the grid

Input of construction elements (DIN 276 structure) Full life cycle (A1-3;B4;C3-4;D)

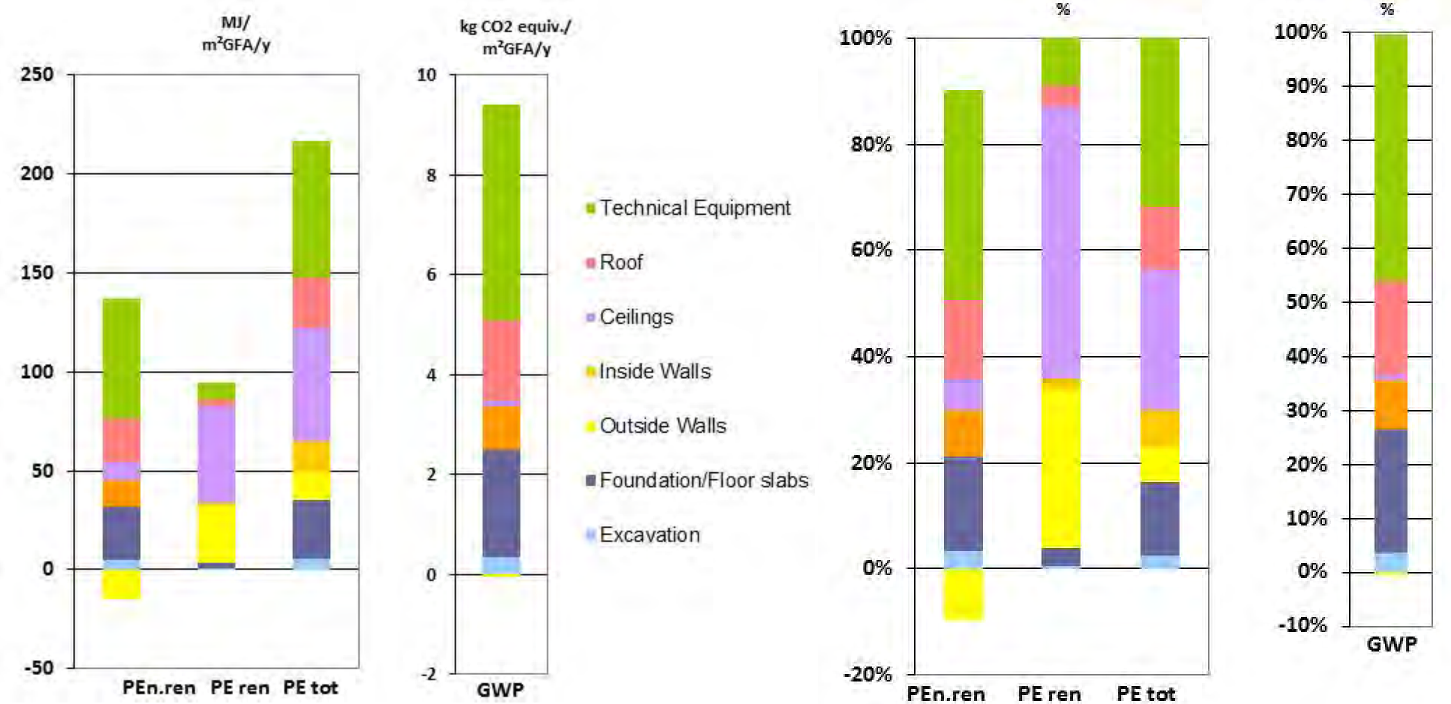


Figure 5: Contribution from the construction elements for the construction stage and end-of life treatment of the materials divided into 7 different building cost groups, replacements also included.

Impact categories evaluated

GWP: Global warming potential

$PE_{n,ren}$: Primary Energy, non-renewable

PE_{ren}: Primary Energy, renewable

Results

The project design is marked by three specialities:

- The structural parts in wood or wood based elements
- Full electricity covering by PV)
- Minimised ultimate energy demand.

These elements result in a “net-zero”-building and energy balance of PE Total and a “net-zero” value for the impact of GWP. The indicator total PE can reach a net-zero-level, because the input of the necessary heating demand is covered with a heat pump using also electricity from the PV.

The weight of the building is only 2/3 of comparable buildings with mineral structure. The distribution between the construction elements (following the cost categories of the DIN 276) shows for PE n.ren. a strong influence of the technical equipment., for PE ren. a dominant construction (90%), for the total PE 2/3 for the construction and 1/3 for the technical equipment. The GWP is marked also by the amount of 50% for technical equipment which is a result for the low input of the regrown materials for the construction parts .

Denmark

Key issues related to Annex 57:
2.2 Significance of elements in the building
3.1 Length of the reference study time

Case study DK1
Novo Nordic HQ - Denmark

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 and 100 years respectively. The study showed that the building materials contributed with **36%** of Primary Energy (PE) and **49%** of Global Warming Potential (GWP) with RSP of **50 years**, and **27%** of PE and **37%** of GWP when RSP extended to **100 years**.

Embodied Energy (EE) and Embodied Greenhouse Gases (EG) was evaluated. The length of RSP is an important factor for the results.

REFERENCE STUDY PERIOD

	50	100	years
EE	89	60	MJ/m^2_{GFA}/year
EG	7,9	4,8	kg CO_2 equiv. /m^2_{GFA}/year

Evaluation of different building parts showed the significance of the shell and core compared to the final fitting of internal walls , doors etc. Evaluation of the different building materials showed that for EG, concrete contributed with **42%** , steel with **37%** and aluminum with **8%.** For EE, concrete contributed with **20%,** steel with **48%** and aluminum with **10%**.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to the life cycle of a new office building in Denmark. The study evaluates:

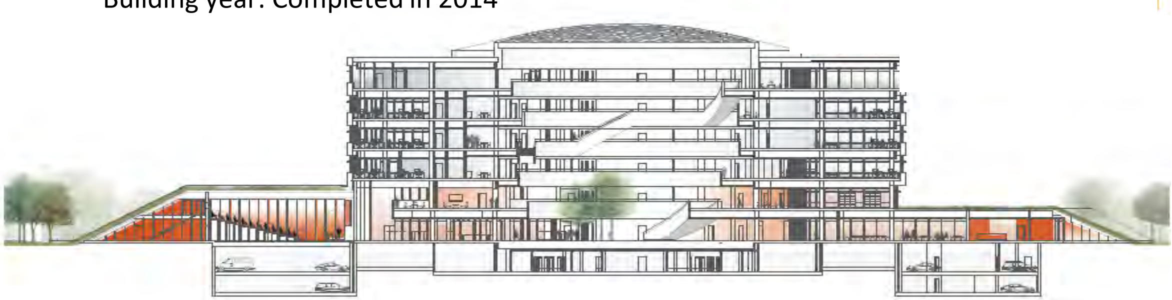
- The significance of different life cycle stages and processes
- The materials' contribution to the impacts compared to the total impacts
- The Embodied Energy (EE) and Embodied Greenhouse Gases (EG)
- The impacts related to different building materials

Additionally the study evaluates:

- The length of the reference study period on the results of the study

BUILDING KEY FACTS

Intended use: Office building
Size: 33.000 m² GFA
Location: Bagsværd, Denmark
Architect: Henning Larsen Architects
Building year: Completed in 2014



DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	X

LCA BACKGROUND

Reference study period: 50 and 100 years
Calculation of Energy: Primary energy use (non-renewable + renewable)
Calculation of GWP: GWP (100 years)
Databases used: PE International, ESUCO, Specific EPDs
Energy supply: Thermal energy from natural gas, electricity from EU-27 mix
Standards/guidelines: EN 15978 standard and DGNB International guidelines

REFERENCES

Nygaard Rasmussen, F. (2012) Certification of sustainable buildings in a life cycle assessment perspective. M.Sc. Thesis, Environmental Engineering, Technical University of Denmark, Lyngby.

Rasmussen, F. N., Birgisdottir, H. & Birkved, M. (2013) System and scenario choices in the life cycle choices of a building: changing impacts of the environmental profile, Proceedings of the Sustainable Buildings - Construction Products and Technologies. Verlag der Technischen Universität Graz, pp. 994-1003

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. The DGNB method allows a cut-off of materials that make up less than 1 % of the buildings mass or less than 1 % of the GWP or the PE consumption from materials. Since DGNB simplified calculation method was chosen, the final results was multiplied by a factor of 1.1 (DGNB International, 2010).

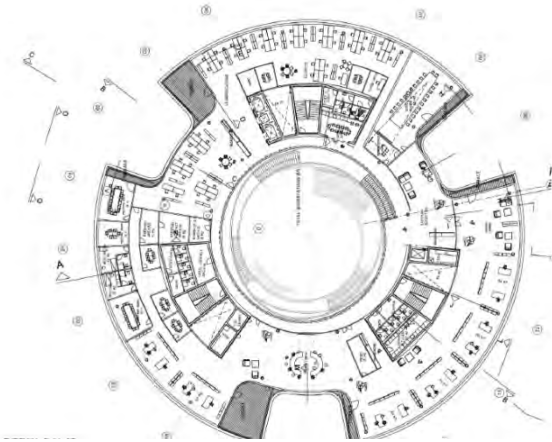
Operation stage modeling: The energy consumption in the building's operation stage is modeled with datasets representing average heating technologies and an EU-27 power grid mix. The re placements of building materials and components in the operation stage are only allowed in integers, i.e. a component with a life time of 45 years is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span (DGNB International, 2010). The CEN/TC 350 standards allow for an individual assessment of a product and the probability of its replacement, if the service life of this component is near the chosen required service life of the building. E.g. if the replacement of a component with a life time of 45 years in a building with a life time of 50 years is regarded as uncertain within the 50 years, this actual replacement can be disregarded (CEN/TC 350, 2011).

End of life stage and next product system modeling: The EoL modeling can be simplified into groups of materials. Metals and mineral building materials are recycled with some predefined recycling potentials, materials with a heating value (e.g. wood and plastics) are incinerated and other materials are landfilled. Only metals with shares of primary manufacturing have recycling potentials. This means that e.g. reinforcement steel, which is made of 100% steel scrap, does not have a recycling potential (DGNB International, 2010).
Due to limitations of the database used, impacts and benefits from the two life cycle stages are calculated as single sums.

THE BUILDING

The structural components are armed concrete and construction steel, and the facade is composed of glass, white glazed tiles and white aluminum lamellas. Above the atrium, a glass dome makes the top roof section. The building is a low energy building (class 2015 in the Danish Building Regulation) with an expected use of heating energy of 13.8 kWh/m2/year and electrical energy of 12.3 kWh/m2/year

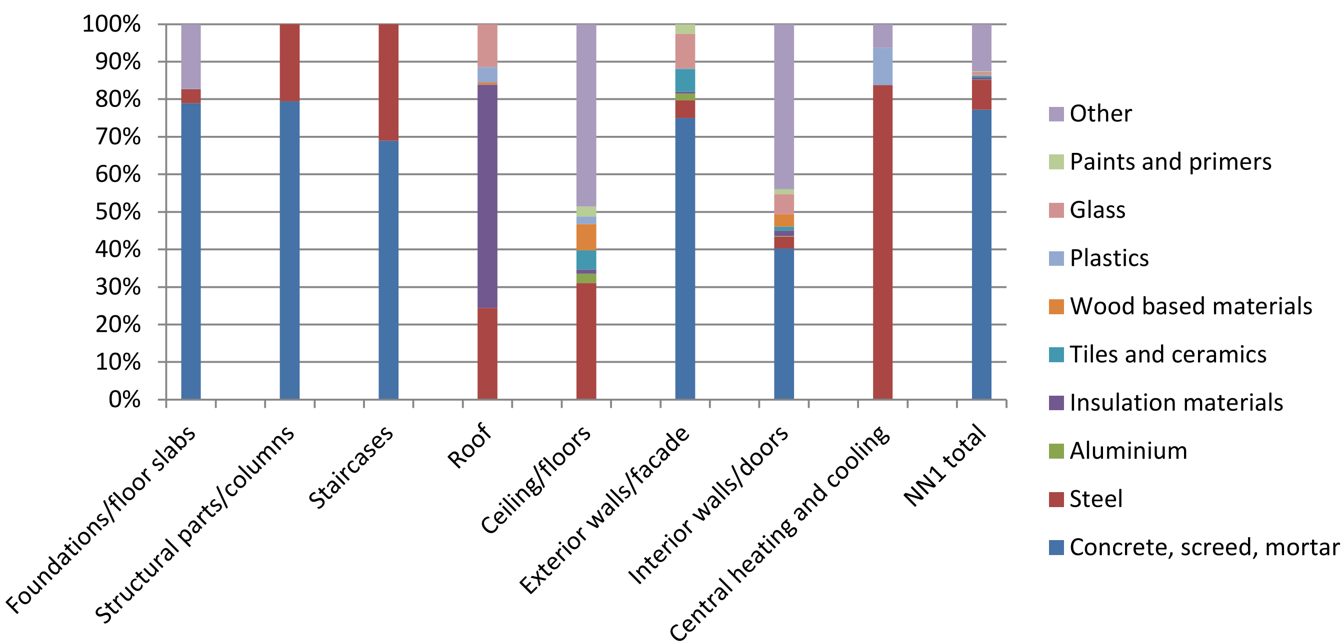
Material use for construction	Mass [kg]
Concrete, screed, mortar	38,650,000
Steel	3,950,000
Aluminium	69,550
Insulation materials	288,700
Tiles and ceramics	214,250
Wood based materials	86,500
Plastics	72,250
Glass	341,700
Paints and primers	104,000
Other (primarily gravel)	6,278,150



MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 51,000 tons or 1550 kg/m^2_{GFA}.

Material use for construction



RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:

248 MJ/m$^2_{GFA}$/year

- construction materials: 36%
- operational energy: 64%

Global Warming Potential

16,1 kg CO_2 equiv. /m$^2_{GFA}$/year

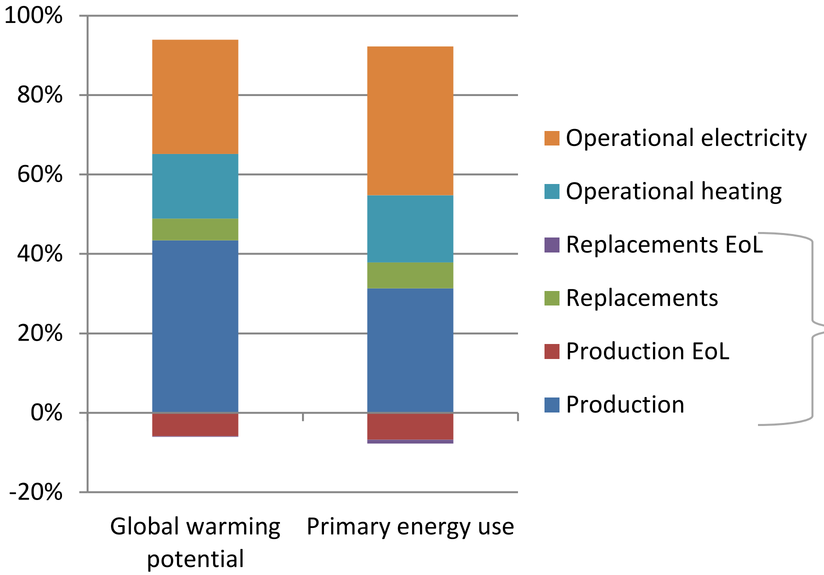
- construction materials: 49%
- operational energy: 51%

Embodied Energy:

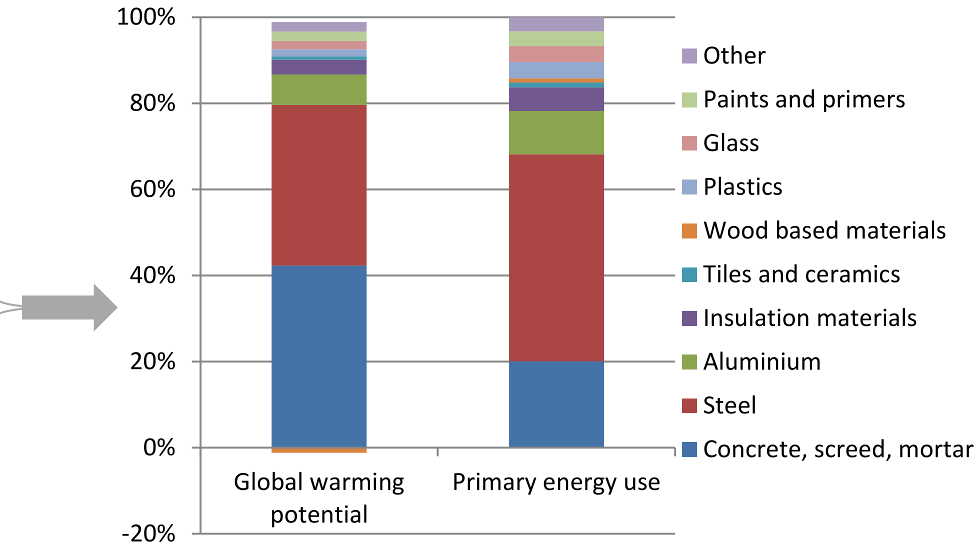
89 MJ/m$^2_{GFA}$/year

Embodied Greenhouse gases:

7,9 kg CO_2 equiv. /m$^2_{GFA}$/year



Distribution between construction materials and operational energy for the reference study period of 50 years



Contribution from the life cycle of construction materials divided into different types of building materials.

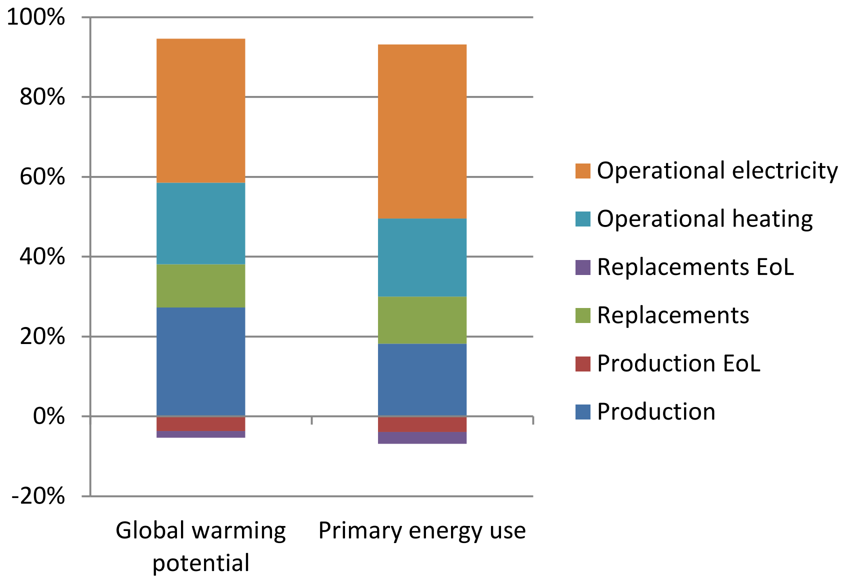
RESULTS OF STUDY PERIOD = 100 YEARS

Total Primary Energy consumption:
219 MJ/m$^2_{GFA}$/year
- construction materials: 27%
- operational energy: 73%

Global Warming Potential
13 kg CO_2 equiv. /m$^2_{GFA}$/year
- construction materials: 37%
- operational energy: 63%

Embodied Energy:
60 MJ/m$^2_{GFA}$/year

Embodied Greenhouse Gases:
4,8 kg CO_2 equiv. /m$^2_{GFA}$/year



Distribution between construction materials and operational energy for the reference study period of 100 years

Importance of the reference study period (RSP)

Using a 100 year RSP instead of 50 years lowers the embodied energy (total primary energy) from 89 to 60 MJ/m$^2_{GFA}$/year and the embodied Greenhouse Gases from 7,9 to 4,8 kg CO_2 equiv. /m$^2_{GFA}$/year.

The case study showed that materials with expected service life of 80-100 years, such as concrete and steel, were important for the results of the study contributing with 50-80% of the impact categories.

LCA with use of shorter RSP, such as 50 years, does not support the use of long lasting building materials. Such assumptions could possibly lead building designer to choose materials that in the long run are not necessarily environmental beneficial.

It is therefore very important to find the right balance between crediting the potential environmental benefits of using materials with long service life and handling the increasing uncertainties in forecasting the building's use stage scenarios (e.g. energy supply scenarios) for up to 100 years.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Denmark / moderate climate
Building/ Usage type	Office building, new construction
Energy-standard	Low Energy 2015 in accordance with the Danish Building regulation of 2010
Gross floor area/ Net floor area	33,000/24,300 m2 (large unheated basement not included as net floor area)
Gross volume/ Net volume	n/a
Reference area for EE/EC	GFA 33,000
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete, steel)
Thermal insulation	Insulation of walls, roof insulation
Ventilation system	Automatic ventilation
Heating and cooling system	Heating: District heating Cooling: Mechanical cooling, groundwater cooling
Final energy demand electricity	12,3 kWh/m2a
Final energy demand for heating and hot water	Room heating 8,6 kWh/m²a (per NFA) Hot water 5,4 kWh/m²a (per NFA)
Final energy demand for cooling	7,8 kWh/m²a
Benchmark	n/a
Purpose of assessment	to evaluate the use of Primary Energy (PE) and the Global Warming Potential (GWP) related to the life cycle of a new office building in Denmark.
Assessment methodology	According to the methodology of DGNB Denmark
Reference Study Period	50/100 years
Included life cycle stages	A1-A3, B4, (B6), C3-C4, D

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Foundation Ceiling Roof Pillars/columns External walls (underground and above ground) Windows, doors Internal walls Internal doors, dividing walls Flooring Wall covers Ceiling covers Main technical components (ventilation units etc)
Scenarios and assumptions used	In accordance with the Danish DGNB system (2011)
Accounting of electricity mix	static emissions factors, Thermal energy from natural gas, electricity from EU-27 mix
Databases used	PE International, ESUCO, Specific EPDs
LCA Software used	
Method of materials quantification	Tendering documents, architects' drawings
Values and sources of primary energy and emission factors	
Character of the indicator used	
Indicators assessed	Primary energy total (non-renewable + renewable) GHG emissions

Key issues related to Annex 57:
1.1 Selection of materials
2.2 significance of elements in the building
4.4 Handling credits for recycling of metals

Case study DK2
UPCYCLE HOUSE- Denmark

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

An LCA case study was performed to investigate the environmental effects of a building made of upcycled materials compared with a building made of traditionally produced materials. The study entailed the development of a price-based methodology to allocate environmental impacts from upcycled materials.

Embodied Energy (EE) and Embodied Greenhouse gases (EC) was evaluated.

	Upcycle House	Reference house	
EE	55	175	MJ/m$^2_{GFA}$/year
EG	1.04	5.5	kg CO_2-eq/m$^2_{GFA}$/year

A disadvantage of upcycling is that it requires complex and individual planning of the production stage and is difficult to apply for mass production. However, the analysis showed that if a building part can be replaced by an equal performing waste product made from the same material, then the environmental damage reduction is between 65 and 90 % depending on the allocation factor. Thus, Implementation of the upcycling strategy may face practical challenges, but the strategy to reduce environmental damage shows a big potential for the future.

OBJECTIVES OF CASE STUDY

To develop an operational methodology for conducting Life Cycle Assessment (LCA) on a residential building made from upcycled materials (reused and recycled materials), the Upcycle House. Furthermore the study aims at investigating the embodied primary energy and greenhouse gases of materials used for the construction in Upcycle House compared with the embodied primary energy and greenhouse gases of materials used in a Danish reference residential house.

The study evaluates:

- The Embodied primary energy (EE) of building materials in construction
- The Embodied Greenhouse gases (EG) of building materials in construction
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Residential building
Size: 129 m^2 GFA (104 m2 NFA)
Location: Nyborg, Denmark
Architect: Lendager Architects
Building year: Construction initiated primo 2013. To be completed mid-2013

[Lendager Architects]

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SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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														

Life cycle stages included:
Only life cycle stage modules related to the production of materials used in the building are included in the study. The included processes thus solely represent modules from the production life cycle stage. Both houses fulfill the Danish requirements for building class 2015 in terms of energy consumption in the use stage.

LCA BACKGROUND

Reference study period:	50 years
LCIA methodology:	Impact 2002+
Impact categories assessed:	Climate Change (500 years) in [kg CO2-eq] Primary Energy Use in [MJ]
Databases used:	PE International

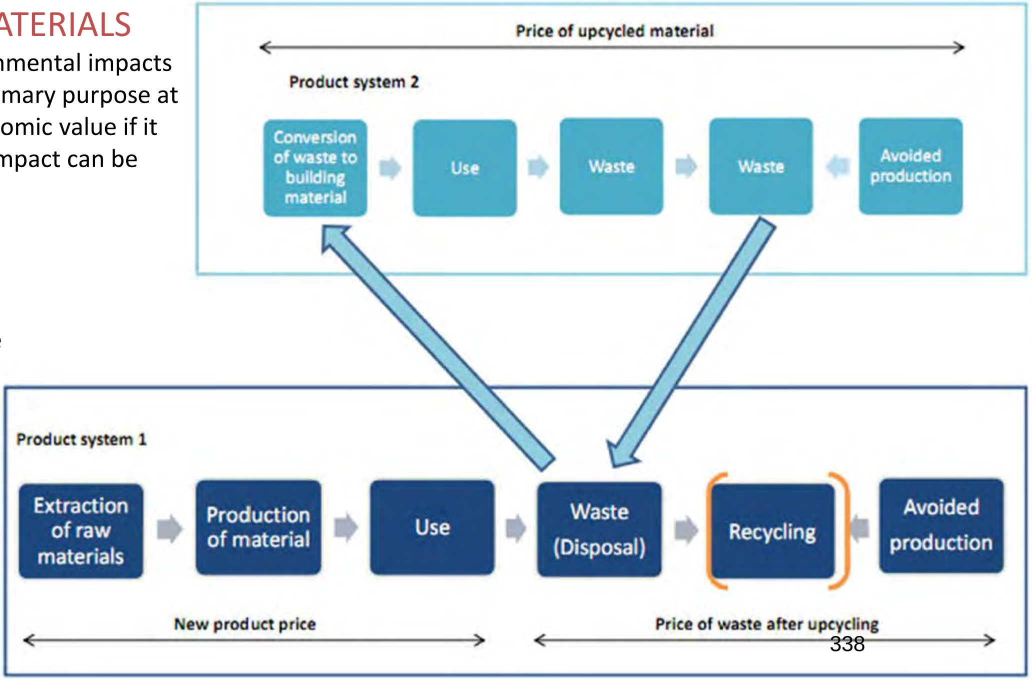
METHODOLOGY FOR ALLOCATION OF UPCYCLED MATERIALS

The use of waste products in a system is generally related to low environmental impacts because the material is regarded as a byproduct or it is useless for its primary purpose at the end of the life cycle. Nevertheless, waste material still holds an economic value if it can be used for further product processing (recycling). In that case the impact can be allocated by the current waste demand on the market (price allocation).

Usage of upcycled waste in a product system changes into an additional life cycle in the waste disposal stage. Consequentially the upcycle waste can be seen as “borrowed” material from another life cycle. Therefore the environmental impact of the waste products will be evaluated in the relation to the entire life cycle. The impact allocation factor (R.U.M.) is thus derived from the economic value (price) by the formula:

$$R.U.M = \frac{P.U.M}{P.U.M + I.P. + P.W.}$$

where R.U.M. is ratio of environmental impact of upcycled material
P.U.M. is price of upcycled material
I.P is initial price
P.W. is price of waste value after usage

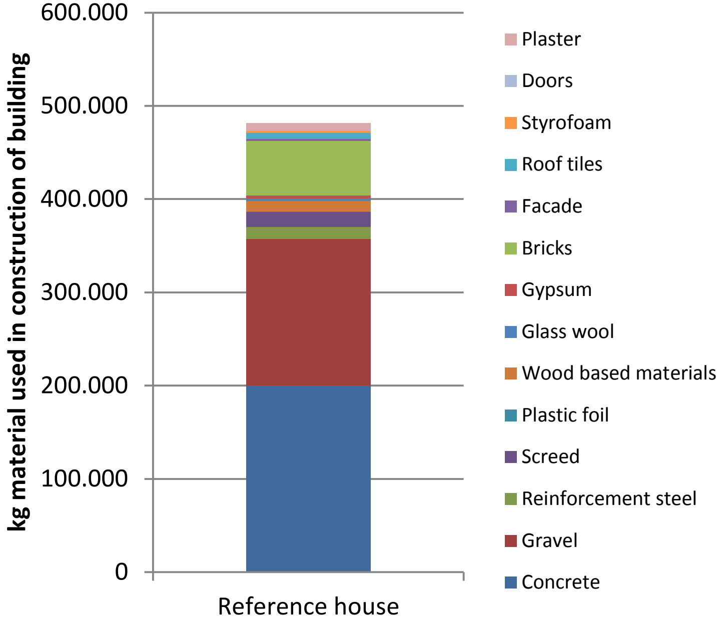


[Morten Birkved, DTU Management Engineering, 2012]

BUILDING DESCRIPTION - INVENTORY

THE REFERENCE BUILDING

The building is a 162 m2 single family house constructed with a concrete strip foundation and a floor slab of armed concrete. External walls are made of concrete with an outer shell of masonry. The roof is clad in concrete roof tiles. Insulation in walls and roof is glass wool.



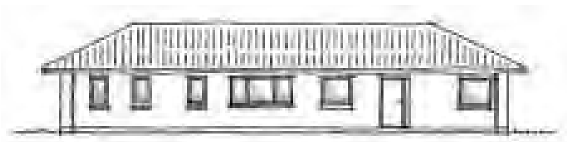


Illustration of reference house [Danish Building Research Institute]

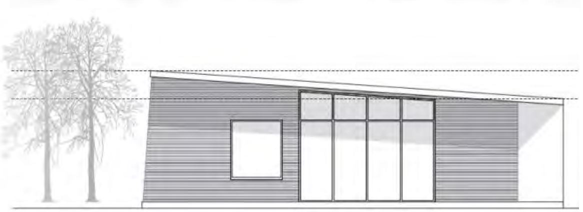
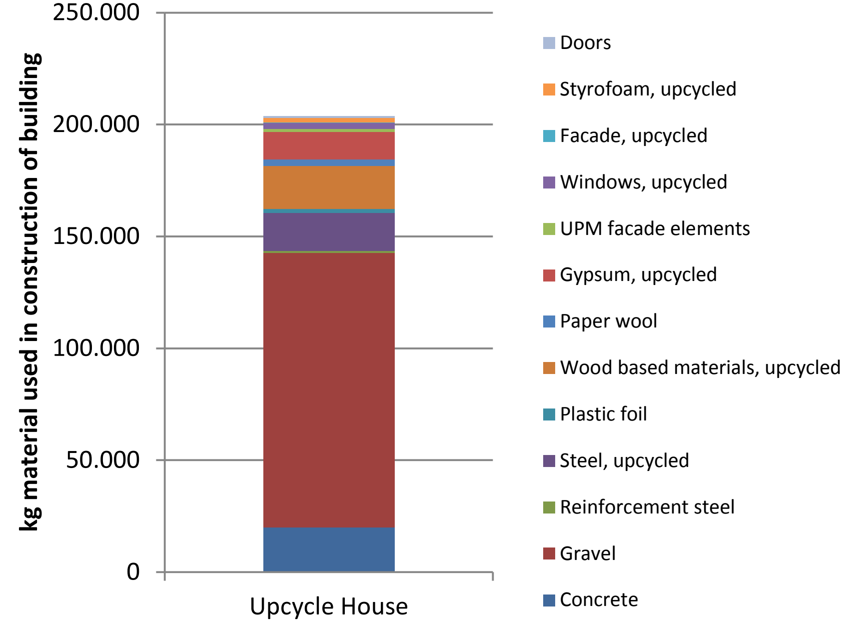


Illustration of Upcycle House [Lendager Architects]

UPCYCLE HOUSE

The building is a 162 m2 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.



Allocation factors for upcycled materials	Steel/container steel		0.12
	Plastic foil		0.50
	Wood based materials		0.14
	Gypsum		0.35
	UPM		0.35
	Doors		0.35
	Windows		0.12
	Facade elements		0.35
	Wood boards (OSB)	339	0.60
	Styrofoam		0.35

RESULTS

UPCYCLE HOUSE

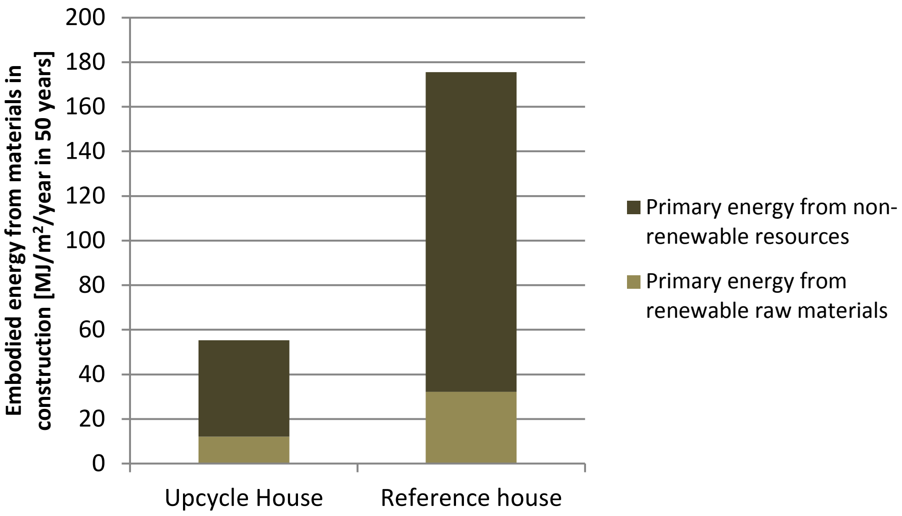
Embodied Energy:
55 MJ/m^2_{GFA}/year

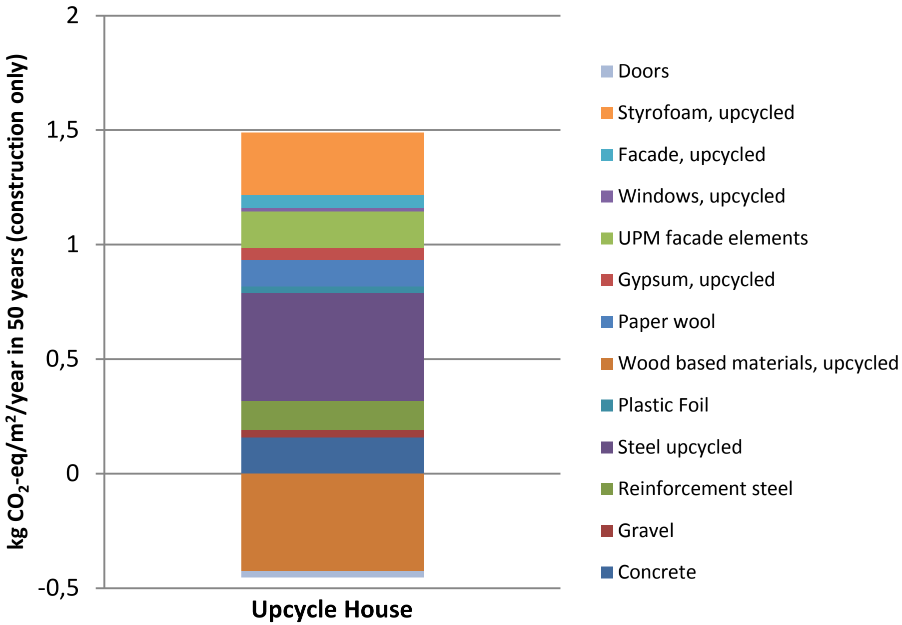
Embodied Greenhouse gases:
1.04 kg CO_2-eq/m^2_{GFA}/year

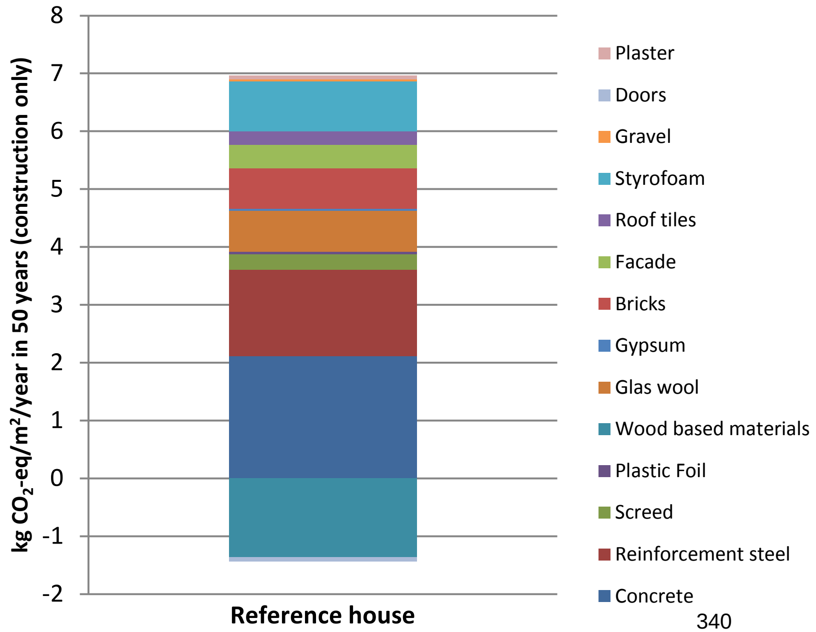
REFERENCE HOUSE

Embodied Energy:
175 MJ/m^2_{GFA}/year

Embodied Greenhouse gases:
5.5 kg CO_2-eq/m^2_{GFA}/year







CONCLUSIONS

AIM OF UPCYCLING

The target of upcycling is to build a one family house with as low as possible environmental impact using waste materials. Theoretically a building construction can be built of 100 % of upcycled material, but increased upcycling material share in a building is coherent with high raw material supply complexity. Thus, high upcycling complexity could lead to high costs and high production or logistic effort. Therefore each building material choice requires individual research and life cycle assessment to adjust the environmental advantages and the meaning of use.

ADVANTAGES OF UPCYCLING

Environmental damage reduction of upcycling depends on the upcycled material share, production process of the product (direct / indirect upcycling) and material choice. Basically if a building part can be replaced by an equal performing waste product made from the same material then the environmental damage reduction is between 65 and 90 % depending on the allocation factor. The biggest environmental upcycling success depends on individual selected ideas, in this case the ship container, which fulfills the high material requirements with very short production process and which performs well compared to the reference benchmark.

DISADVANTAGES OF UPCYCLING

Nevertheless upcycling has several disadvantages concerning its application on buildings. One disadvantage of upcycling is that it requires complex and individual planning of the production stage and is difficult to apply for mass production. Unique products with unstandardized measures entail unpredicted problems in the manufacturing, construction and use stage. Furthermore, waste material use does not necessarily result in less environmental impacts than the benchmark and the building design therefore requires individual adjustment. Further critic on the upcycling performance on buildings is that there might be a quality decrease (in terms of service life) of the one family house although it delivers the same key parameters as an equivalent reference house.

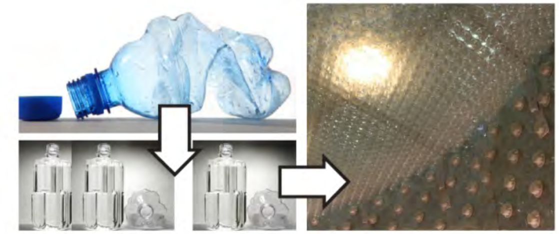
CONCLUSIONS BASED ON CASE STUDY

Implementation of the upcycling strategy may face many practical challenges, but the strategy to reduce environmental damage shows a big potential for the future. Effective upcycling success still depends on availability of matching waste material and must be regionally assessed. It is not necessary to exclusively use waste material to reach high environmental damage reduction. Therefore upcycling should be practically implemented as a combination with the use of environmentally friendly materials like wood.

REFERENCES

Sander, Eugen; Reduction of environmental impact of building production by material upcycling; M.Sc. thesis project; Management and Engineering; Technical University of Denmark; 2012

Examples of upcycled materials *[Lendager Architects]*



Plastic bottles → PolliBrick

Plastic waste → UPM ProFi facade

Paper waste → Paper wool

Wood waste → Wood boards (OSB)

Key issues related to Annex 57:
1.2 Flexibility and space efficiency in design/layout
1.3 Prolongation of building life time
2.1 Significance of stages in the life cycle

Case study DK3
MiniCO2-houses Denmark

KEY OBSERVATIONS

4 test residential houses build to reduce EG through different design measures. The test houses are compared to a typical residential construction.

Zero Maintenance Houses I (DK3a) and II (DK3b) are designed for low maintenance and long service life of Building:

RSP = RSL	EG [kg CO2-eq/m2/year]	EE [MJ/m2/year]
Zero Maintenance House I	2.0	31
Zero Maintenance House II	1.6	46
Reference House	3.7	71

The Adaptable House (DK3c) is designed to enhance flexibility and adaptability in the use stage of the building

RSP = 50 years	EG [kg CO2-eq]	EE [MJ]
The Adaptable House (147 m2)	34,000	561,000
Refurbishment scenarios	8,000	110,000
Reference House (149 m2)	42,000	712,000
Refurbishment scenarios	15,000	252,000

The Quota House (DK3d) is designed to minimize energy consumption in the building's use stage

	Construction and materials		Use stage energy	
RSP = 50 years	EG [kg CO2-eq/m2/year]	EE [MJ/m2/year]	GWP [kg CO2-eq/m2/year]	Primary energy use [MJ/m2/year]
The Quota House	6.1	120	35	600
Reference House	5.6	96	46	790

OBJEGTIVES OF CASE STUDY

To assess the embodied greenhouse gas emissions (EG) and embodied primary energy use (EE) from the life cycle of 4 experimental single family residential buildings. Each building aims at reducing life cycle EG through the optimization of one of the following design parameters :

- Design for prolongation of material service life (a-b)
- Design for adaptation in the use stage of the building (c)
- Design for reduction of energy consumption in use stage(d)

BUILDINGS KEY FACTS

Size: 136-156 m^2 GFA

Location: Nyborg, Denmark

Architects: Various

Building year: 2013-2014

Project founder: Realdania By og Byg

DK3c: Adaptable House [©Realdania By og Byg]

DK3a: Zero Maintenance I [©Realdania By og Byg]

DK3d: Quota House [©Realdania By og Byg]

DK3b: Zero Maintenance II [©Realdania By og Byg]

DK3e: Reference House [©SBi]

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X	(c) (e)	(d)				X	X	X

LCA BACKGROUND

Reference study period (RSP): Design a: RSP=Required Service Life (RSL)
Design b and c: RSP=50 years

LCIA methodology: CML

Impact categories assessed: EG, as in the CML category GWP
EE, as primary energy

Databases used: ESUCO (developed for DGNB scheme by PE International)

REFERENCES

Rasmussen, F; Birgisdóttir, H. (2013) Livscyklusvurdering af MiniCO2-husene i Nyborg (Danish), Danish Building Research Institute, Aalborg University, Copenhagen

MOE Consulting Engineers (2013) Kvotehuset TeamPlus - Kvoten, MOE Consulting Engineers, Aarhus

Product stage:
Includes impacts related to raw material extraction and manufacturing of building materials in main building elements (external and internal walls, foundation, floor slabs, attic and roof, windows and doors). Rough estimations of mechanical and electrical installations and distribution systems are also included. All houses fulfill the Danish requirements for building class 2015 in terms of energy consumption in the use stage.

Use stage:
For all houses the replacement of materials according to the study period is included.
Design b (adaptability) furthermore includes a total of 3 scenarios of refurbishment concerning:
- Refurbishment of inner wall (demolition + new wall)
- Change of kitchen position (demolition of wall + new wall + new flooring)
- Addition of 55 m2 floor area in the original design of the building
- Design d includes numbers from the operational energy use for a household of 4, including numbers for both building operation and user specific consumption of electricity for cooking, cleaning, entertainment etc.

End-of-life and Next product system:
The two life cycle stages are included in the calculations for all houses. Assumed scenarios for main waste categories:
- wood and plastics: incinerated in cogen plant, substituting average heat and energy mix technologies
- concrete and tiles: crushed and used as road fill, substituting gravel
- insulation materials and gypsum: landfilled
- metals: recycled. Share of primary metals substituting primary metal input in new product system

Due to limitations of the database used, impacts and benefits from the two life cycle stages are calculated as single sums.

THE CONSTRUCTIONS

ZERO MAINTENANCE HOUSE I (DK3a)

The building is a 136 m2 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.

Leth & Gori Architects

ZERO MAINTENANCE HOUSE II (DK3b)

The building is a 156 m2 single family house constructed with pre-fab 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 .

by Arkitema Architects

THE ADAPTABLE HOUSE (DK3c)

The building is a 147 m2 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.

by Henning Larsen Architects

THE QUOTA HOUSE (DK3d)

The building is a 138 m2 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.

by Pluskontoret Architects

THE REFERENCE BUILDING (DK3e)

The building is a 149 m2 single family house constructed with a concrete strip foundation and a floor slab of armed concrete. External walls are made of concrete with an outer shell of masonry. The roof is clad in concrete roof tiles. Insulation in walls and roof is mineral wool.

THE DESIGN MEASURES TO REDUCE EG

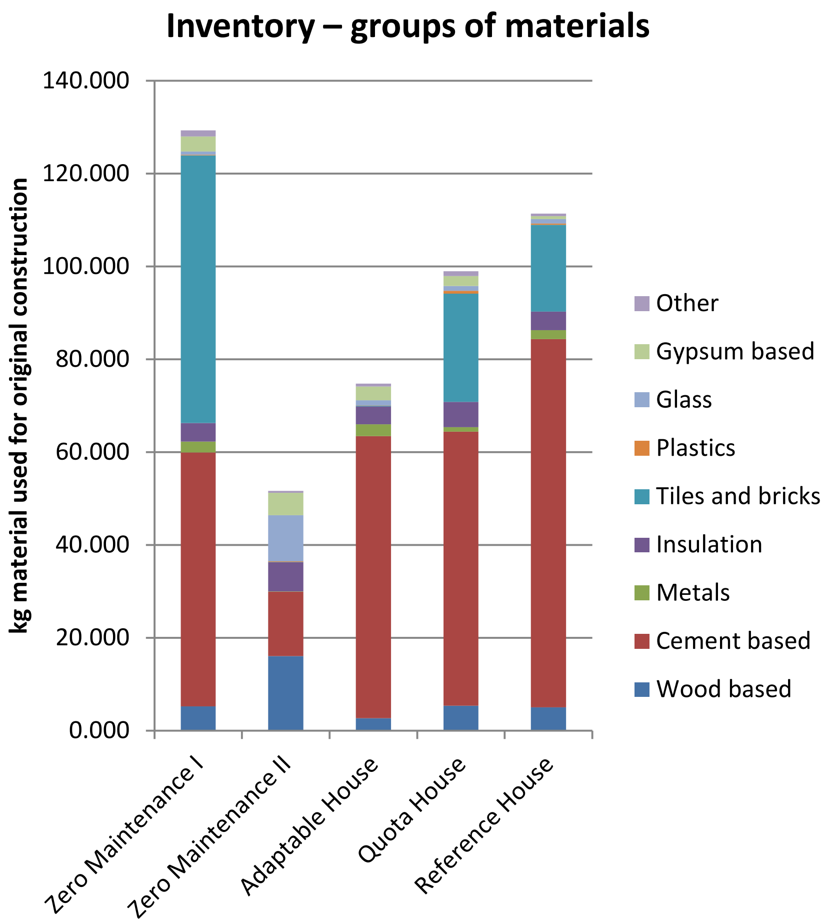
Durable building materials chosen for the main structure. A large roof overhang protects windows and doors from weathering. Service life of windows is estimated increased from 25 years to 40 years. Service life of building estimated as 150 years

Glass cladding protects the wooden construction elements. Overhang furthermore protects weaker building components (like windows). Service life of windows is estimated increased from 25 years to 40 years. Service life of building estimated as 150 years

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. Direct reuse of wall elements are used in calculations of use stage refurbishment scenarios

Technical and design solutions to encourage energy efficient behavior among occupants: Integrated in the design of the house is a greenhouse, a cold storage room, a media room and clothes drying facilities. Smart-grid-style electronic devices are employed in kitchen, washing and entertainment equipment. An overall monitoring concept, "The Quota", helps the occupants manage the energy use throughout the year.

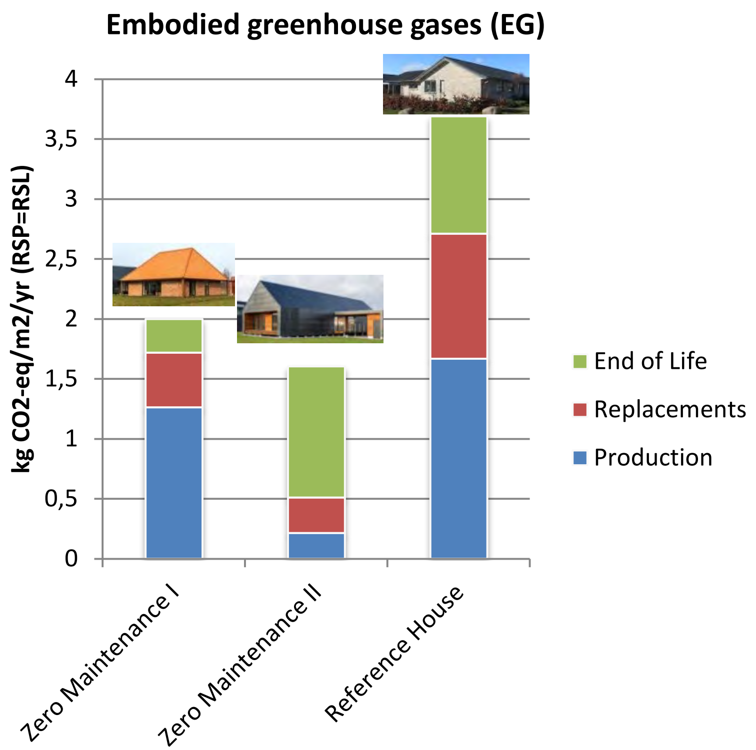
No measures to reduce neither embodied nor operational energy. This house serves as a comparative building to the MiniCO2-houses

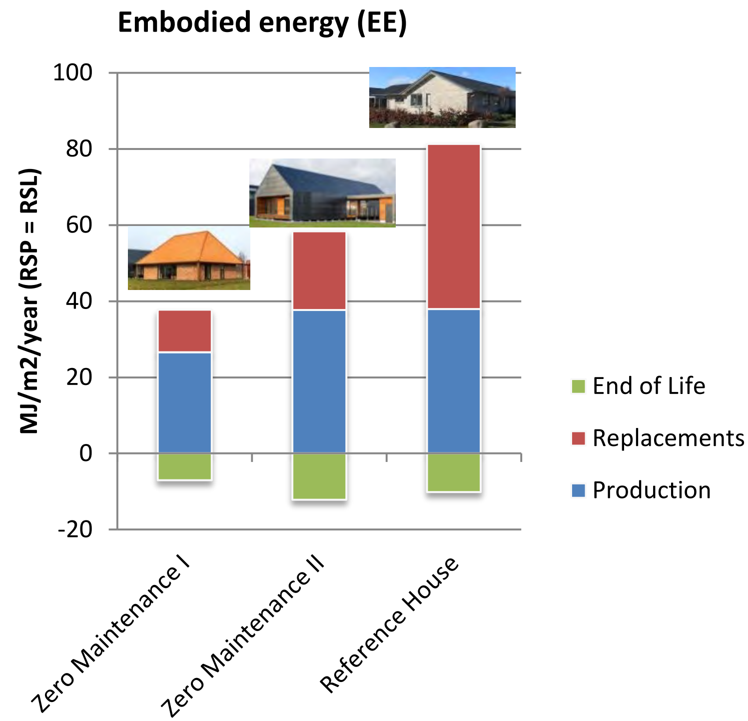


Materials in construction	Zero Maintenance I	Zero Maintenance II	Adaptable House	Quota House	Reference House
Wood based	5200	16000	2700	5400	5000
Cement based	55000	14000	61000	59000	73000
Metals	2400	100	2600	1000	1900
Insulation	4000	6200	3800	5500	4000
Tiles and bricks	58000	50	150	23000	19000
Plastics	200	200	100	600	200
Glass	700	9900	1100	1100	1000
Gypsum based	3200	4900	3000	2100	600
Other	1400	400	600	1000	600

All houses in the case study are constructed to comply with the requirements for the 2015 low-energy-class in the Danish Building Regulation

DESIGN SOLUTIONS FOR LOW MAINTENANCE AND LONG BUILDING SERVICE LIFE



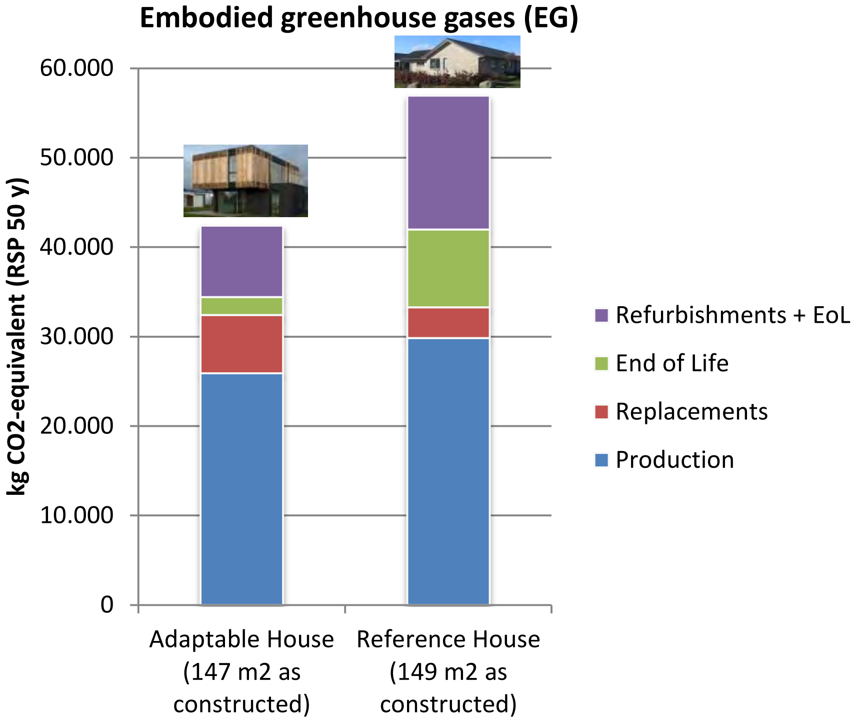


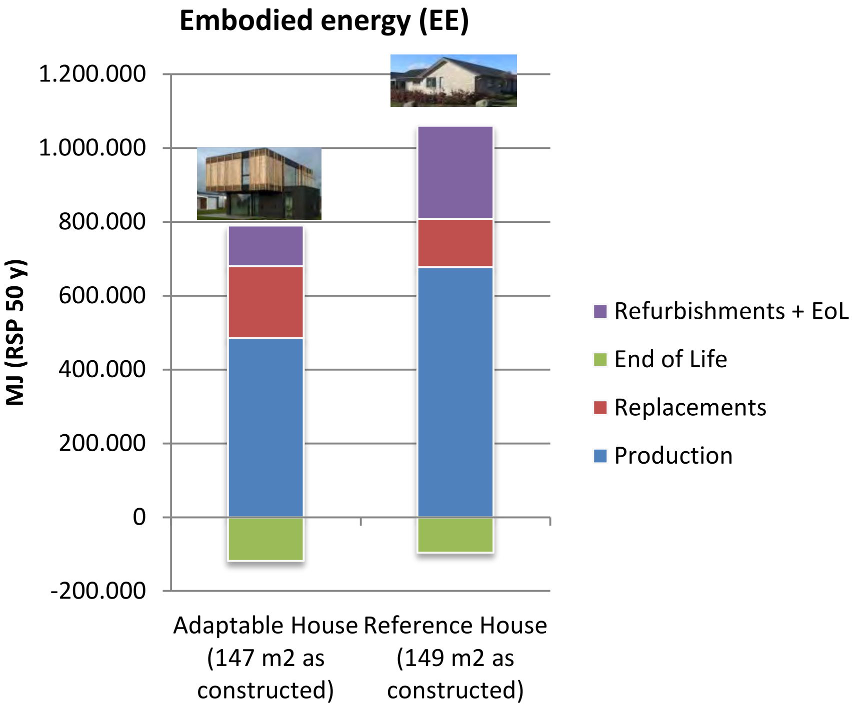
Notice: The Zero Maintenance Houses (ZMHs) are both calculated with RSL of 150 years whereas the Reference House is calculated with an RSL of 120 years

ABOUT THE RESULTS

EoL and replacement scenarios are important contributors to the total results for both EG and EE. The longer RSP the more significant these two life cycle stages are.
In the case of ZMH II, a large share of wood is used in the construction. The LCI data for wood includes stored greenhouse gases and hence gives a large negative number for the production numbers for the EG. The stored greenhouse gases is released in the incineration process of the EoL.
Replacement of window glass is a major contributor to the loads from the replacement stage in all houses.
Even though the tile making process is energy intensive, a house like ZMH I still results in only half the amount of EE as a reference house. This has to do with the design of the house where weak components are protected, a strategy also used in ZMH II but with a totally different look, and different results due to the material composition of the construction.
The ZMHs show ways of reducing EG and EE through design for low maintenance although the results are very sensitive to the scenarios chosen for the use stage.

DESIGN SOLUTION FOR FLEXIBILITY AND ADAPTABILITY IN THE BUILDING'S USE STAGE





Notice: Results are given as totals for a reference study period of 50 years. The refurbishment scenarios for both houses entails the rearrangement of an inner wall, rearrangement of kitchen area and construction of 55 m2 additional space following the original design of the house.

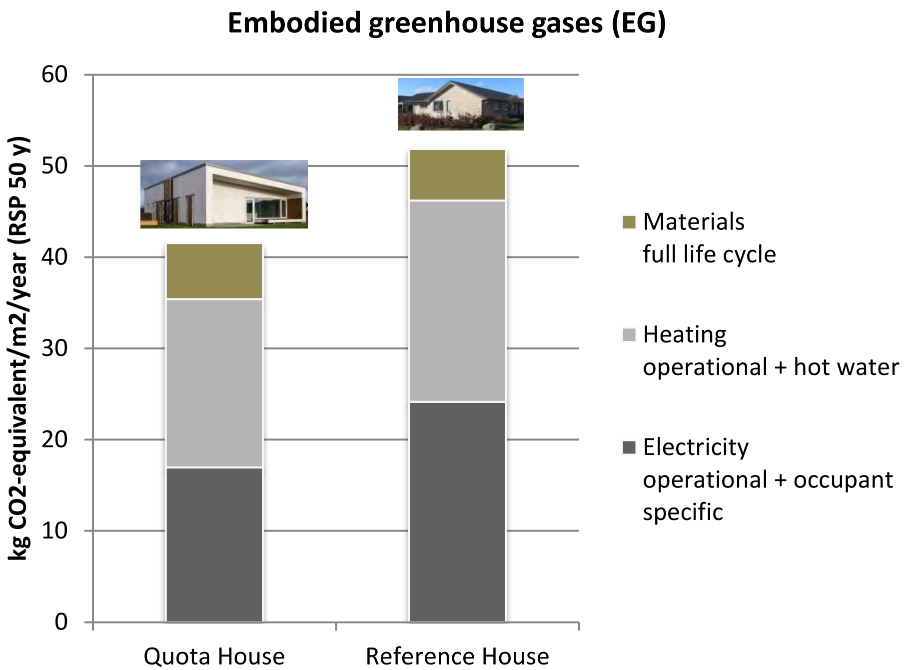
ABOUT THE RESULTS

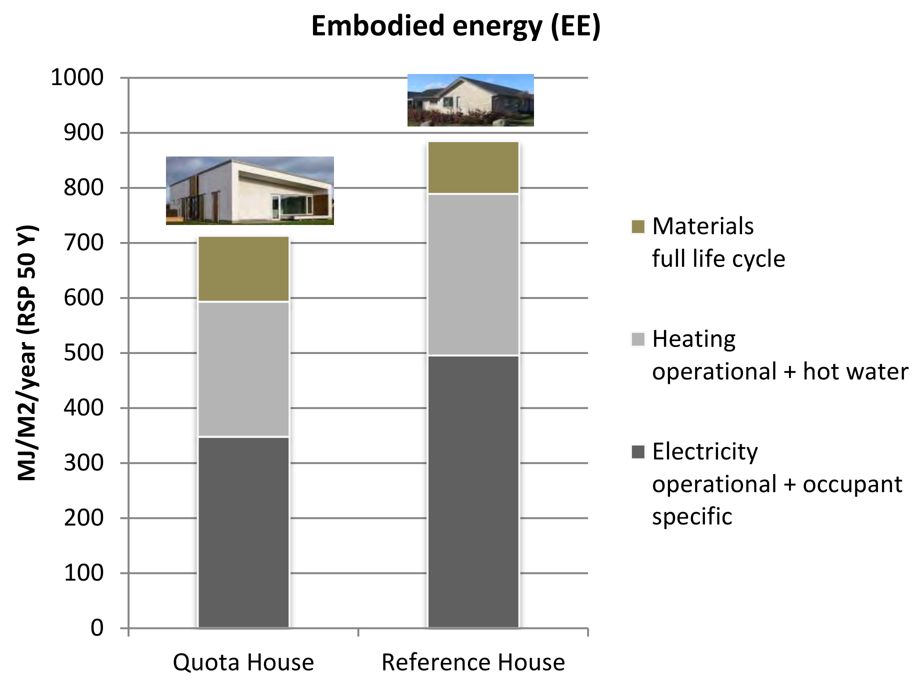
The calculated "package" of refurbishment scenarios presents a large share of the impacts for both EE and EG in both houses. The inherent flexibility of the adaptable house does have a positive effect in the chosen scenarios, lowering the total impacts.

Most of the refurbishment impact is related to the expansion of living area and less related to rearrangement of inner walls and elements. This serves to show that the reusability of outer wall and roof elements is a design parameter on which impact potentials can be lowered.

With an expansion, the house is in reality a new construction from the original design, thus there are some methodological issues about the calculations which is not dealt with in this study

DESIGN SOLUTION TO MINIMIZE OCCUPANTS' ENERGY CONSUMPTION IN USE STAGE





Notice: Energy consumption in use stage is calculated by MOE Consulting Engineers

ABOUT THE RESULTS

According to standards like the European EN 15978 only operational energy is included when calculating BLCA. In this study the total energy use of the occupants is included because the design measures in the Quota House aimed at reducing both operational and user specific energy consumption. The design and technological measures in the Quota House lowers the total EG and EE compared to a reference house.
When compared only on the life cycle of the construction itself, the Quota House turns out to be less EG and EE efficient than the reference house (e.g. 6 kg CO2-eq/m2/year against 5.5 kg CO2-eq/m2/year). This extra impact from the Quota House is paradoxically enough primarily caused by the deign elements to reduce energy consumption, i.e. the cold storage room and the greenhouse. The case study thereby illustrate the importance of assessing broadly when performing BLCAs.

Case study DK4
7 OFFICE BUILDINGS - Denmark

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

7 new office buildings, erected in the period 2009-2014 participated in the pilot phase for the Danish adaptation of the DGNB certification system for sustainable buildings.

An LCA screening is part of the assessment criteria. Results on embodied impacts (construction + replacements) from the screenings are as in the table below:

Building	EG [kg CO2-eq/m2/year]	EE [MJ/m2/year]
A	5.1	161
B	5.1	69
C	7.2	76
D	7.5	91
E	7.1	88
F	6.0	82
G	6.9	88

Operational energy within the different buildings vary greatly and determines the total impact from the building life cycle.

The pilot phase screenings also shows that End-of-Life (EoL)scenarios for materials can affect materials related results substantially, and that the EoL-scenarios are difficult to apply correctly for the individual LCA auditors.

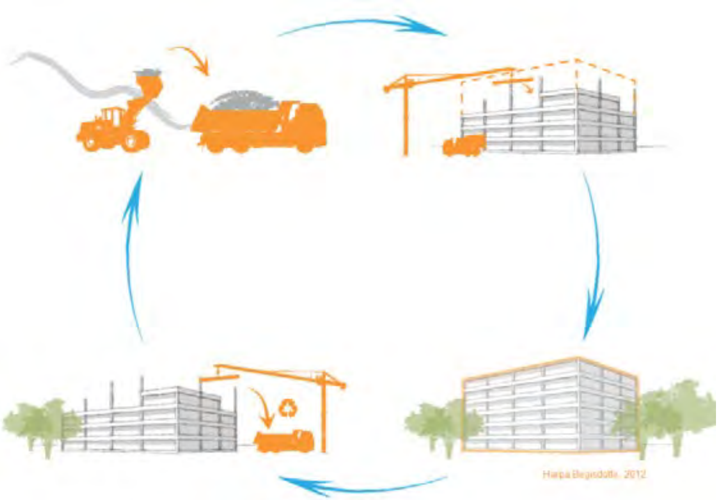
OBJECTIVES OF CASE STUDY

To calculate the life cycle based embodied green house gases (EG) and embodied energy (EE = non-renewable + renewable primary energy use) profiles of 7 new office buildings certified in the Danish DGNB certification scheme for sustainable buildings.

The Danish DGNB system is administered by the Danish Green Building Council (Dk-GBC). All LCA screenings are performed by trained auditors working on the individual projects.

BUILDINGS KEY FACTS

Size: 963-45,890 m^2 GFA
Location: Denmark
Architects: Various
Building year: 2009-2014



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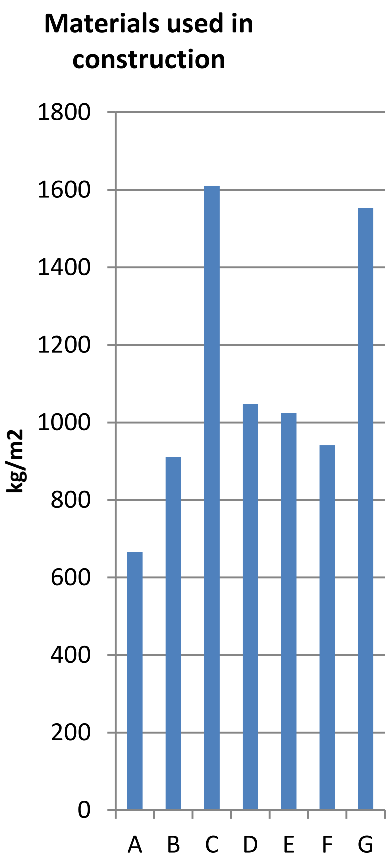
The 7 DGNB certified office buildings

The buildings were pilot projects in the adaptation process of the DGNB certification system to meet Danish conditions. The pilot phase was conducted in 2012. Year of building completion spans from 2009-2014, thus some of the 7 buildings are projected to comply with the Danish Building Regulation version 2008 and some to comply with version 2010.

Shape and size of the building vary, but all are constructed with concrete/steel frames and concrete slabs. Appearance of buildings is diverse with a range of heavy and light facades designed with composites, fiber cement, double glass, bricks or natural stone.




Green Lighthouse [©VELUX, Photo: Adam Mørk]


Buddingevej 272 [©MOE]


Rambøll [©Jens Lindhe]


GAPS [©Karlsson architects/ VLA Photo : Jens Lindhe]

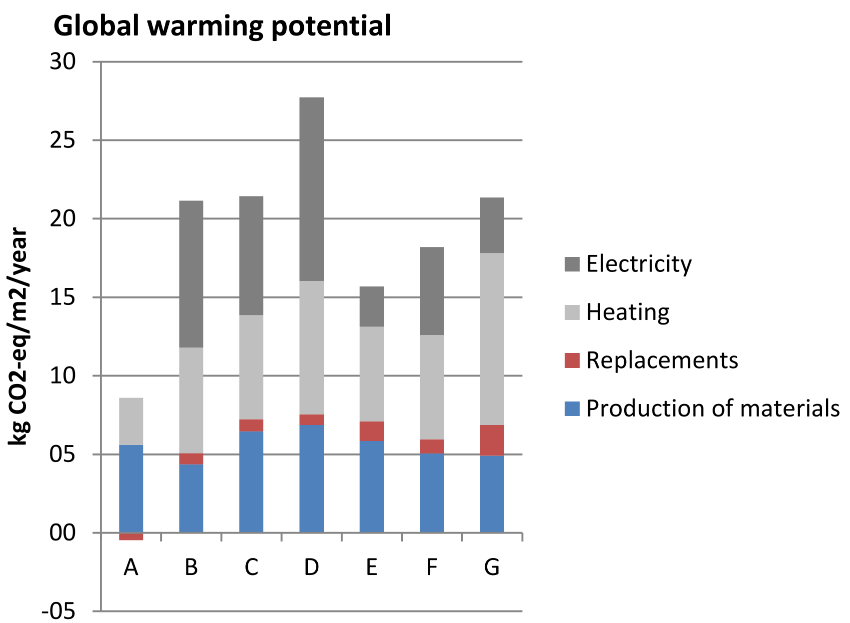

Skejby Company House [©NCC]

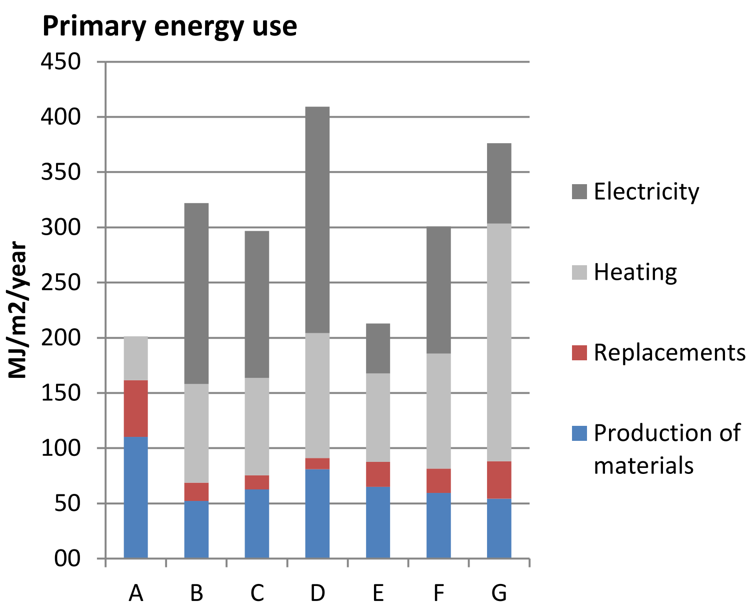

KPMG [©3XN Architects]


Pakhuset [©Lundgaard & Tranberg Architects, Photo: Jens Lindhe]

POTENTIAL IMPACTS AND RESOURCE USES

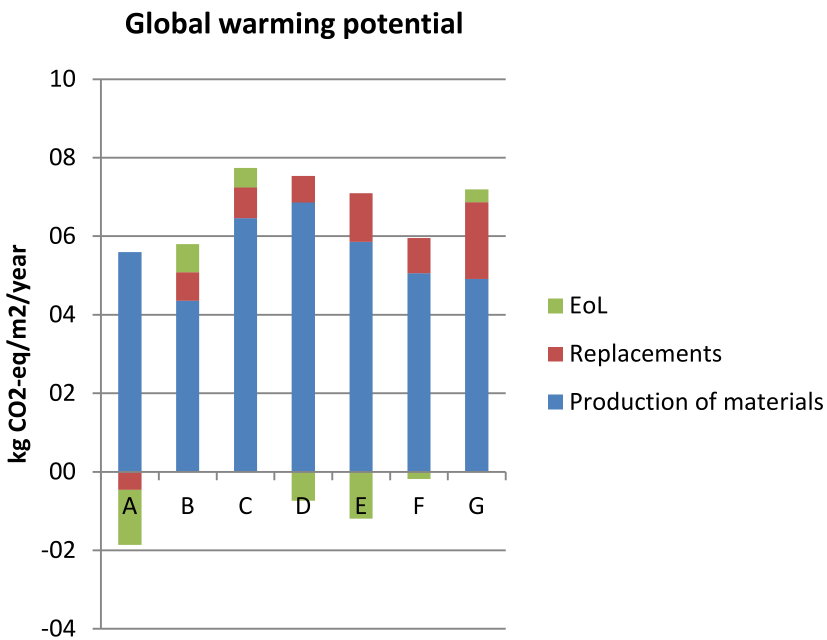
Global warming potential	A	B	C	D	E	F	G
Embodied green house gases (EG) [kg CO2-eq/m2/year]	5.1	5.1	7.2	7.5	7.1	6.0	6.9
Operational carbon [kg CO2-eq/m2/year]	3.0	16.1	14.2	20.2	8.6	12.2	14.5

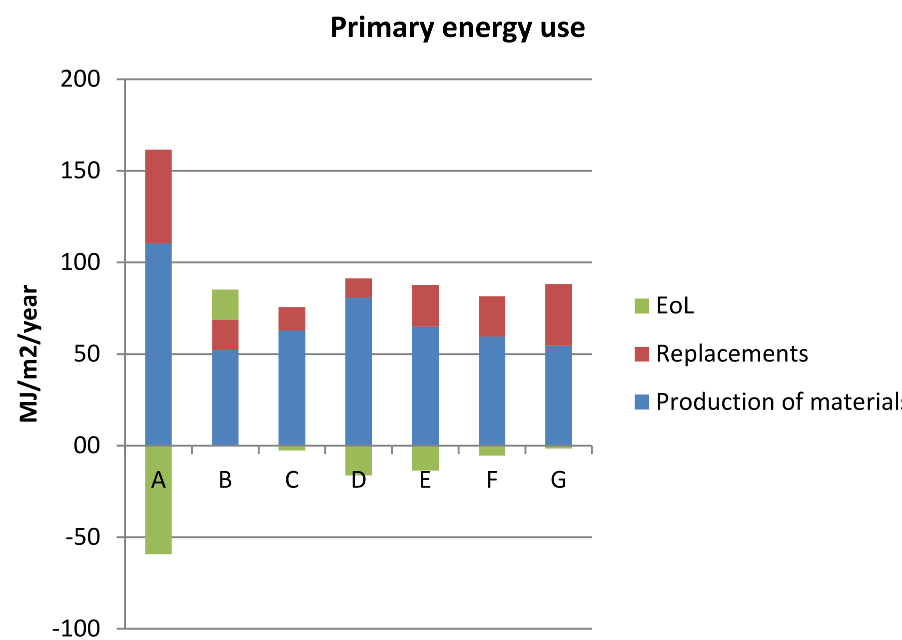




Primary energy use	A	B	C	D	E	F	G
Embodied energy (EE) [MJ/m2/year]	161	69	76	91	88	82	88
Operational energy [MJ/m2/year]	39.8	253.4	221.0	318.1	125.4	219.4	288.1

RISK OF NOTABLE EoL ERRORS





ABOUT THE RESULTS

Even though many of the buildings, by and large, make use of the same materials for the constructions, analyses of the inventory of the LCA screenings show great inconsistency in the choice of EoL scenarios for the materials and hence EoL-specific impact results in all directions as shown in the figures above. Frequent errors with significant influence on a material's environmental profile are for instance a "recycling of stainless steel" –scenario for the material "reinforcement steel", or a "landfilling of construction materials"-scenario for wood materials. Scenario choices like these greatly affects the total results and corrupts the potential comparison of the buildings because calculations are performed on unequal terms. The pilot phase thus shows the Danish Green Building Council that better guidance, in terms of default EoL scenarios for Danish conditions, are to be provided for the building auditors.

Italy

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
2.3 Material type contribution
5.1 Length of reference study period

Case study IT1
Kenaf-fibre insulation board

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The paper presents a life cycle assessment of a kenaf-fibre insulation board.

The aim is to assess the board eco-profile and to compare, on the basis of a life-cycle approach, the energy and environmental benefits and drawbacks related to its employment into a typical residential dwelling. A comparison among various insulating materials has been carried out.

The results show that the use of natural fibres involves a significant reduction of the environmental impacts.

This study shows as the overall energy impact of the building could be more easily evaluated with a life cycle analysis approach.

Embodied Energy (EE) data and life cycle analysis should be included in energy certification schemes in order to effectively lead the building sector toward sustainability.

OBJECTIVES OF CASE STUDY

The main goal of the study is to define the energy and environmental profile of an insulation product based on a natural fibre composite material.

FUCTIONAL UNIT (FU)

The mass (kg) of insulating board which involves a thermal resistance R of 1 (m^2K/W)

PRODUCT KEY FACTORS

The assessed product is a fibre reinforced composite made by kenaf vegetable fibres which are incorporated in a polyester matrix.

Kenaf is cultivated in Italy and other Mediterranean countries and mainly used in the thermal insulation field and in the pulp production. Kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability.

Thermal conductivity should remain unvaried in the board lifetime. However, it could increase depending on moisture and chemical and physical deterioration of the material.

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SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

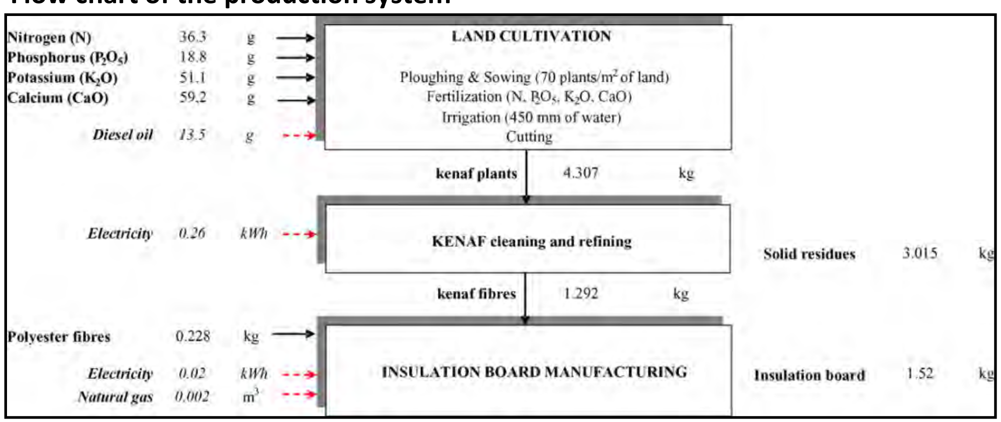
A 1-3 Product stage			A 4-5 Construction process stage		B 1-7 Use stage							C 1-4 End-of-Life				D Next product system
Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy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

LCA BACKGROUND

Databases used: Italian Agency for Environment Protection (ANPA), Italian Data Bank as Support of Life Cycle Assessment, Database LCA, Ver. 2.0, 2000 (in Italian language); The Boustead Model, Black Cottage, UK. Environmental Database, Ver. 4. 4, Boustead Consulting Ltd., West Sussex, 2001; GEMIS, Öko-Institut (Institut für angewandte Ökologie—Institute for Applied Ecology) Global Emission Model for Integrated Systems
(GEMIS), German Environmental Database. Version 4.3.

Standards/guidelines: International standard of the ISO 14040 series

Flow chart of the production system



Source: Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2008. Building energy performance: A LCA case study of kenaf-fibres insulation board. Energy and Buildings 40, 1-10.

Life cycle stages included:
In this study energy and mass flows and environmental impacts have been assessed from the production of raw materials to the manufacture of the end-product, following the ‘‘cradle to gate’’ approach.

Cultivation and crop of kenaf. Production of kenaf plants takes place mainly in Italy. Fibres are also partially bought from foreign Mediterranean countries (in particular from Marocco). Data regarding the consumptions of fertilisers and diesel have been detected during an Italian average cultivation cycle. Water consumptions are not detected during the cultivations.

Transports along all phases. It has been assumed that national transports occur by road lorry. Cargo ships are employed for international transports from Mediterranean countries.

Kenaf fibres refining and manufacturing of the insulation board. A typical production cycle from an Italian factory has been monitored.

Installation, maintenance and use. Concerning installation and maintenance, impacts are neglected. In fact, the insulation board is installed by hand, and does not require maintenance when it is incorporated in the wall. Regarding the use phase, the primary energy saving and the avoided CO_{2eq} emissions have been estimated during the operation time.

End of life. Concerning to the disposal phase, the option of incineration is assumed. The CO_2 emissions from the combustion of the kenaf fibres have been not taken into account.

Life cycle inventory results per functional unit

Energy consumption	Unit	Quantity
Energy use	MJ	28.38
Feedstock, fossil	MJ	8.82
Feedstock, renewable	MJ	22.17
Total energy consumption	MJ	59.37
Water consumption		
Water	kg	10.7
Air emissions		
Dust	g	429
CO	g	8.9
CO_2	g	2.908
SO_x	g	14.6
NO_x	g	17.2
N_2O	g	0.5
Methane	g	3.8
HF	g	0.004
HCl	g	0.13
Metals	g	0.052
Ammonia	g	0.33
VOC	g	1.26
Water emissions		
COD	mg	967
BOD	mg	216
Dissolved solids	mg	13
Suspended solids	mg	3.889
Hydrocarbons	mg	40
Phenol	mg	13
Na^+	mg	760
Na^{4+}	mg	3
Phosphate as (P_2O_5)	mg	1
Dissolved organics	mg	2.450
Nitrogenous matter	mg	1
Solid waste		
Mixed municipal solid waste	kg	1.73
Inert minerals/metal	kg	0.24
Slag/ash	kg	0.04
Residues/by-products		
Vegetable residues	kg	3.00

LIFE CYCLE IMPACT ASSESSMENT RESULTS

Impact analysis results per f.u.

Embodied Energy (EE)	Embodied Carbon (EG)
• 59,37 MJ_{prim}	• 3.17 $kgCO_{2eq}$

Greenhouse gas (GHG) emissions represent the main environmental release in the board life-cycle, accounting for about 3.17 kg CO_{2eq} per f.u. The highest share is caused by the manufacture of input materials and, in particular, of the polyester fibres, which account for about 39% of the total.

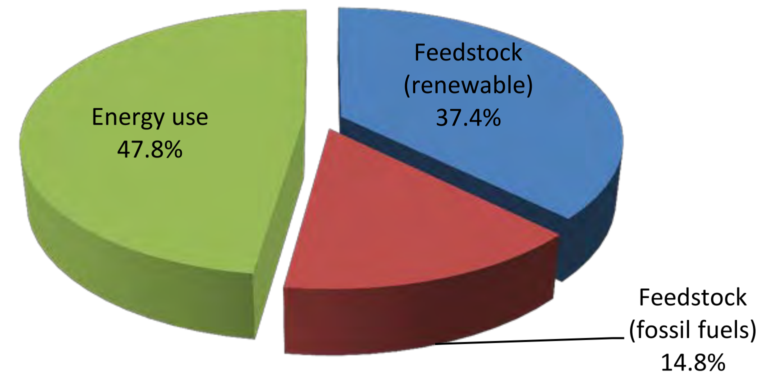
Transports account for 23%, while the final disposal accounts for 25% of the total GHG emission, because of the combustion of the polyester fibres.

Total generated wastes and residues are about 2.0 kg per f.u.

This quantity does not include the vegetable residues due to the fibres processing. These residues have been considered as byproducts of the process because they are not disposed but addressed to external companies for the production of RDF.

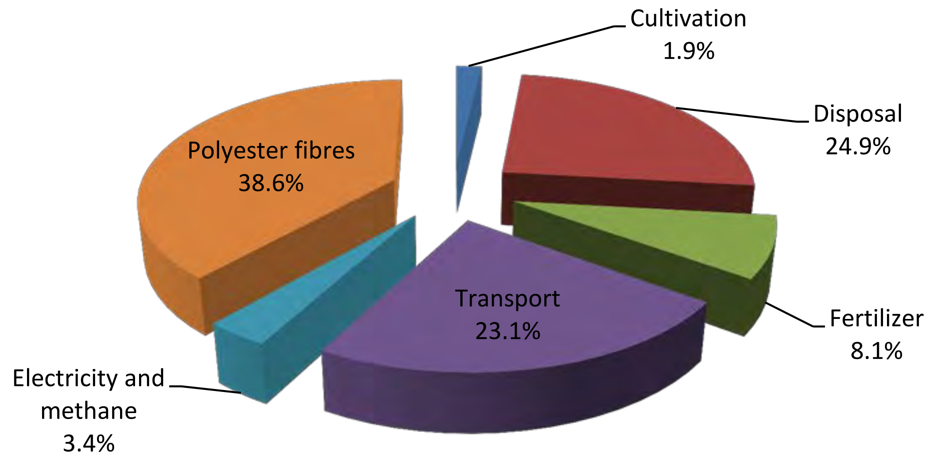
Other wastes are essentially non-hazardous materials mainly derived from the production of raw materials.

Sharing of energy consumption in the kenaf board production



Source: Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2008. Building energy performance: A LCA case study of kenaf-fibres insulation board. Energy and Buildings 40, 1-10.

Sharing of greenhouse gas emissions in the kenaf board life-cycle



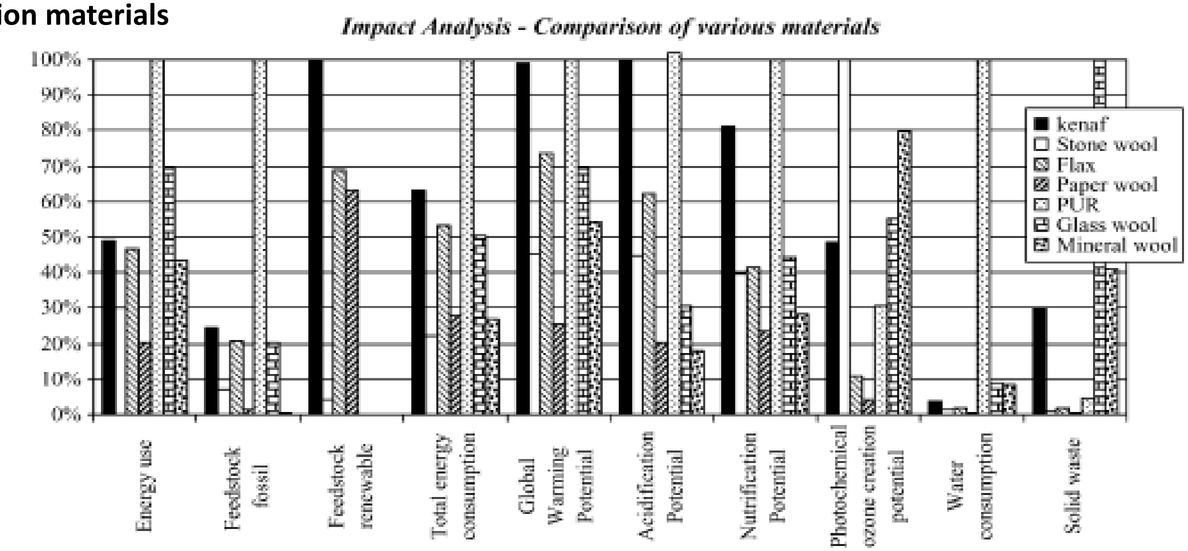
Source: Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2008. Building energy performance: A LCA case study of kenaf-fibres insulation board. Energy and Buildings 40, 1-10.

Impact analysis results per f.u.

Impact category	Unit	Value
Acidification potential (AP)	g SO_{2eq}	27.4
Nutrification potential (NP)	g $PO_4{}^{3-}{}_{eq}$	2.4
Phochemical ozone creation potential (POCP)	g C_2H_{4eq}	2.2
Ozone depletion potential (ODP)	kg CFC-11_{eq}	Negligible
Water consumption	Kg	10.7
Total wastes	kg	2.0

Energy and enviromental comparison of insulation materials

The life-cycle impacts of kenaf board have been compared to the performances of replaceable products. The comparison has included various typologies of mineral, synthetic and natural fibre composites.



Source: Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2008. Building energy performance: A LCA case study of kenaf-fibres insulation board. Energy and Buildings 40, 1-10.0

		Kenaf	Stone wool	Flax	Paper wool	PUR	Glass wool	Mineral wool
Energy consumption								
Energy use	MJ	28.4	17.4	26.9	11.8	57.6	39.9	25.0
Feedstock, fossil	MJ	8.8	2.5	7.5	0.4	36.0	7.4	0.2
Feddstock, renewable	MJ	22.2	0.9	15.3	14.0	0.0	0.0	0.0
Total	MJ	59.4	20.8	49.7	26.2	93.6	47.3	25.2
Enviromental impact indexes								
Global warming potential	kg CO_{2eq}	3.2	1.45	2.36	0.82	3.2	2.2	1.7
Acidificationb potential	g SO_{2eq}	27.4	12.3	17	5.5	27.9	8.4	4.9
Nutrification potential	g $PO_4^{3-}{}_{eq}$	2.4	1.16	1.22	0.7	2.94	1.30	0.8
Photochemical ozone creation potential	g C_2H_{4eq}	2.2	4.6	0.5	0.2	1.4	2.5	3.7
Water consumption	kg	10.7	3.9	5.7	0.8	297.7	27.0	25.6
Wastes								
Total wastes	kg	2.0	0.054	0.122	0.032	0.32	6.6	2.7

CONCLUSIONS

- The results show that the use of natural fibres involves a significant reduction of the environmental impacts derived from the employment of synthetic insulating materials, maintaining high thermo-physic and noise-abatement properties.

- The life-cycle impacts of kenaf board have been compared with the performances of various replaceable products, as polyurethane, glass wool, flax rolls, stone wool, mineral wool and paper wool. Such a comparison shows that the highest impacts are related to synthetic materials, while the better performances are due to mineral wools

REFERENCE

Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2008. Building energy performance: A LCA case study of kenaf-fibres insulation board. Energy and Buildings 40, 1-10.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
2.3 Material type contribution
5.1 Length of reference study period

Case study IT2
Energy retrofit of a single-family house

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Starting from the results of a "cradle to grave" life cycle study of an existing Mediterranean single-family house, in this study a set of retrofit actions voted to reduce the energy consumption during the operation is analysed. The proposed actions are addressed to improve the thermal performance of the building envelope and the energy efficiency of technical equipment. Performance assessment of these actions has been carried out not only considering the related effects on energy saving for building operation, but also taking into account other phases of the life cycles. Infact, these measures will cause an increase in the building embodied energy, which is the energy embedded in building materials, utilised in transportation and construction processes, in maintenance and demolition. Thus, a balance between the energy saving during operation and the avoided environmental benefits due to the other phases has been done. In particular, the embodied energy and the environmental impacts related to production, transportation and installation phases of the required material/components for retrofit implementation are assessed.

OBJECTIVES OF CASE STUDY

The main goal of the study are:

- To assess the energy and environmental impacts of the retrofit actions;
- To assess the net energy saving achievable by the proposed action and the related embodied energy;
- To evaluate the environmental benefits and drawbacks concerning the assessed retrofit actions to highlight whether the energy saving and the avoided environmental impacts offset the embodied energy of the retrofit actions and the related life cycle environmental impacts

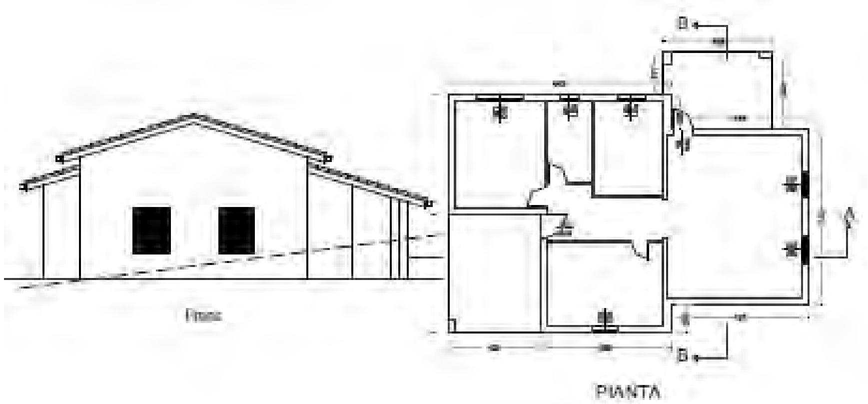
BUILDING KEY FACTS

Intended use: Residential building

Total floor area: 110 m^2

External wall area: 411 m^2

Gross volume: 402 m^3



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Source: Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M., 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits

Functional Unit

In the examinated case study each retrofit action proposed was selected as fuctional unit as follow:

- Thermal insulation of the building facade(224 m^2) by means of EPS board (Expanded Polystyrene) coating, 12 cm thickness. With this measure U value decreases tofrom 0.96 to 0.27W/(m^2 K);
- Thermal insulation of the roof (142 m^2) by means of rockwool boards, 8 cm thickness. With this measure U-value decreases from 0.60 to 0.25 W/(m^2 K);
- Dismantling and renovation of the ground floor (142 m^2), adding a layer of XPS (Extruded Polystyrene), 8 cm thickness. With this measure U-value decreases from 1.60 0.39 W/ (m^2 K);
- A 2.16 kWp PV grid connected plant to be installed on the building roof;
- A condensing boiler for replacing the existing boiler, with an average efficiency η=0.92.

Lifespan

A 50-year lifespan for the retrofit actions was assumed, except for the PV plant and the condensation boiler which were assumed to be replaced once during this time.

LCA Background

Reference study period: 50 years

Databases used: ECOINVENT, Life Cycle Inventories of Production Systems. Swiss Centre for Life Cycle Inventories; 2007

Standards/guidelines: International standard of the ISO 14040 series

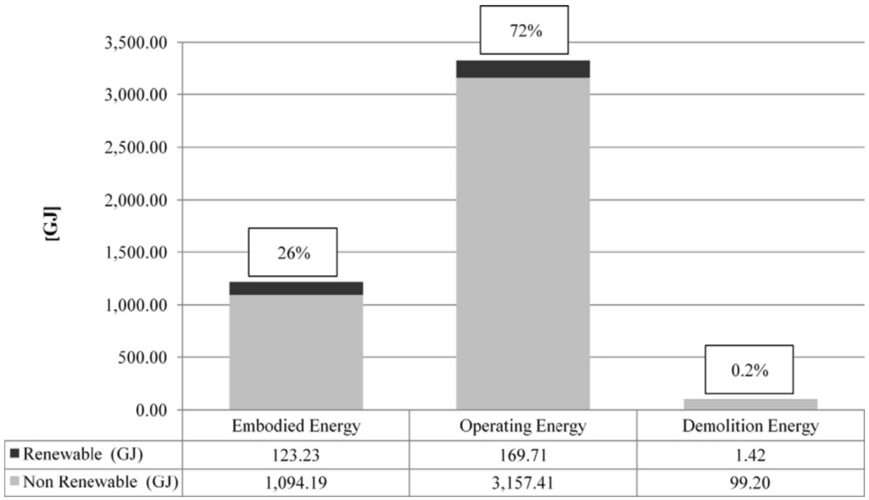
Building life cycle stages included in the study, according to EN15978

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				X		x		X		X	X	X	X	X

THE BUILDING

The assessed building is a Mediterranean sigle-family house. The structural frame is made of reinforced concrete with masonry block walls. The external walls construction include 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 as 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.

Functional unit: the building



Source: Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M., 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits.

Eco-profile of the reference building

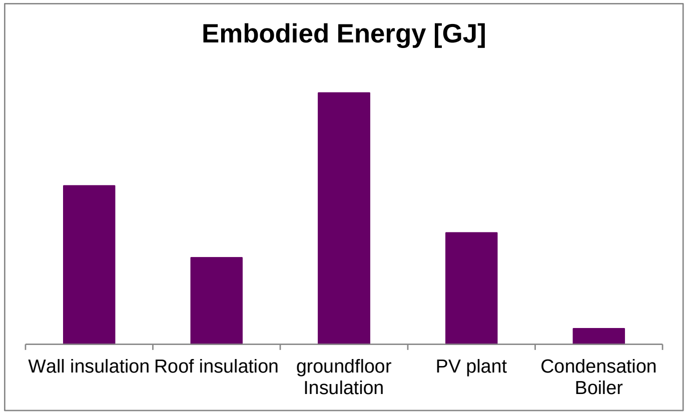
Embodied energy (EE)	Embodied carbon (EG)
• 4645 GJ	• 324,270 Kg CO_{2eq}

Indicator	Unit	Value
Ozone Depletion Potential (ODP)	Kg CFC-11_{eq}	0.05
Acidification potential (AP)	Kg SO_{2eq}	1193
Eutrophication Potential (EP)	Kg $PO_4{}^{3-}{}_{eq}$	270
Photochemical Ozone Creation Potential (POCP)	Kg C_2H_{4eq}	378

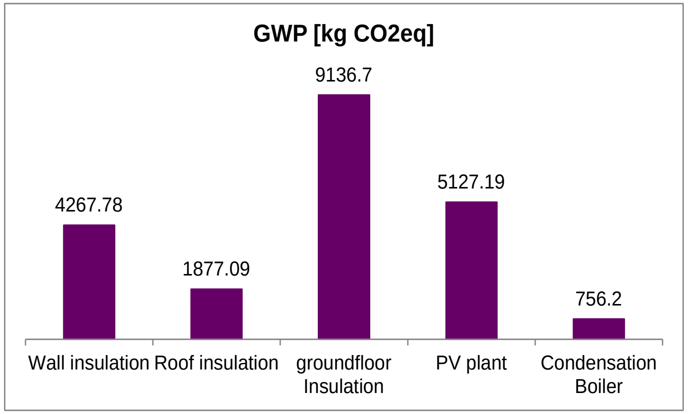
Contribution to the energy and enviromental impacts of each retrofit measure

Retrofit action	Embodied Energy (GJ)	Embodied Carbon (kg CO_{2eq})
Envelope		
Wall	69.77	4267.78
Roof	38.03	1877.09
Ground floor	110.67	9136.70
Plants		
PV plants	49.07	2563.59
Condensation boiler	6.84	378.10

If all the retrofit actions under assumption were implemented, the CED caused by them would amount to 274.3 GJ. The most significant contribution would be given by the envelope's thermal insulation, which affects CED for about 80%, while the share of the PV plant results about 18% (49 GJ). The production process of the high-efficiency boiler would affect the CED for about 2% (6.8 GJ). The renovation of the building ground floor would cause the highest contribution to the CED. This was essentially due to the thermal mass of the employed materials. In fact it would require the dismantling of the existing ground floor and the reconstruction of another one with improved thermal properties. The impact of ground floor renovation accounted for about 43% on GWP, while the retrofit actions on the roof and the walls accounted for 8.87% and 20.16%, respectively. The PV plant contributed for 24% to GWP.



Source: Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M., 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits.



Source: Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M., 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits.

Annualized net energy saving and enviromental benefit related to each action

Retrofit action	Annual primary energy saving for operation (GJ/y)	Avoided annual GWP (kg CO_{2eq}/y)
Envelope insulation		
Wall	1.91	143.40
Roof	0.16	26.00
Ground floor	2.00	109.57
Plants		
PV plants	26.66	1807.65
Condensation boiler	1.29	35.71
Total	32.02	2122.33

Retrofit action	Avoided annual ODP (kg CFC-11_{eq})	Avoided annual AP (kg SO_{2eq})	Avoided annual EP (kg $PO_4^{3-}{}_{eq}$)	Avoided annual POCP (kg C_2H_{4eq})
Envelope				
Wall	-4.5E-06	0.11	0.02	0.46
Roof	-9.8E-06	-0.11	-0.01	0.12
Ground floor	-1.0E-03	0.15	0.03	0.58
Plants				
PV plants	1.8E-04	7.44	1.66	0.71
Condensation boiler	-1E-06	0.08	-0.05	0.09
Total	-8.6E-04	7.51	1.65	1.96

The PV plant resulted to be the most effective measure to save primary energy and to avoid impacts, contributing for nearly 80% in the majority of the assessed categories. Furthemore, it resulted in the unique actions which involve a reduction in ODP. The roof insulation caused the lower contribution in the net energy saving, which resulted in 0.90 GJ/y. With regard the enviromental impacts they would be reduced by about 30-35%, depending on the indicators, except for ODP. The most significant contribution to such an impact was given by the renovation of the ground floor. It increased, essentially due to production of the XPS (Extruded Polystyrene) to be used in the ground floor retrofit

Primary energy consumption for building end uses

Before retrofit

End uses	Lifespan consumption (GJ)	Specific consumption (GJ)
Heating	533.5	0.10
Cooling	148.9	0.03
DHW	436.0	0.08
Cooking	133.4	0.02
Electric appliances	1,978.0	0.36
Other uses	98.0	0.02
Total	**3,327.8**	**0.61**

After retrofit

End uses	Lifespan consumption (GJ)	Specific consumption (GJ)	Retrofit saving (GJ)
Heating	85.4	0.02	448.1
Cooling	138.4	0.03	10.5
DHW	401.1	0.07	34.9
Cooking	133.4	0.02	0.0
Electric appliances	546.6	0.10	1431.4
Other uses	97.7	0.02	0.3
Total	**1,402.6**	**0.26**	**1,952.2**

The following main hot-spots can be highlighted from the study

1. The LCA of the existing building confirmed that generally the operation step involves the highest contribution to the life cycle primary energy consumption, accounting for 72% of the CED. The monitoring of the user behaviour during the operation step showed that the building annual operating energy mostly arises from the electricity consumption for lighting, electrical appliances and summer cooling, followed by the energy consumption for heating and DHW;
2. The outcomes of the LCA of the building retrofit showed that these actions would cause additional primary energy consumption and environmental impacts mostly due to the production phase, but looking at the building eco-profile as whole, the CED results decreased: the operating energy was reduced; an extra embodied energy was involved for the production of the retrofit actions. The end-of-life on the building life-cycle increases due to the demolition energy of about 2%;
3. If all the proposed retrofit measures were implemented, the building CED would decrease from 855 MJ/m^2 year to 555 MJ/ m^2 year, while GWP would decrease from 59 kgCO_{2eq}/m^2 year to 40 kgCO_{2eq}/m^2 year.

Retrofit action	**Embodied Energy (EE) (GJ)**	**Operation Energy (GJ)**	**Demolition Energy (GJ)**	**CED (GJ)**
Before retrofit	1217.4	3327.0	110.6	4645
After retrofit	1547.5	1403.0	103.5	3054
Shell retrofit				
Wall	69.8	-165.0	0.3	-95.0
Roof	38.0	-45.5	1.1	-6.4
Ground floor	110.7	-210.9	1.3	-98.9
Plants retrofit				
PV plants	98.1	-1431.0	0.1	-1333.0
Condensation boiler	13.6	-71.6	0.1	-57.9
Total	330.10	-1924.0	2.9	-1591

Contribution to the building from each retrofit action (GJ)

REFERENCE

Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M., 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits

Case study IT3

Operation and embodied energy of a case study

KEY OBSERVATIONS

This study introduces the life-cycle perspective in the energy balance of Net Zero Energy Buildings (Net ZEB), including in the annual energy demand of Net ZEBs not only the operation energy but also the sum of all energies incurred in the other life cycle phases. For this purpose, embodied energy of the building and its components, intended as both initial and recurring embodied energy, and demolition energy for the building end-of-life must be annualized and summed to the annual operating energy loads. The study starts from the results of one of the six case-studies of the SubTask B in the International Energy Agency joint Solar Heating and Cooling Task40 and Energy Conservation in Buildings and Community Systems Annex 52, whose purpose is to document state of the art and needs for current thermo-physical simulation tools in application to Net Zero Energy Buildings.

The case study is an Italian building, called Leaf House, tailored to be a Net ZEB. The annual final energy balance, assessed with regard to electricity, shows a deficit which makes the case study a nearly Net ZEB, when the encountered energy flows are measured at the final level. Shifting from final to primary energy balance the case-study moves to a non-Net ZEB condition, because of the large difference between the conversion factors of photovoltaics generated electricity and imported electricity. The adoption of a life cycle perspective and the addition of embodied energy to the balance causes an even largest shift from the nearly ZEB target: the primary energy demand is nearly doubled in comparison to the primary energy case.

OBJECTIVES OF CASE STUDY

The main goal of the study is:

- To assess the life-cycle energy balance of an Italian nearly Net ZEB, including in the annual energy demand of Net ZEBs the operation energy, and the sum of all energies incurred in the other life cycle phases.

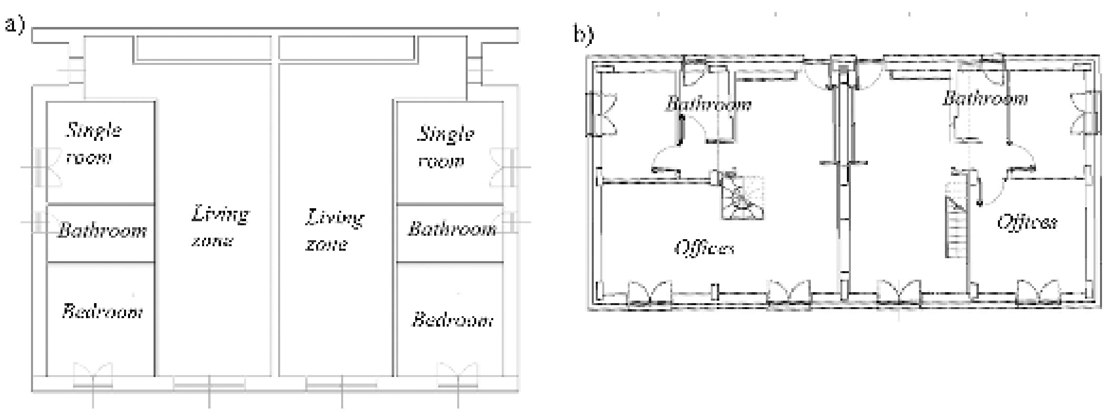
BUILDING KEY FACTS

Intended use: Residential building

Location: Angeli di Rosora, Ancona, Italy

Heated floor area: 481.76 m^2

Volume: 1475.33 m^3



a-b Ground, first (a) and second (b) floors of the Leaf House

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

Functional Unit: Leaf House

Lifespan: 70 years

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Building life cycle stages included in the study, according to EN15978

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	X	X		X			X	X		X	X			X

LCA Background

Reference study period: 70 years

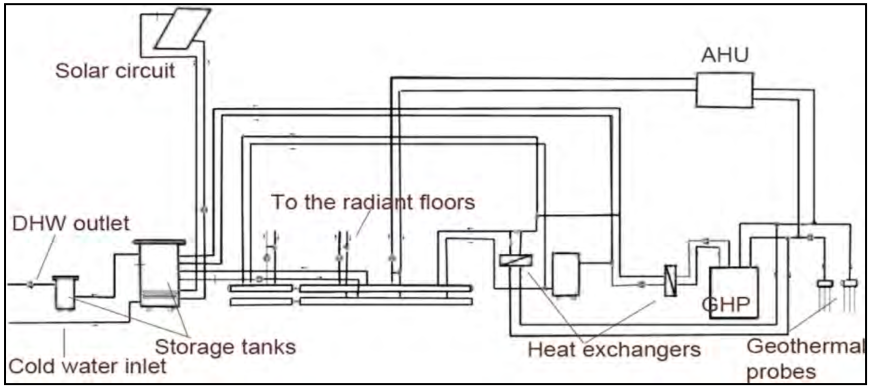
Quality data: Site-specific data were integrated with literature data. In particular, data related to the existing building derive from Loccioni Group and from some producers of building materials and plant components.

Standards/guidelines: International standard of the ISO 14040 series

THE BUILDING

The Leaf House was built according to the Italian requirements of the energy regulation in force, integrating different sources of renewable energy. A proper monitoring system records the energy and environmental data of all rooms of the six apartments. The thermal energy system in the LH is equipped with the following main components:

- A solar collector system;
- Three geothermal probes;
- The heat pump;
- An air handling unit (AHU);
- An auxiliary boiler;
- A photovoltaic system.



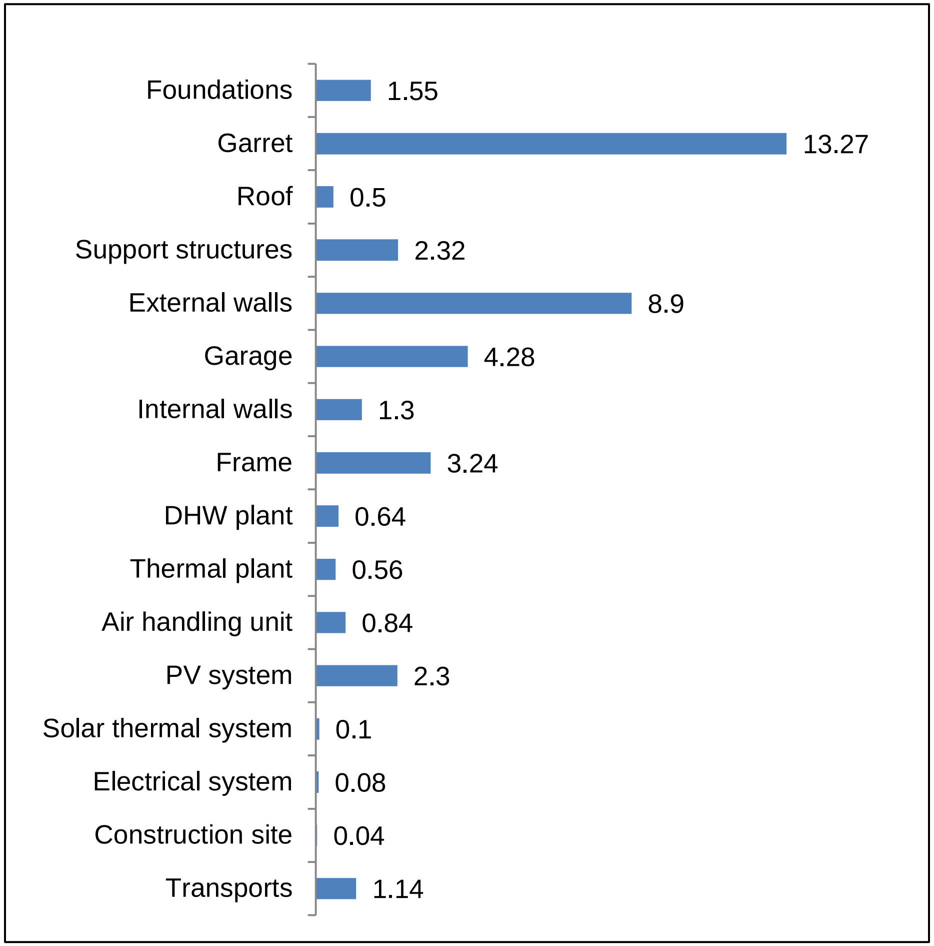
Simplified scheme of the Leaf House thermal plant

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

External structures	U value	Windows	U value
Walls	0.15	Overall	1.4
Floor	0.30	Glass only	1.15
Roof	0.25		

Thermal properties and the material composition of the building envelope [W/(m² K)]

Initial embodied energy of the building distinguished for envelope elements and plant components

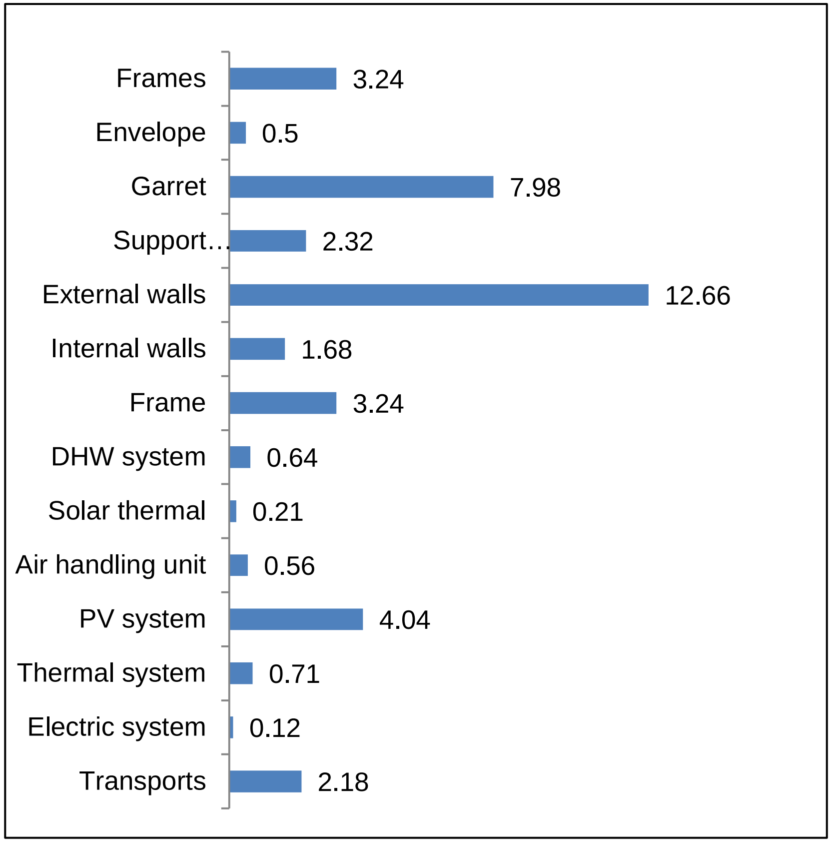


Embodied energy in the building elements for the production phase [MWh/y]

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

The initial embodied energy is estimated as the energy content, valued as primary energy, of the building related materials and components, and technical installations, including all the steps from the raw material acquisition to manufacturing processes

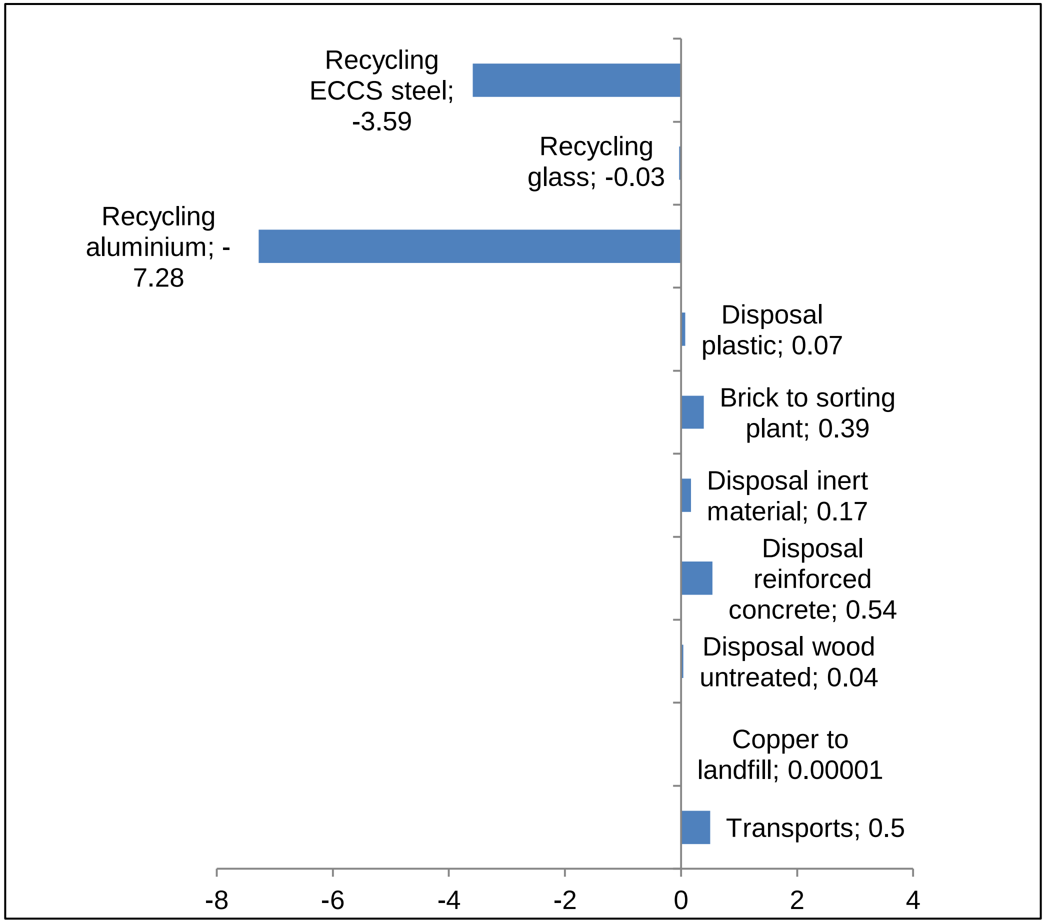
Recurring embodied energy for the envelope elements and plant components



Recurring embodied energy in the building elements [MWh/y]

The recurring embodied energy represents the primary energy consumption related to the maintenance and/or refurbishment of some building components and technical installations.

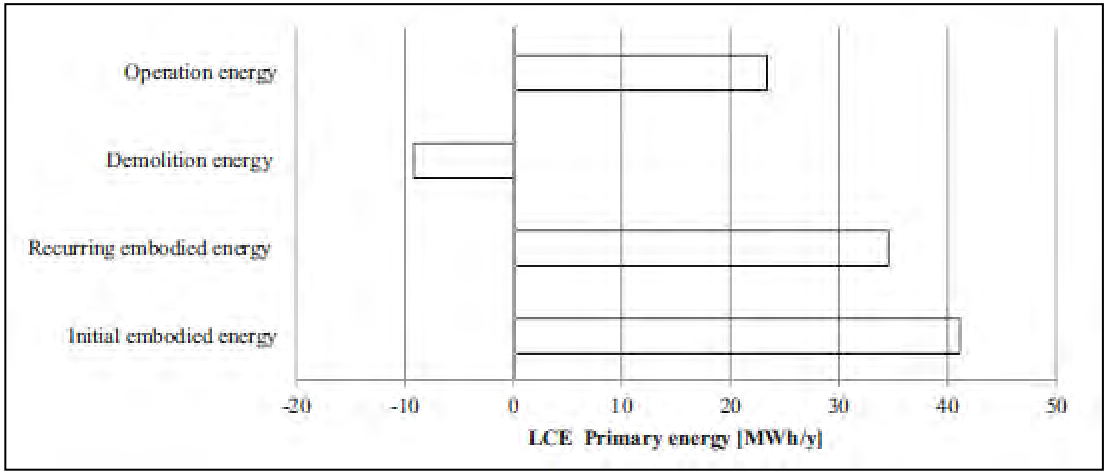
Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.



Demolition energy for building elements [MWh/y]

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

Initial embodied energy (MWh/y)	41.1
Recurring embodied energy (MWh/y)	34.5
Annualized demolition energy (MWh/y)	-9.2

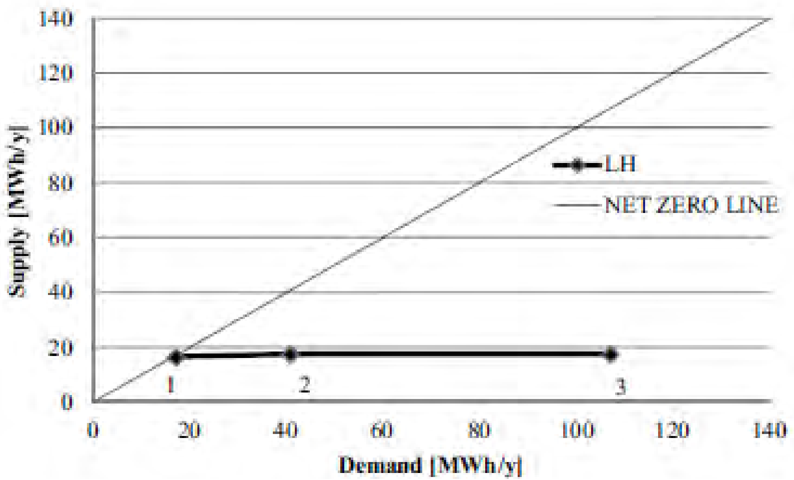


Relative role among embodied energy (initial and recurring), demolition energy and operating energy, valued as primary energy, in the lifespan.

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

Different conditions that have been described for the different annual balances that were assessed:

1. Final energy as metric.
2. 2. Primary energy as metric.
3. 3. LCE driven energy balance



Final energy (1), primary energy (2), and LCE Net ZEB balances

Source: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

When the operating energy balance is assessed in primary energy, the annual energy deficit rises from 0.91 MWh/y to 31 MWh/y. Such a shift is obviously very case-sensitive, as it is very depending on the configuration and nature of the on-site generation system, on the consumers' behaviour, on the mis-match level of the case-study and on the average efficiencies of the local electrical generation system (grid electricity).

CONCLUSION

The calculation of primary energy in Net ZEBs balance allows differentiation between electricity and fossil fuel use and includes an indication of the efficiency of delivering heating, domestic hot water, and lighting. As a result, when suitable conversion factors between final and primary energy are taken into account, depending on the energy carriers used and on the Italian energy generation system, the case-study moves far from the nearly Net ZEB condition. Thus, when adopting a primary energy metric it can’t be considered a nearly Net ZEB, rather it is representative of the low-energy building category, according to the reviewed literature. Since the primary energy conversion factor for PV generated electricity is lower than the grid one, the Leaf House could reach the target of nearly primary Net ZEB only maximizing the self-consumption of the on-site generation and avoiding to import energy from the grid. With regard to the primary energy consumption due to the natural gas for auxiliary boiler, it implies a further increase in the supply deficit.

Furthermore, in the common definitions of Net ZEB the life-cycle perspective is not included in energy balances, thus neglecting the incidence of the increased embodied energy (EE) on the energy saving in Net ZEB operation.
As presented in the above sections, the introduction of the energy life-cycle approach allows to compare the EE plus the primary energy used in building operation together with the energy generation produced by on-site renewable systems, thereby shifting the energy balance from the neutral condition. Such an approach allows to assess the magnitude of the deficit from the net zero target according to a lifecycle approach, and to point out the relative importance of operating and embodied energy in Net ZEBs.

Obviously, the introduction of the life-cycle analysis increases the complexity of the energy balance calculation and introduces a further deficit in the energy balance from the neutral condition. However, it emphasizes the EE of the building as a key issues to not be neglected in the exhaustive evaluation of the energy demand of low energy buildings.

REFERENCE: Cellura, M., Guarino, F., Longo, S., Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study.

Case study IT4
”Sicilian Tiles”

KEY OBSERVATIONS

The results of a Life Cycle Assessment (LCA) study can be affected by several uncertainty sources, mainly due to the methodological choices, the initial assumptions, i.e. allocation rules, system boundaries and impact assessment methods, and the quality of the available data. To estimate the uncertainty it is necessary to obtain reliable, transparent and representative LCA results and to correctly support decision-makers in the selection of different product or process options.

Starting from a LCA study of the so-called “Sicilian tiles”, typical roof tiles employed in restoring old buildings of the Mediterranean area, the most relevant sources of uncertainty in the LCA study are identified. Then a sensitivity analysis is performed to estimate the effects on the tile eco-profile of different secondary input data and of the chosen methods for the environmental impact assessment. The results show that, in some cases, significant differences in the energy and environmental indices can be obtained, pointing out the need of developing sensitivity analysis for strengthening the reliability of the obtained eco-profiles.

OBJECTIVES OF CASE STUDY

- To perform a Life Cycle Assessment (LCA) of the so-called “Sicilian tiles”, which are typical roof tiles used in the past and recently employed in restoring old buildings in the Mediterranean area
- To highlight the most significant energy and environmental issues of the examined product.

Stated the main uncertainty sources, a sensitivity analysis is performed to assess the influence of the initial choices and assumptions on the tile eco-profile. In particular the authors assess the effects of: (1) the secondary data; (2) the Environmental Impact Assessment (EIA) methods; and (3) the characterization factors for the Global Warming Potential (GWP) calculation.

FUNCTIONAL UNIT (FU)

The production of 1000 kg of tiles

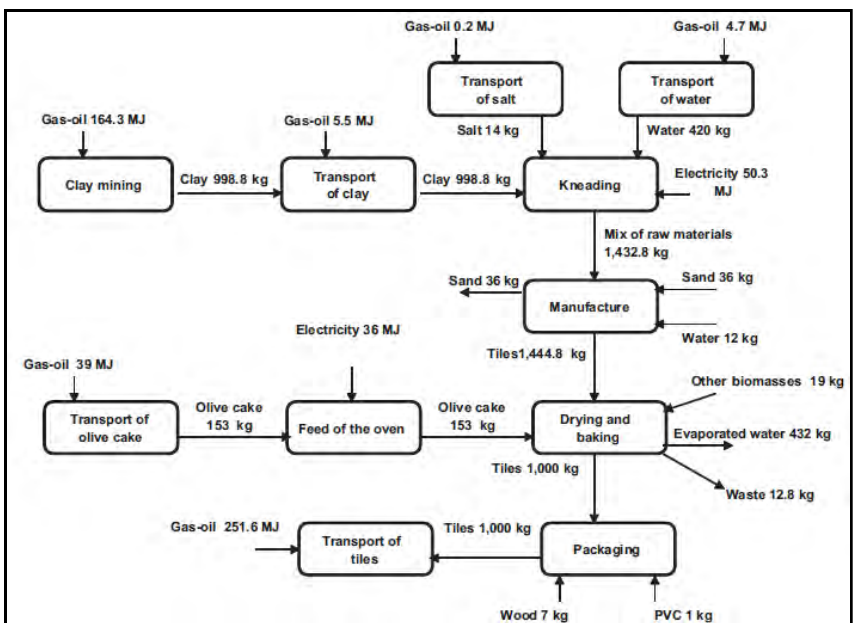
PRODUCT DESCRIPTION

This study regards a clay tile used in the Mediterranean building context

Building life cycle stages included in the study

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 materials and fuels supply	Transport ation to site of production	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	X													

Flow chart of the production of 1 FU



LCA BACKGROUND

Quality Data:
The following primary data have been collected from an infield enquiry (reference year 2005):
- the consumption of raw materials (clay, water, salt and sand);
- the consumption of electricity and fuels (biomass and gas-oil) in the clay mining and in the tile production;
- the amounts of PVC and wood used in the packaging phase;
- the fuel consumption in the transportation of raw materials and
fuels to the firm, and in the final product delivery.
Secondary data are derived by literature, such as the eco-profiles of electricity, gas-oil, biomass, raw materials and use of trucks

Database used: PRè – Product Ecology Consultants. SimaPro7. Environmental database; 2010.

Standards/guidelines: International standard of the ISO 14040 series

Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

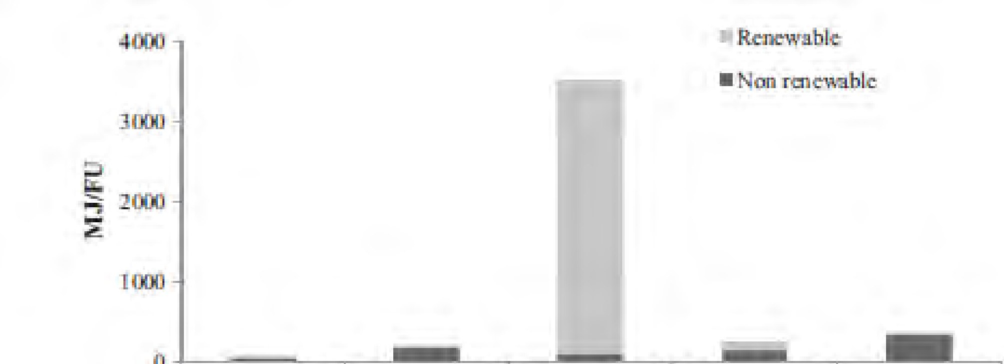
Life cycle inventory results per FU

	Clay mining	Manufacture	Drying and baking	Packaging	Transports
Resourse use					
Clay (kg)	998.8	0.27	4,00E-03	0.03	-
Gravel (kg)	0.04	38.5	0.12	0.5	-
Sodium chloride (kg)	7.2E-04	14.2	3,00E-03	0.73	-
Water (kg)	11.7	1208	394	142	-
Oil, crude (kg)	0.85	2	1.32	0.27	7.8
Coal (kg)	0.09	2.2	0.90	0.70	0.14
Air emissions					
CO_2	2.8	13.3	8.3	6.7	25.6
CO	0.01	8.00E-03	3.00E-03	6.00E-03	0.14
NO_x	0.03	0.03	31.5	0.02	0.5
SO_x	4.3E-03	0.08	0.4	0.02	0.04
Methane	2,00E-03	0.02	0.01	0.01	0.03
Water emissions					
BOD_5	1.2E-03	4.1E-03	9.8E-06	2.1E-03	3.5E-05
COD	1.2E-03	7.5E-03	1.2E-04	3.3E-03	1.1E-05
Solved substances (kg)	5.8E-05	1.00E-03	5.6E-04	3.1E-03	1.5E-03
Nitrate (kg)	1.2E-04	5.8E-03	6.2E-05	1.1E-03	2.5E-04
Sulphate (kg)	9.9E-03	0.2	9.2E-03	0.1	7.3E-03
Waste					
Mineral waste (kg)	-	-	12.9	0.06	-
Sand waste (kg)	-	32.5	-	-	-

The GER amounts to about 4367 MJ/FU, of which 19% is due to fossil sources and 81% to the renewable ones. The GER mainly arises from the baking phase (about 80.5% of GER) and it is essentially due to the biomass burning. Transportation, manufacture and packaging steps accounts for the 8%, 5% and 5.5% of the total GER, respectively. The lowest share comes from the clay mining, which is about the 1% of the total GER. With regard to GWP, that amounts to about 58 kg CO_{2eq}, transportation involves the highest contribution (about 46%). The manufacture step shares for about 24%, the baking step for about 15%, while the packaging and clay mining for 10% and 5%, respectively.

Embodied Energy (EE)	Embodied carbon (EG)
• 4367 MJ	• 58 Kg CO_{2eq}

Global energy requirement



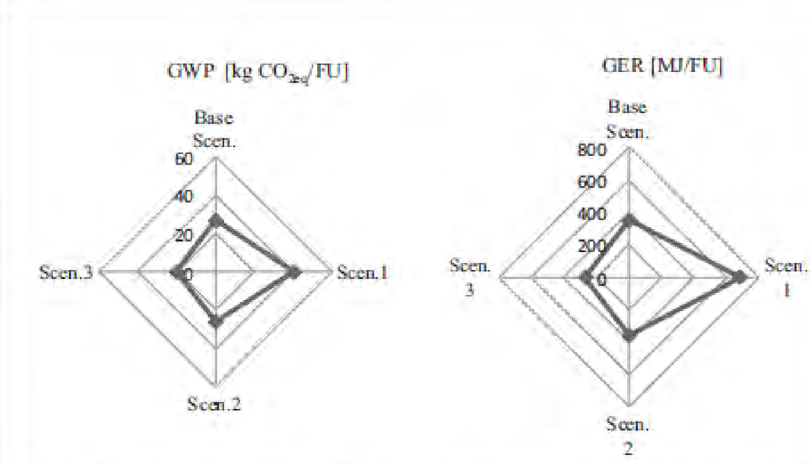
	Clay mining	Manufacture	Drying and baking	Packaging	Transports
Renewable	0,2	21,4	3418,9	110,6	0,4
Non renewable	43,9	188,1	102,6	131,5	349,6

Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

The authors carried out a sensitivity analysis in order to assess the effects on the FU eco-profile by different secondary data. In detail, the following life-cycle phases are considered:

- **Transportation**. The extent of the variation on the FU eco-profile is estimated by using different databases and varying the features of the vehicles as type, age and load;
- **Electricity**. Different eco-profiles of electricity production in Italy are compared.
- **Baking step**. Variation of the results is assessed by using different literature data on air emissions from the combustion of biomass.

Comparison of different transport scenarios (transport step)



Environmental Impact	Base Scenario	Scenario 1	Scenario 2	Scenario 3
GER [MJ]	350	683	364	268
GWP [kg CO_{2eq}]	26.8	40.5	26.0	20.1
ODP [kg CGC-11_{eq}]	2.0E-05	4.9E-05	9.0E-11	0
AP [kg SO_{2eq}]	0.27	0.28	0.15	0.14
EP [kg $PO4^{3-}{}_{eq}$]	0.06	0.05	0.03	0.02
POCP [kg C_2H_{4eq}]	0.17	0.18	0.03	0.02

Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

Transportation

Base Scenario: road transport by diesel-truck, average load 50%, includes production and combustion of fuels. Trucks with capacity of 16 tons are used for the transportation of clay, salt, water, sand and mineral wastes to landfill; olive cake and tiles are delivered by trucks with capacity of 28 tons and 40 tons, respectively;
Scenario 1: inventory analysis includes construction of the infrastructures (roads, bridges and tunnels), manufacturing of the truck, direct energy and working material consumption and emissions during operation. The trucks used for transportation are those assumed in the Base Scenario;
Scenario 2: diesel trucks of 14–20 tons are used to transport raw materials and mineral wastes, trucks of 20–28 tons to transport olive cake, and truck with semi-trailer to transport the tiles;
Scenario 3: trucks of 4 tons are used to transport sand, water and salt, trucks of 9 tons to transport clay and mineral wastes to landfill, articulated of 13–14 tons to transport olive cake and tiles.

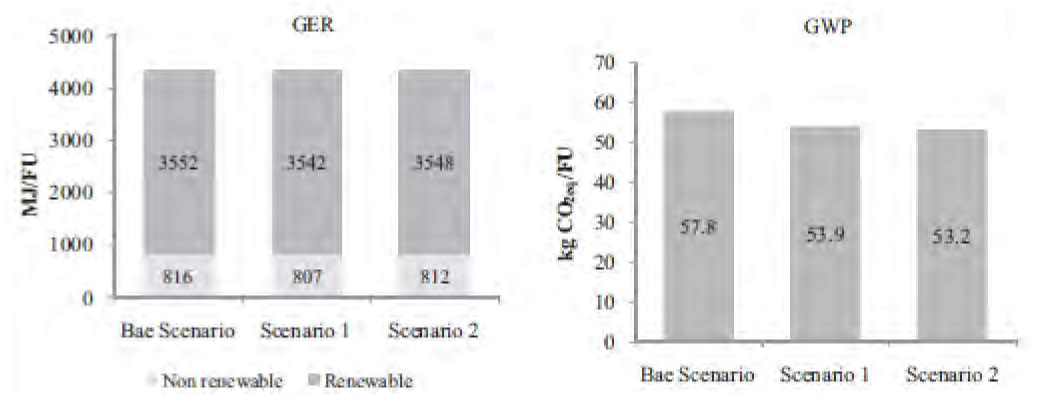
Electricity

Base Scenario: ETH-ESU 96 database: inventory table includes domestic low voltage electricity supply, imports, transport and transformation losses as well as material and construction requirements for transmission and distribution. Country mix is referred to a five years average (1990–1994). Contributions of renewable energies such as wind power, geothermal power and photovoltaic are considered in addition to the hydroelectric power;

Scenario 1: Ecoinvent database. It includes the electricity production in Italy and imports, the transmission network, direct SF_6-emissions to air and electricity losses during low-voltage transmission and transformation from medium-voltage. Average technology is used to distribute electricity. The time period is not specified;

Scenario 2: Boustead Model database [23]: the electricity ecoprofile is referred to the Italian energy mix (year 1996), no detail for the voltage is provided.

Comparison of different electricity eco-profile



Environmental Impact	Base Scenario	Scenario 1	Scenario 2
ODP [kg CFC-11$_{eq}$]	3.6E-05	2.1E-05	2.2E-05
AP [kg SO_{2eq}]	16.5	16.4	16.6
EP [kg $PO_4^{3-}$$_{eq}$]	4.17	4.19	4.18
POCP [kg C_2H_{4eq}]	0.22	0.19	0.23

Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

Baking step

The baking step takes place in a traditional furnace fed by "olive cake", a waste biomass of the Mediterranean olive oil production process

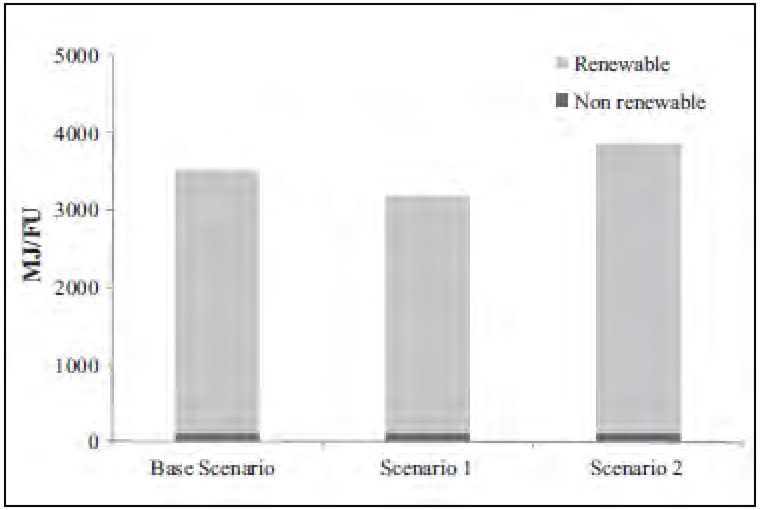
Base Scenario: heating value: 19.9 MJ/kgfuel, emissions from experiment 1
Scenario 1: heating value: 17.8 MJ/kgfuel, emissions from experiment 1
Scenario 2: heating value: 22.14 MJ/kgfuel, emissions from experiment 1
Scenario 3: heating value: 19.9 MJ/kgfuel, emissions from experiment 2

Pollutants caused by olive cake combustion

	H_2O (kg/kg)	CO_2 (kg/kg)	NO_x (kg/kg)	SO_2 (kg/kg)	Dust (kg/kg)
Experiment no. 1	0.3	0.004	0.2	0.002	0.25
Experiment no. 2	0.3	0.003	0.2	0.02	0.2

Scenario 3 does not affect GER, while Scenario 2 has not an influence on the environmental impacts of FU.
By varying the heating value of the olive cake from the lowest to the highest, the primary energy requirement in the baking step varies from 3,188 MJ/F.U. (Scenario 1) to 3855 MJ/F.U. (Scenario 2).
While the contribution by non-renewable sources (102.6 MJ/F.U.) is unvaried, the contribution of renewable energy has a variation of about 9.8% with respect to the Base Scenario.
Regarding the environmental impacts, EP, ODP and GWP does not vary significantly, while POCP has a huge variation mainly due to the significant differences in the amount of the SO_2 emissions changing from one scenario to another.

Global Energy Requirement (baking step)



Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

Enviromental impacts caused by olive cake combustion

Enviromental impact	Base scenario	Scenario 3	Variation
AP (kg SO_{2eq})	16.1	18.9	17%
EP (kg $PO_4^{3-}{}_{eq}$)	4.09	4.09	0%
GWP (kg CO_{2eq})	8.69	8.54	-1.7%
ODP (kg CFC-11$_{eq}$)	Negligible	Negligible	-
POCP (kg C_2H_4)	0.03	0.16	471.4%

Uncertainty due to impact assessment methods

The authors assessed the impact categories of AP, ODP and POCP using the following impact assessment methods:

- **EPD 2008** (Base Scenario used in the case study);
- **CML 2 baseline 2000** (Scenario 1);
- **Ecoindicator 95** (Scenario 2);
- **EDIP/UMIP 97** (Environmental Design of Industrial Products, in Danish UMIP) (Scenario 3);
- **IMPACT 2002+** (Scenario 4);

Environmental impact	Base scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AP (kg SO_{2eq})	16.52	16.63	22.93	22.93	22.93
ODP (kg CFC-11_{eq})	3.6E-05	4.1E-05	5.3E-05	4.1E-05	4.0E-05
POCP (kg C_2H_4)	0.222	0.031	0.08	0.084	0.117

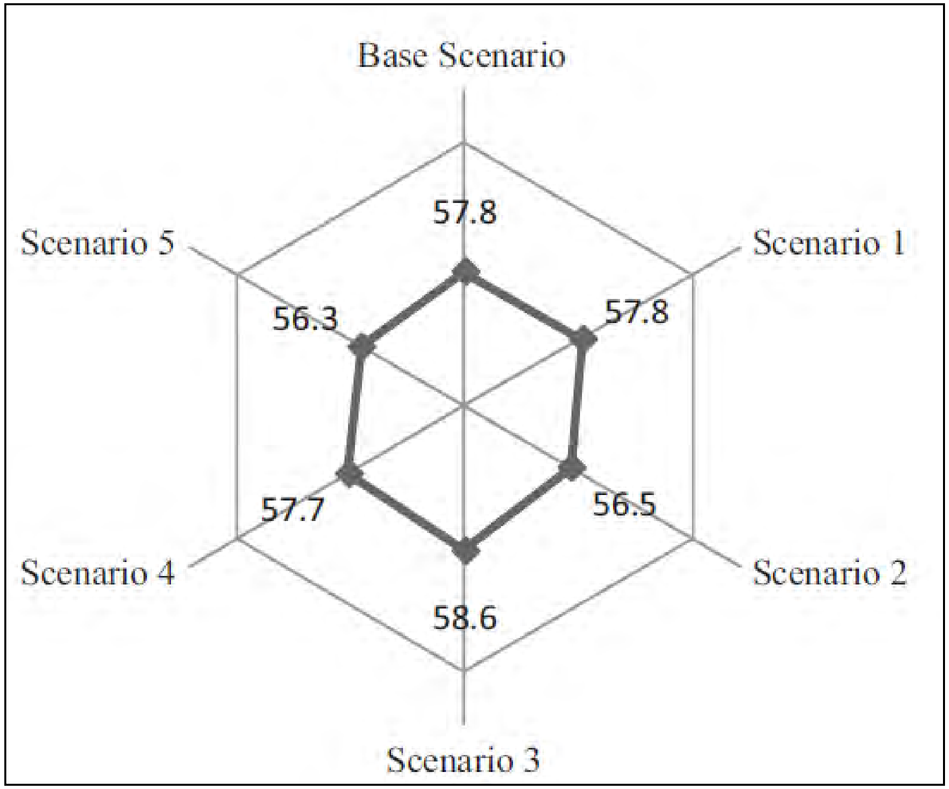
Uncertainty due to the CO_2 characterization factors for Global Warming potential

The authors carry out a scenario analysis to assess the effect on the FU eco-profile by changing the method used to calculate GWP. In particular, the following scenarios are compared with the Base Scenario:

- **Scenario 1:** CML 2 baseline 2000;
- **Scenario 2:** Ecoindicator 95;
- **Scenario 3:** EDIP/UMIP 97;
- **Scenario 4:** IPCC 2007;
- **Scenario 5:** Impact 2002+.

The differences among the compared scenarios result lower than 2.5%. The variation range of GWP goes from 56.3 kg CO_{2eq} (Scenario 5) to 58.6 kg CO_{2eq} (Scenario 3).

Global Warming Potential (kg CO_{2eq})



Source: Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

The performed sensitivity analysis shows that in some cases there is a strong dependence of the FU eco-profile from different choices and assumptions related to secondary data and environmental impact assessment methods.

- GER can vary from 4040 MJ to 4700 MJ, with a variation range of about ± 7.6% from the referring value of 4367 MJ;
- GWP has a variation range from the referring value (57.8 kg CO_{2eq}) that goes from −11.6% to 24%. In particular, GWP value can vary from 51.1 kgCO_{2eq} to 71.5 kg CO_2;
- Regarding AP, a variation from 16.39 kg SO_{2eq} to 22.93 kg SO_{2eq} has been observed; the gap from the reference value (16.52 kg SO_{2eq}) goes from −0.8% to 39%;
- EP is characterized by a low variation (from 4.13 kg $PO_4^{3-}{}_{eq}$ to 4.19 kg $PO_4^{3-}{}_{eq}$) with respect to the Base Scenario (4.17 kg $PO_4^{3-}{}_{eq}$); the variation range is of about −1% to 0.5%;
- A considerable variation is attributable to POCP, that can vary from 0.031 kg C_2H_{4eq} to 0.352 kg C_2H_{4eq} with a variation range of about −86% to 59% from referring value of 0.222 kg C_2H_{4eq};
- A relevant variation (from −56% to 81%) is also concerning the range of ODP. The absolute ODP value can vary from 1.6E−05 kg CFC-11_{eq} to 6.5E-05 kg CFC-11_{eq} whit respect to the reference value of 3.6E-05 kg CFC-11_{eq}.

With regard to the contribution of the above scenario analyses, the obtained results are summarized in the following.
Sensitivity analysis of transportation secondary data has shown a variation for all the environmental impacts with respect to the Base Scenario. In particular, GER vary from −23% to 95%, GWP from −3% to 52%, AP from −48% to 2.5%, EP from −67% to −23%, POCP from −88% to 6%. Relevant variations (from −100% to 150%) occur for ODP impact.
Comparing different electricity eco-profiles, the variations of GER, AP and EP with respect to the Base Scenario are negligible (<1%), the variations of GWP, ODP and POCP are respectively lower than 8%, 43% and 11%.
Using different secondary data of biomass emissions during the baking step, it can be observed that GER varies of about 10% with respect to the Base Scenario, EP and ODP are the same in each examined scenario, while the other impacts have a quite extended range of variation, which goes from 1.7% (GWP) to 433% (POCP).
In the sensitivity analysis of impact assessment methods the environmental impacts vary from 39% (AP) to 86% (POCP) if compared with those of the Base Scenario, while in the sensitivity analysis related to GWP, this indicator has a variation lower than 2.5%.

- The FU eco-profile can be influenced significantly by different choices related to secondary input data and environmental impact assessment methods;
- In order to reduce the uncertainty due to secondary input data, local databases containing site-specific data and related data quality indicators should be realized;
- Furthermore, to correctly support the LCA practitioners to reducing uncertainty due to other subjective choices and to perform LCA studies in accord to specific methodological choices and conventions, beginning from the results of experiences and projects already made, the scientific community needs to define harmonized and standardized rules related to the modelling of a product system, the allocation phase, the system boundaries, the impact assessment methods, the quality requirements for data used in the studies, and all other elements that can be source of uncertainty

REFERENCE

Cellura, M., Longo, S., & Mistretta, M., 2011. Sensitivity analysis to quantify uncertainty in life cycle assessment: The case study of an italian tile. Renewable and Sustainable Energy Reviews 15: 4697–4705

Japan

Key issues related to Annex 57:
1.1 Selection of building materials

Case study JP1
Zero LCCO2 Model - Japan

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Life Cycle Assessment was performed for Reference Study Period (RFS) of 90 years and Embodied Greenhouse gases (EG) was evaluated. The length of RFS is an important factor for the results.

REFERENCE STUDY PERIOD

	90	Years
EG	5.0	kg CO_2 equiv. /m^2_{GFA}/year

OBJECTIVES OF CASE STUDY

This house was built to demonstrate ultimate energy effective measures including operational and embodied energy. Various measures adopted in this house are arranged with EE/EG, life cycle energy/ embodied greenhouse gases, cost of the components and annual energy cost. Designers can now choose the measures or decide the specifications according to the effectiveness.

BUILDING KEY FACTS

A first commercialized $LCCO_2$ minus home for single family in Japan.

Intended use: Detached house for single family

Size: 221 m^2

Location: Tokyo, Japan

Architect: Misawa Homes Co., Ltd.

Building year: 2010

©Misawa Homes Co., Ltd.

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study

Product stage			Construction process stage		Use stage							End-of-Life				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	X	X		X		X		X						

LCA BACKGROUND

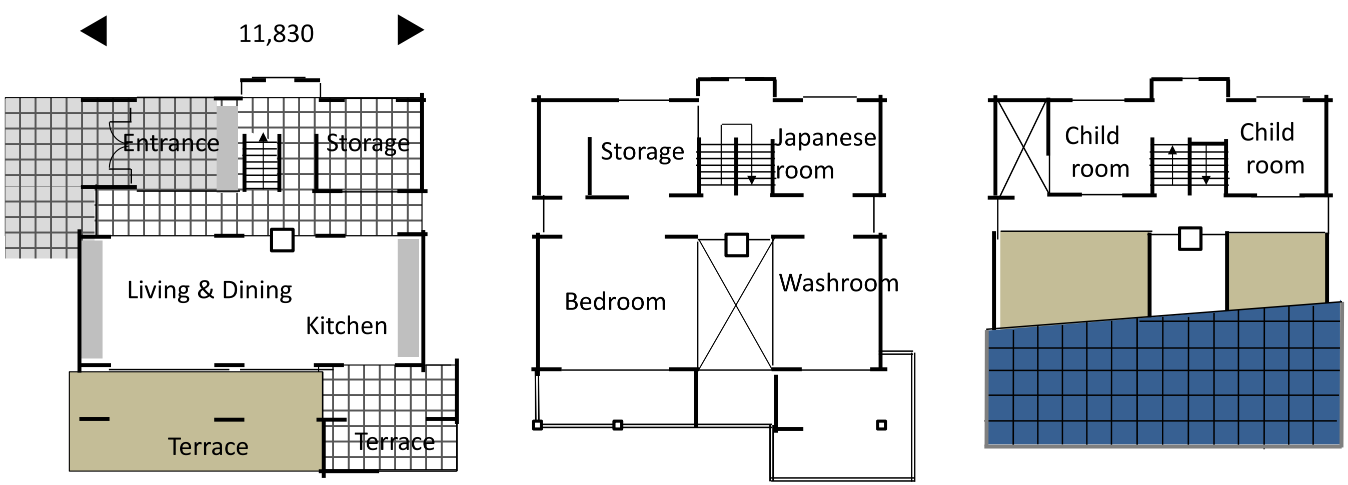
Reference study period: 90 years
LCA methodology: Architectural Institute of Japan
Databases used: Input-Output data of Japan
Energy supply: Electricity from Tokyo Electric Company

Type of building:
A first commercialized $LCCO_2$ minus home for single family in Japan.

	Insulation Specification for LCCO2 minus home (Specification for conventional home)
Ceiling	GW 24 kg/m^3 250 mm (RW 40 kg/m^3 200 mm)
Wall	GW24kg/m^3 150 mm (GW16kg/m^3 75 mm)
Basement (Floor)	PSF B-3 100 mm (GW16kg/m^3 75 mm (for floor))
Window	Plastic sash, Low-e double glazed window with Ar gas (Plastic sash, Low-e double glazed window)
Ventilation	HR central system (HR coefficient 70 %) (HR central system (HR coefficient 70 %))

GW: Fine fiber glass wool, PSF: Poly-Styrene foam, RW: Rock wool, HR: Heat recovery

	Home Appliance Specification for LCCO2 minus home (Specification for conventional home)
Heating and cooling	Air-to-water heat pump system with panel radiators (Room air conditioner using air-to-air heat pump unit)
Hot water	CO2 heat pump system (Gas boiler or electric heater)
Lighting	LED (fluorescent lamp)
Cooking	IH cooking heater (IH cooking heater)
Solar utilization	"Cascade Solar System" which provides electricity and heat (none)

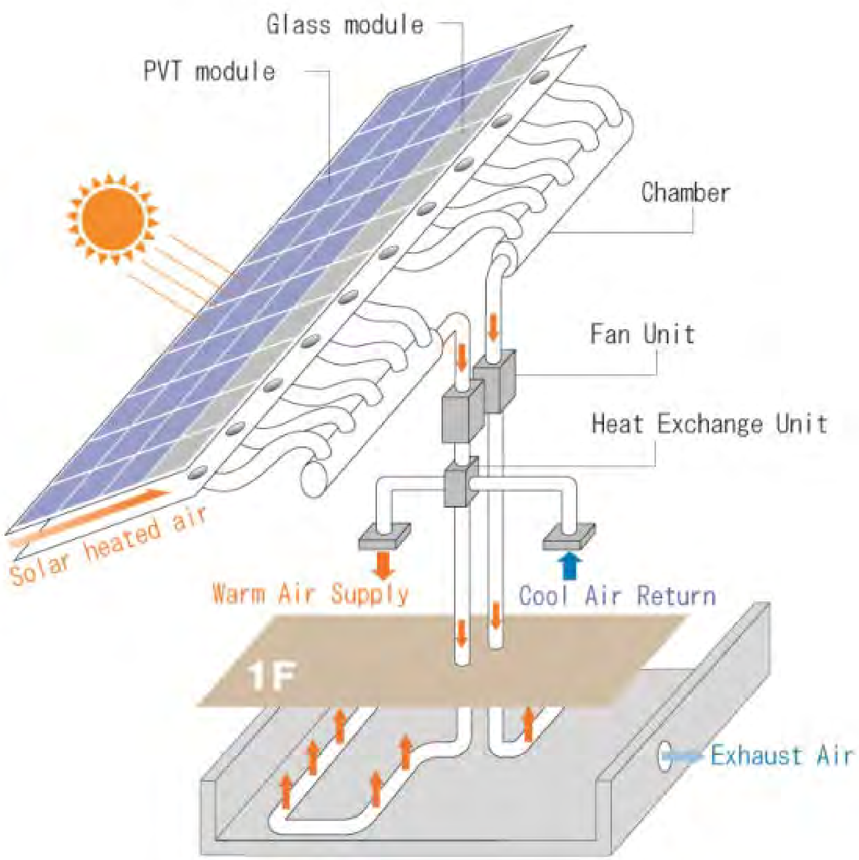


1st floor 2nd floor 3rd floor

Total floor area:221㎡

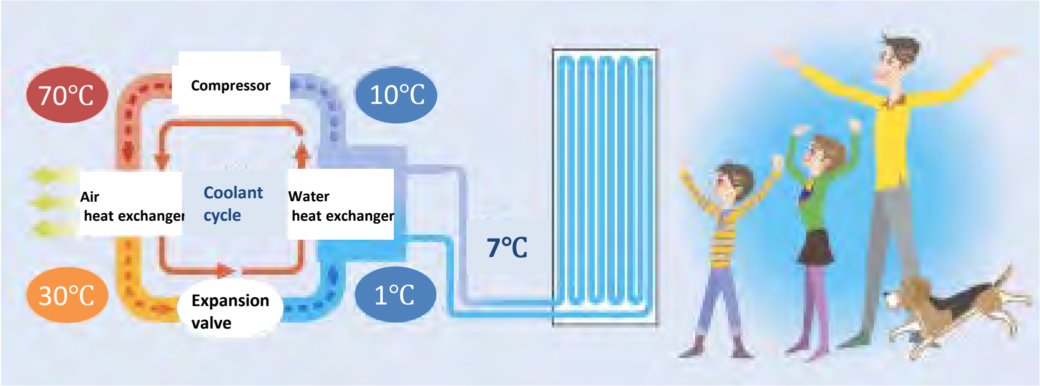
BUILDING DESCRIPTION, Cascade Solar

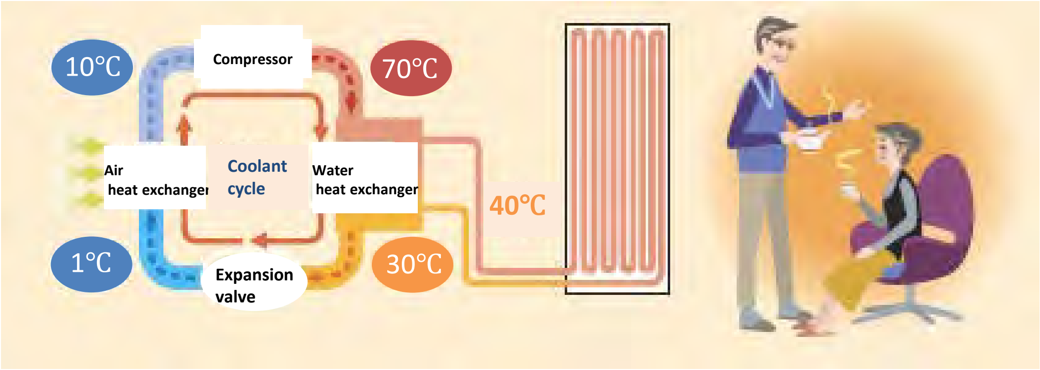
- 9.5kW mono-crystalline PV modules with heat collecting function
- Heat may be delivered by fan for room heating in winter



BUILDING DESCRIPTION, Radiation cooling and heating

- Radiation cooling and heating panel using air-to-water heat pump unit
- High performance aluminum panel enables mild indoor climate





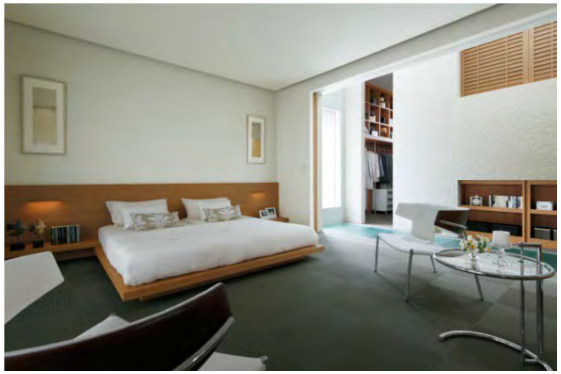
Louver-type Shutter

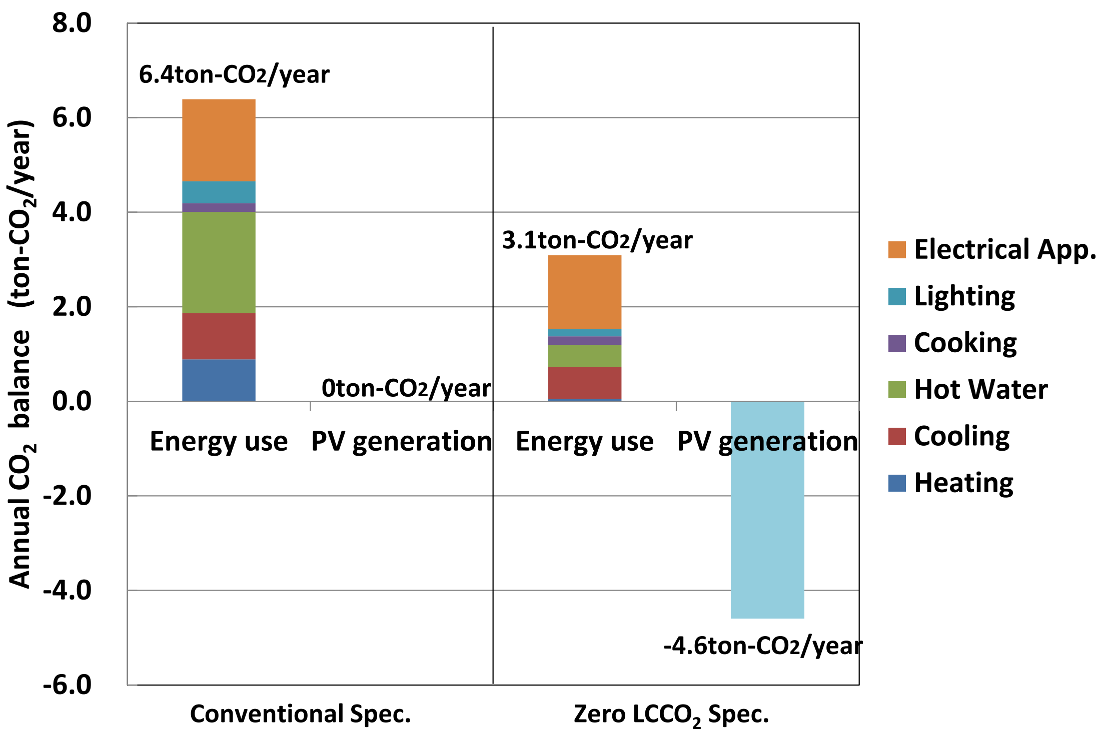
to shade excessive solar heat gain during summer

Open

Close

Half-open

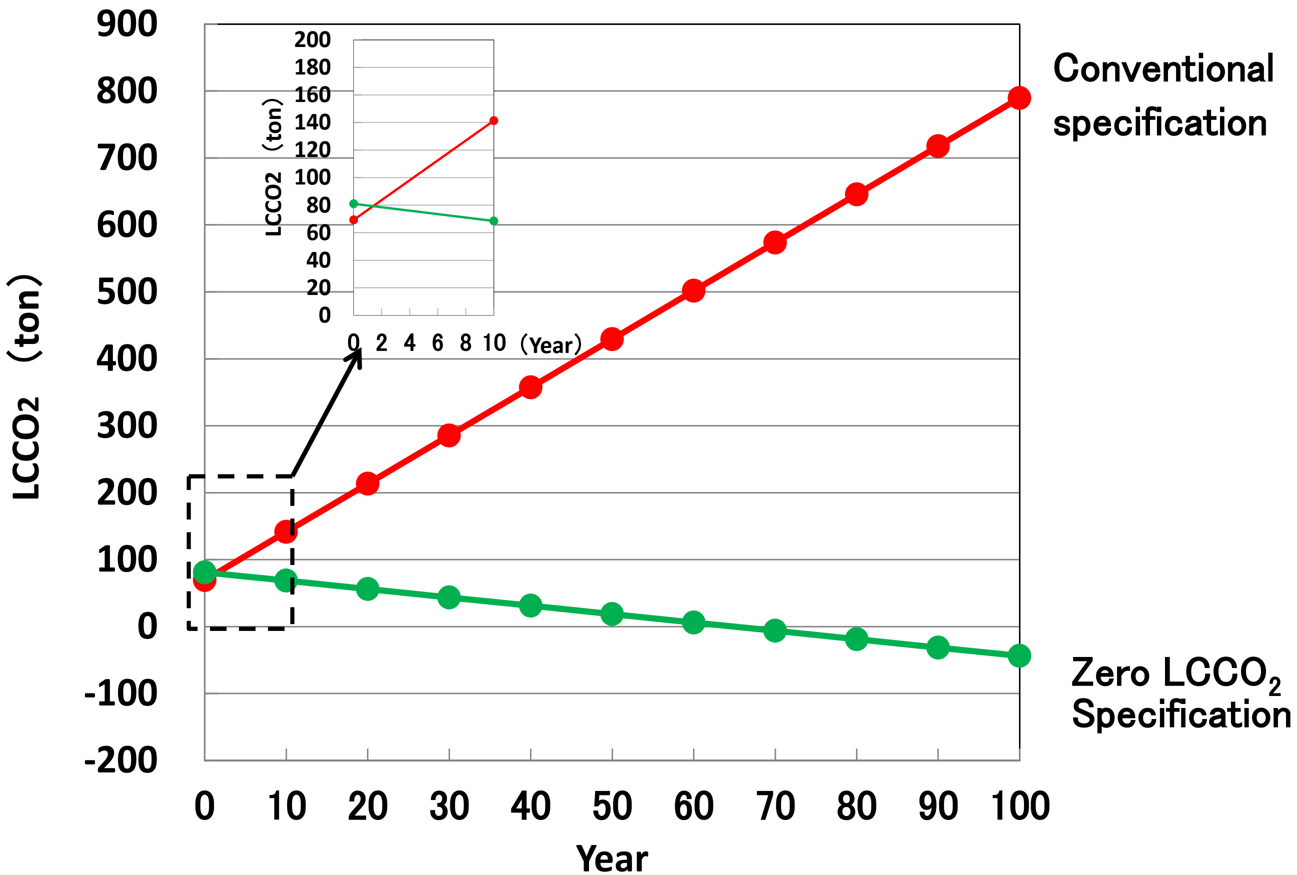




Annual CO2 balance

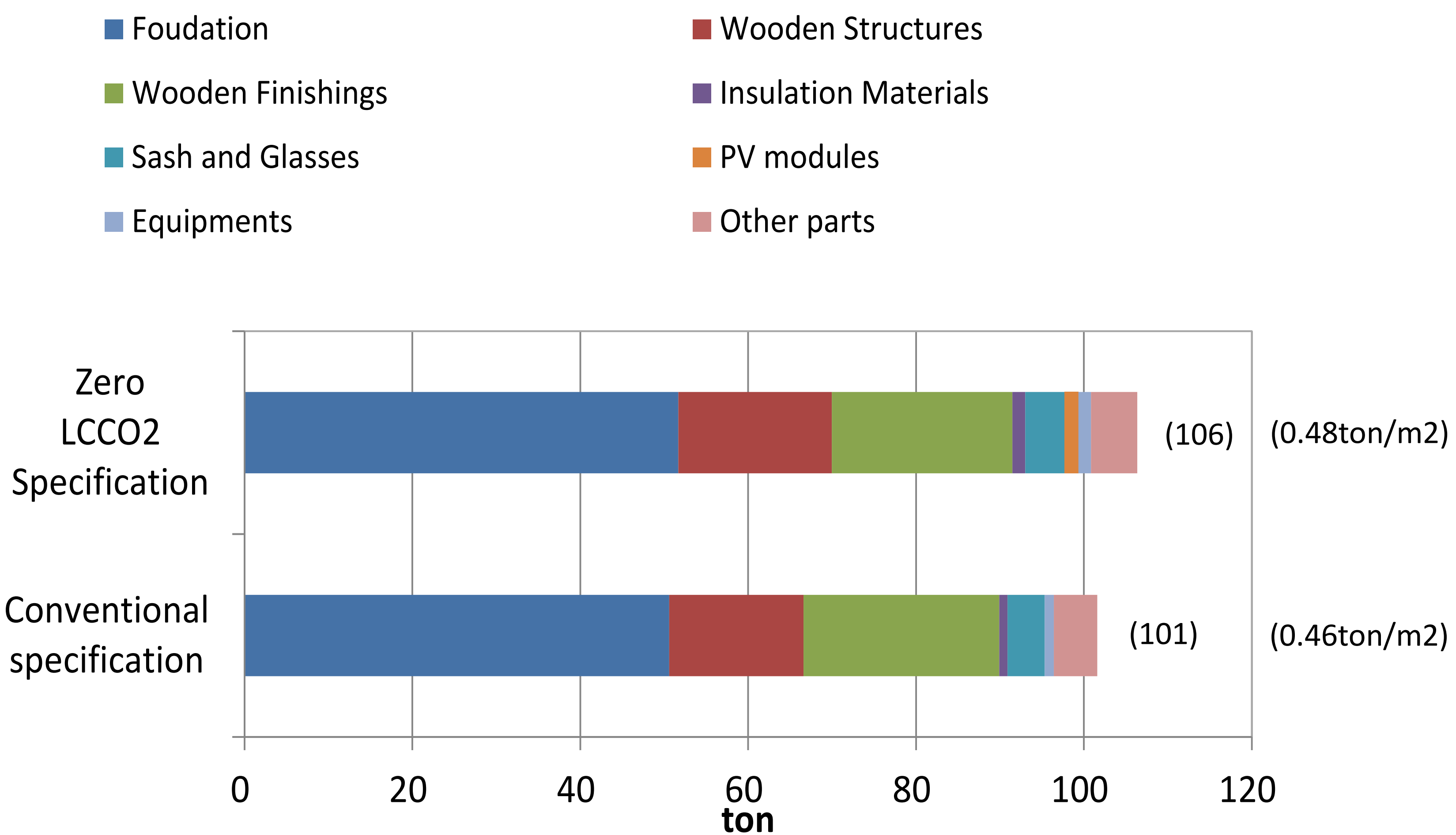
Life cycle CO_2 balance

Life cycle CO2 may reach zero within 65 years and the total CO2 reduction may exceed 500 tons during the life time.

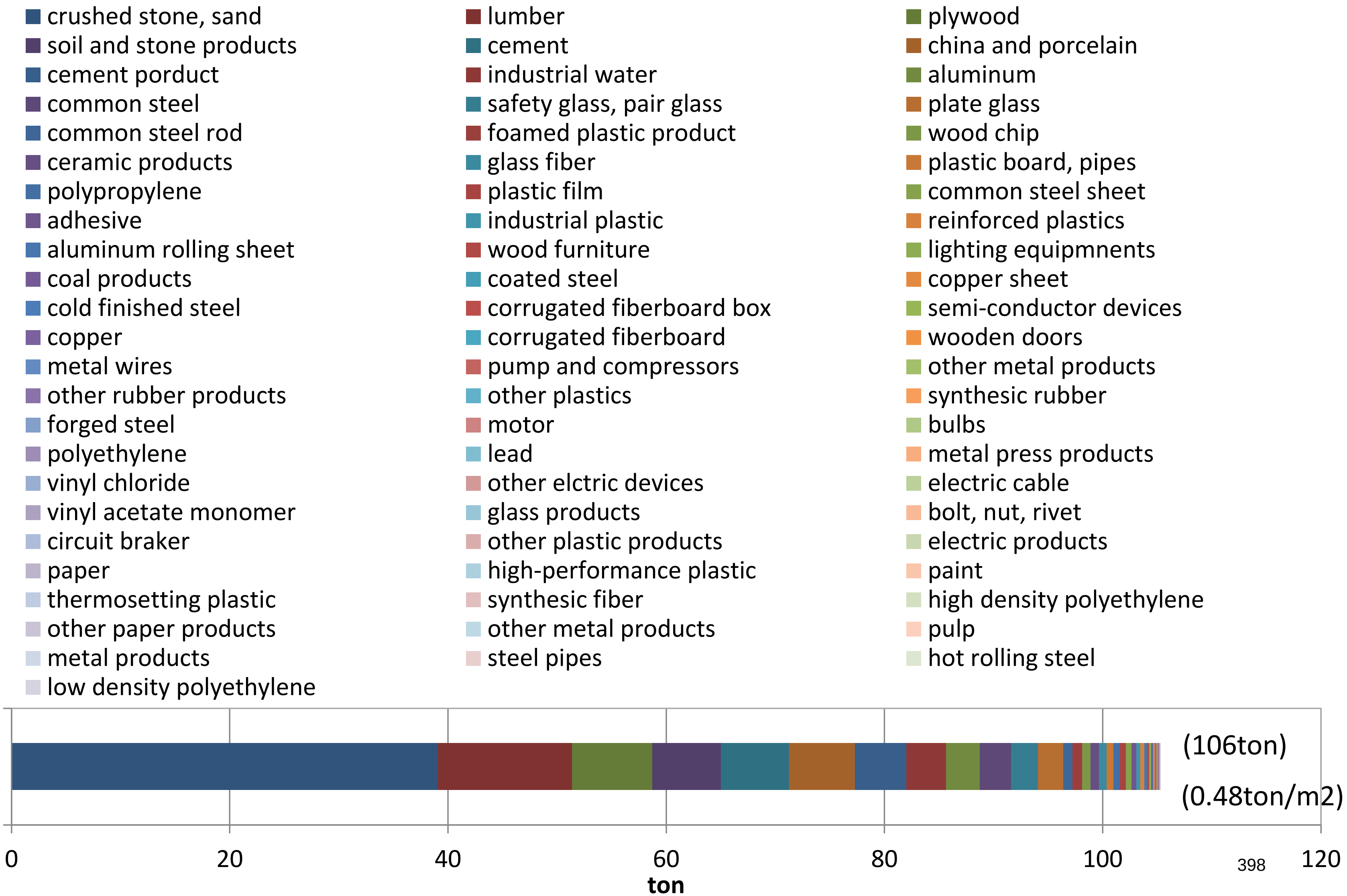


Life cycle CO2 balance

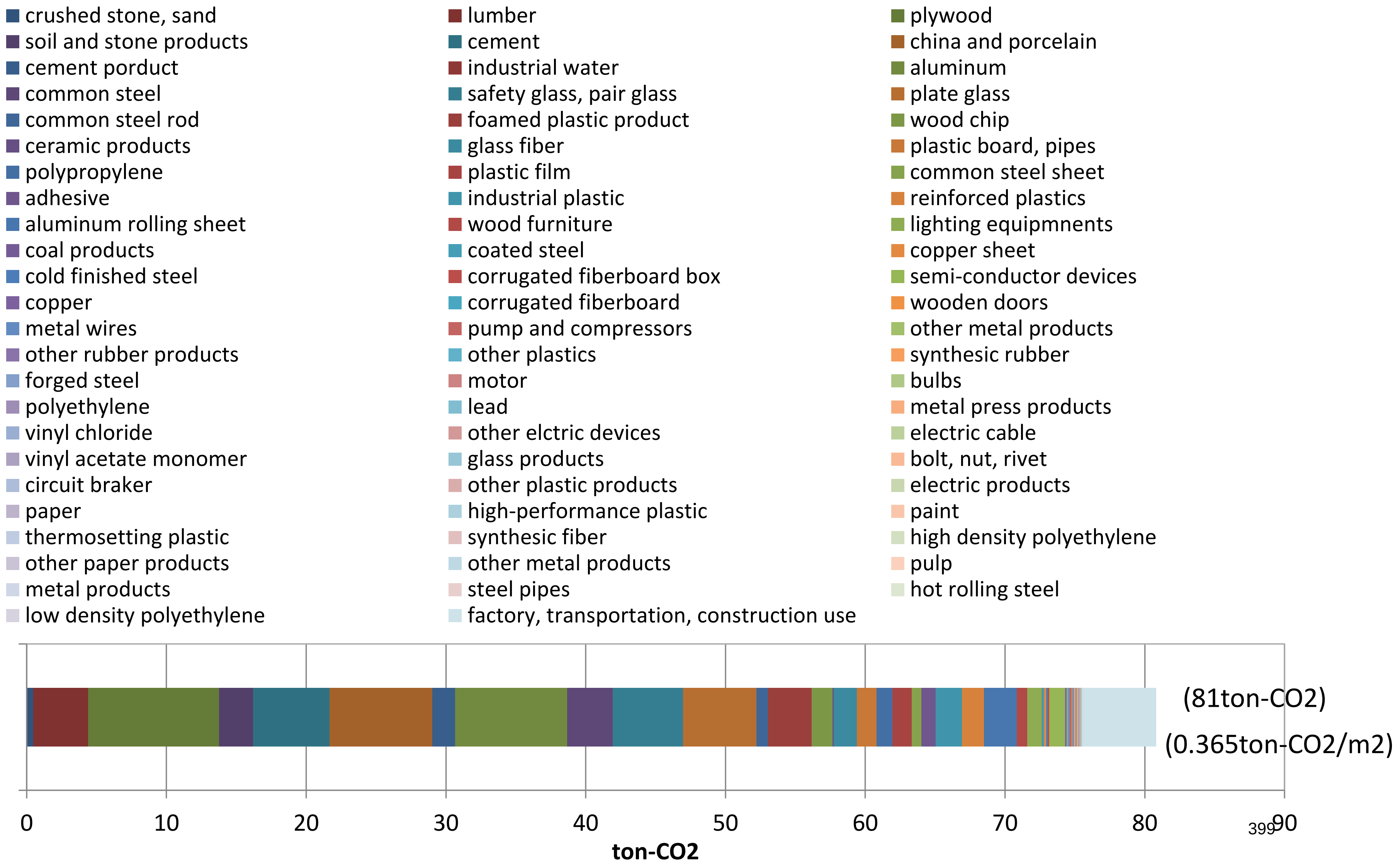
MATERIAL USE AND QUANTITIES



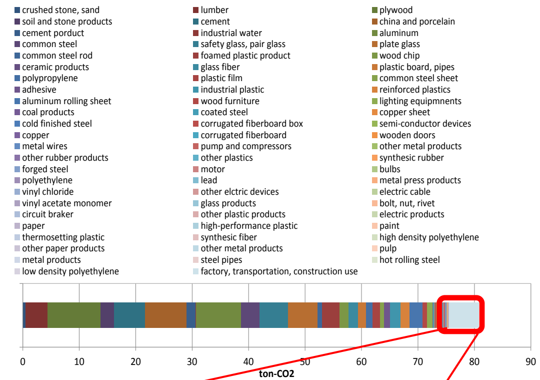
MATERIAL USE AND QUANTITIES (Minute classification)

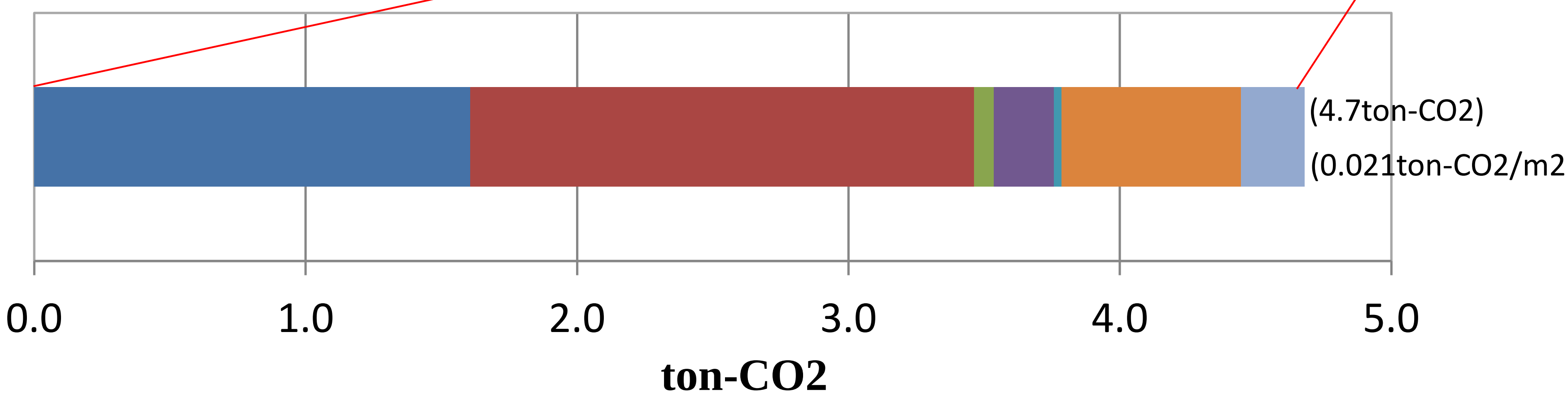


Embodied greenhouse gases of the LCCO2 minus model -Minute classification by materials

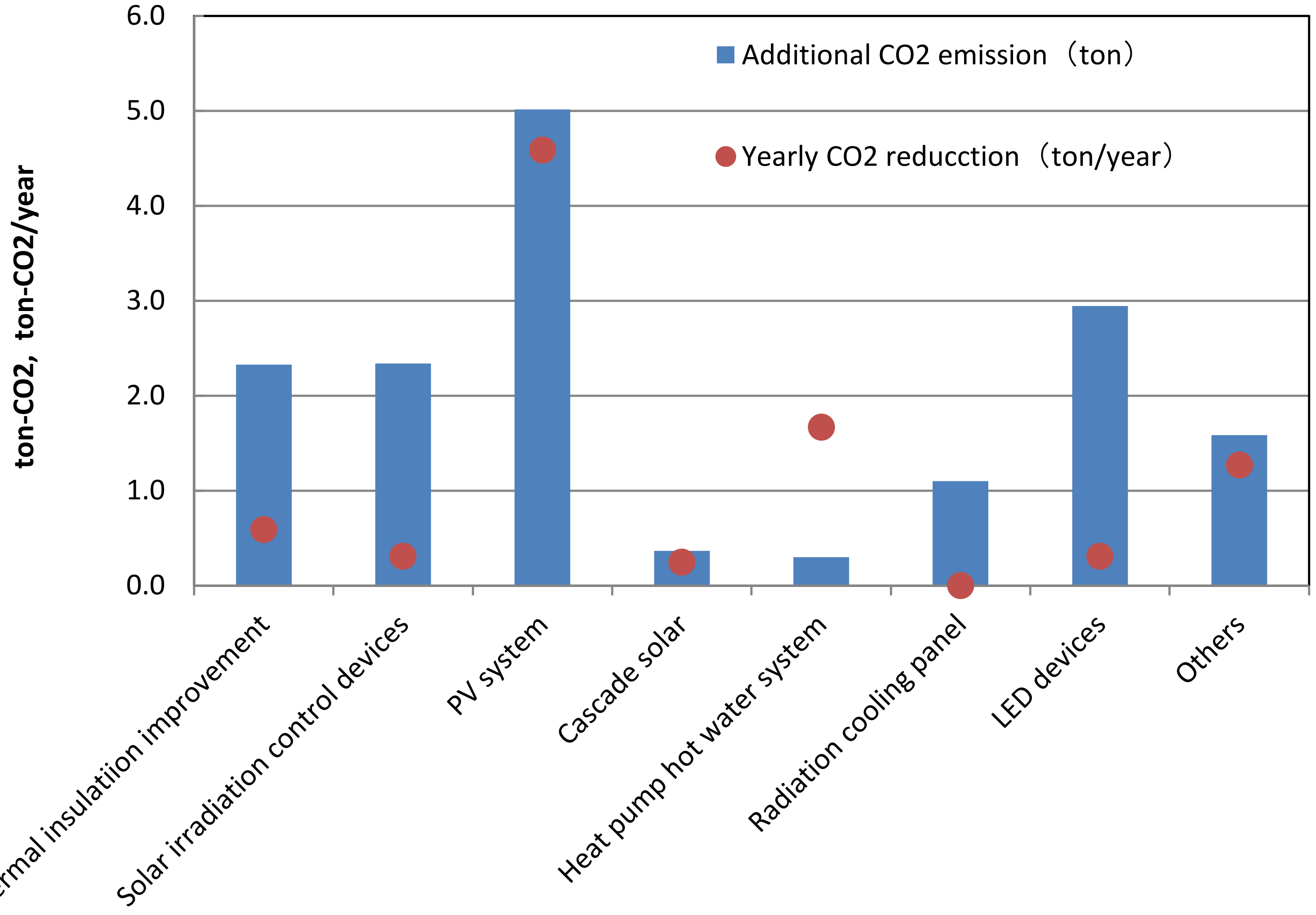


Embodied Greenhouse gas emission at gate factory, transportation, and construction site





Additional embodied greenhouse gas emission for specification improvement



Case study JP2
Low Energy house - Japan

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

LCA of standard model and low energy model is studied.

Low energy model can reduce about 2.7 tonCO2/year of operating embodied greenhouse gas .

According to estimation of embodied greenhouse gas, embodied greenhouse gas which have effect on operating energy are minute of the whole, so only 3.2 tonCO2 increases in low energy model.

So the increase of EG by low-energy model can be recovered in about two years.

Embodied greenhouse gas emission

	Standard	Low Energy	
Construction	40.6	43.8	ton-CO_2
Operation	4.2	1.5	ton-CO_2 /year

OBJECTIVES OF CASE STUDY

To estimate the effects of low energy house

BUILDING KEY FACTS

Intended use: Detached house
Size: 136.2 $m^2{}_{GFA}$
Location: Japan
Architect: Daiwa House Industry Co., Ltd
Insulation:
A. Standard case ; 3.6 $W/m^2{}_{GFA}K$ of Q value
B. Low Energy case ; 2.0 $W/m^2{}_{GFA}$ K of Q value

Fig.1 plans

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study

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								X						

LCA BACKGROUND

LCA methodology: LCA calculation tool (Architectural Institute of Japan based on IO table in Japan)
Databases used: LCA calculation tool (Architectural Institute of Japan)
Operating Energy calculation: Primary Energy consumption calculation program for residential house (Building Research Institute etc)
Energy supply: Electricity from Tokyo Electric Company／LNG from Tokyo Gas Company

THE BUILDING

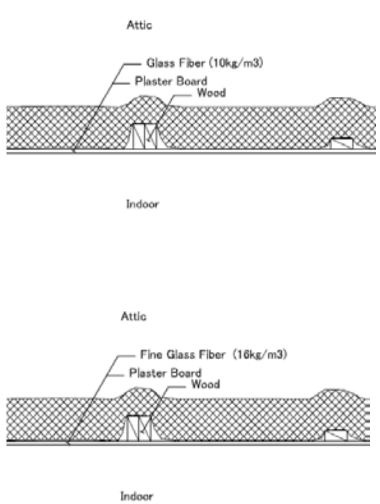
The structure is composed of light weight steel (for frame) and windows are composed of glass, plastic and aluminum (for frame). Exterior wall is covered by fiber reinforced cement sidings and interior wall and ceiling are composed of wood frame and plaster board and wallpaper. The Floor is covered with wooden floor. Insulation and Home Appliance specifications are as follows.

	Insulation Specification	
	Standard Model	Low-Energy Model
Ceiling	GW 10 kg/m³ 100 mm	HGW 16 kg/m³ 100 mm
Wall	GW 10kg/m³ 72 mm	GWB 140kg/m³ 12 mm + HGW 16kg/m³ 60 mm
Floor	PSF A-4 45 mm	GW 32 kg/m³ 80 mm
Window	Aluminum sash, single glass	Plastic sash, Low-e double glazed window

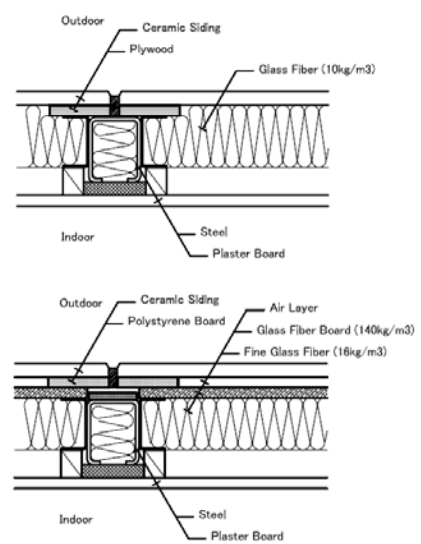
	Home Appliance Specification	
	Standard Model	Low-Energy Model
Heating and cooling	Room air conditioner using air-to-air heat pump unit	Room air conditioner using air-to-air heat pump unit
Hot water	Gas boiler	CO2 heat pump system
Lighting	fluorescent lamp	LED
Solar utilization	-	PV Solar system (3kW)

Standard Model

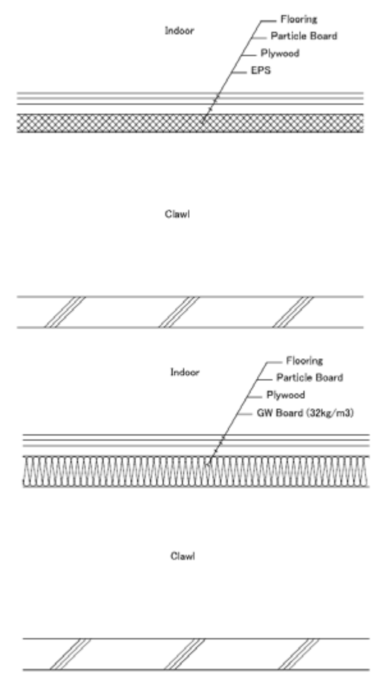
Low-Energy Model



Ceiling



Wall



Floor

Fig.2 details

ANNUAL CO2 BALANCE

In standard model, annual CO2 emission is 4.2 tonCO2/year.
In comparison, low energy model is 3.0 tonCO2/year.
It is mainly caused by reduction in Heating (high performance insulation), Hot water (high efficiency heat pump system), Lighting (LED).
And PV solar system can reduce 1.5 tonCO2/year.
So finally, annual CO2 emission is 1.5 tonCO2/year in low energy model.

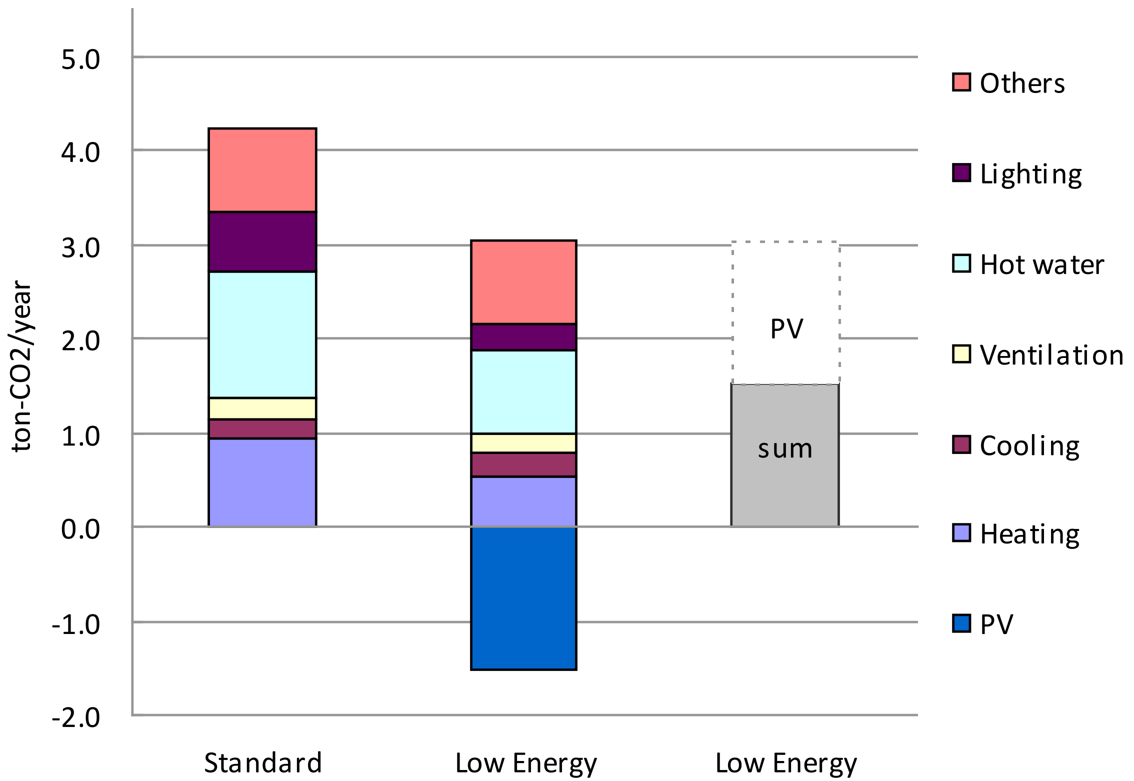


Fig.3 Annual CO2 balance

MATERIAL USE AND QUANTITIES

The gross weight increases only 1.1ton in low energy model.

We changed the thickness of the insulation material and raised the insulation performance of the opening considering not to greatly change the structure. In addition, high efficiency equipments are installed.

Therefore, increase in weight is seen in glass fiber, glass, equipments when we look according to materials.

The total consumption of building materials is estimated to approximately 60.2 tons in low energy model.

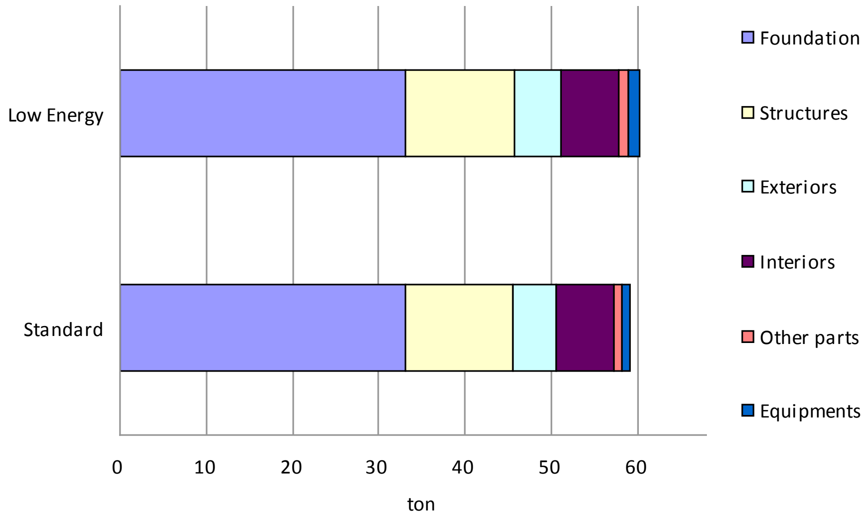


Fig.4 Comparison of weight (classification by parts)

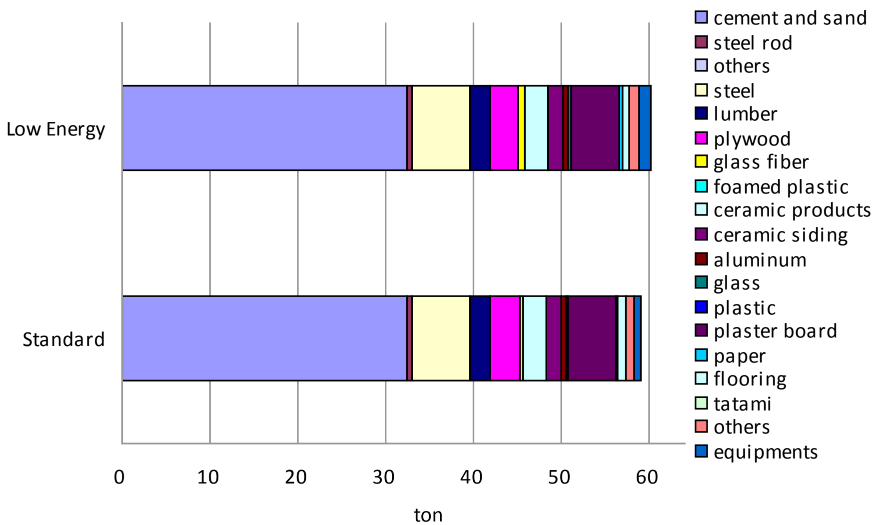


Fig.5 Comparison of weight ((classification by materials)

Embodied GHG

About 3.2 tonCO2 increased in low energy model.
It can be recovered in two years in comparison with the running CO2 mentioned above.

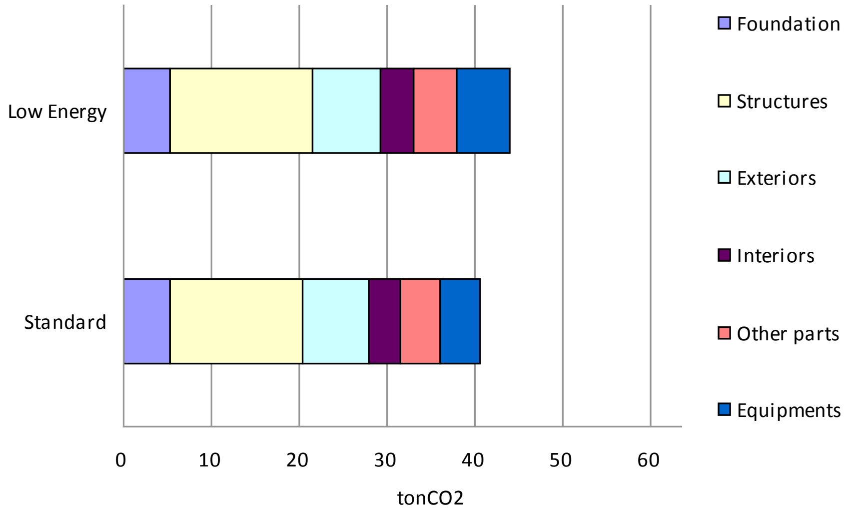


Fig.6 Comparison of CO2 (classification by parts)

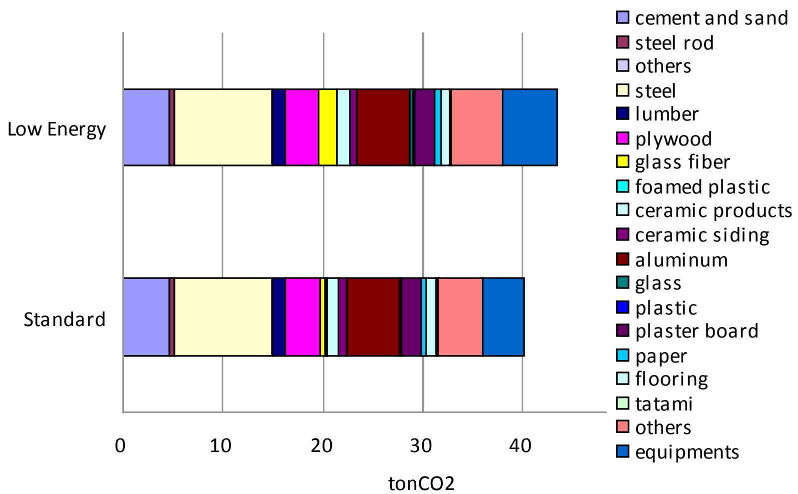


Fig.7 Comparison of CO2 ((classification by materials)

Case study JP3
Wooden house and waste recycle

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The estimation was carried out based on the three distinct settings.

In case1(past) and case2(present), woodchips are assumed to be thermally utilized as a boiler fuel to reduce gas consumption.

In case3(measures), all the recycled matter is assumed to be used for cogeneration to reduce gas and electricity consumption.

When comparing with Case1, Case2 shows an EG decrease of 11.8 t-CO2 (10.7%). When comparing with Case2, Case3 shows an EG decrease of 7.8 t-CO2 (7.9%).

With regard to wooden houses, recycling promotion and expanded utilization of woodchip energy can contribute to reduction in greenhouse gas emissions.

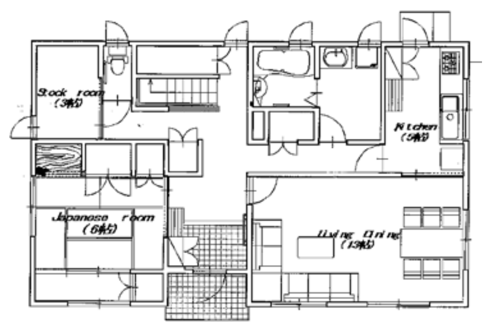
	Case			
	Case1 Past	Case2 Present	Case3 Measures	
EG	12.5	11.2	10.3	kg CO_2 equiv. /m^2_{GFA}/60ys

OBJECTIVES OF CASE STUDY

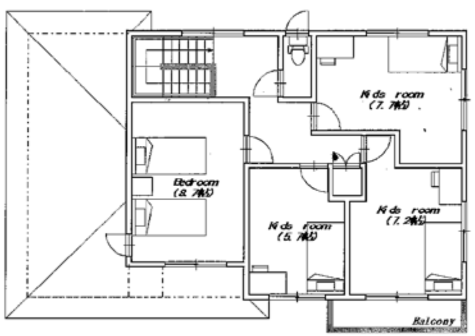
To evaluate the effect of greenhouse gas emissions reduction resulting from the recycling of wooden houses.

BUILDING KEY FACTS

Intended use:	Detached house
Structural type:	Wood-frame construction method
Size:	147.39m2
Location:	Tokyo, Japan
Architect:	Sumitomo Forestry Co.,Ltd.
Building year:	2012



1F Plan



2F Plan

BACK GROUND

Trees absorb and store CO_2 as they grow. As wooden houses retain large quantities of carbon, the produced woodchips after demolition can be thermally utilized as a boiler fuel or in biomass power generating system. Sumitomo Forestry Group promotes sustainable forest management by planting new trees after tree felling (Figure 1).

The Construction Material Recycling Law came into effect in 2002, making it compulsory that waste be demolished for sorting and recycling. The recycling rate of construction waste is improving every year (Figure 2).

In 2008, Sumitomo Forestry Co., Ltd. , in conjunction with Sumitomo Joint Electric Power Co., Ltd. and Furuhashi EPO Corporation, built a biomass power plant in Kawasaki to facilitate the utilization of woodchip energy (Figure 3 and 4).

Fig.1

©Sumitomo Forestry Co.,Ltd.

Fig.2

Source www.k-pumpkin.co.jp

Fig.3

©Kawasaki Biomass Electric power Co.,Ltd.

Fig.4

©Kawasaki Biomass Electric power Co.,Ltd.

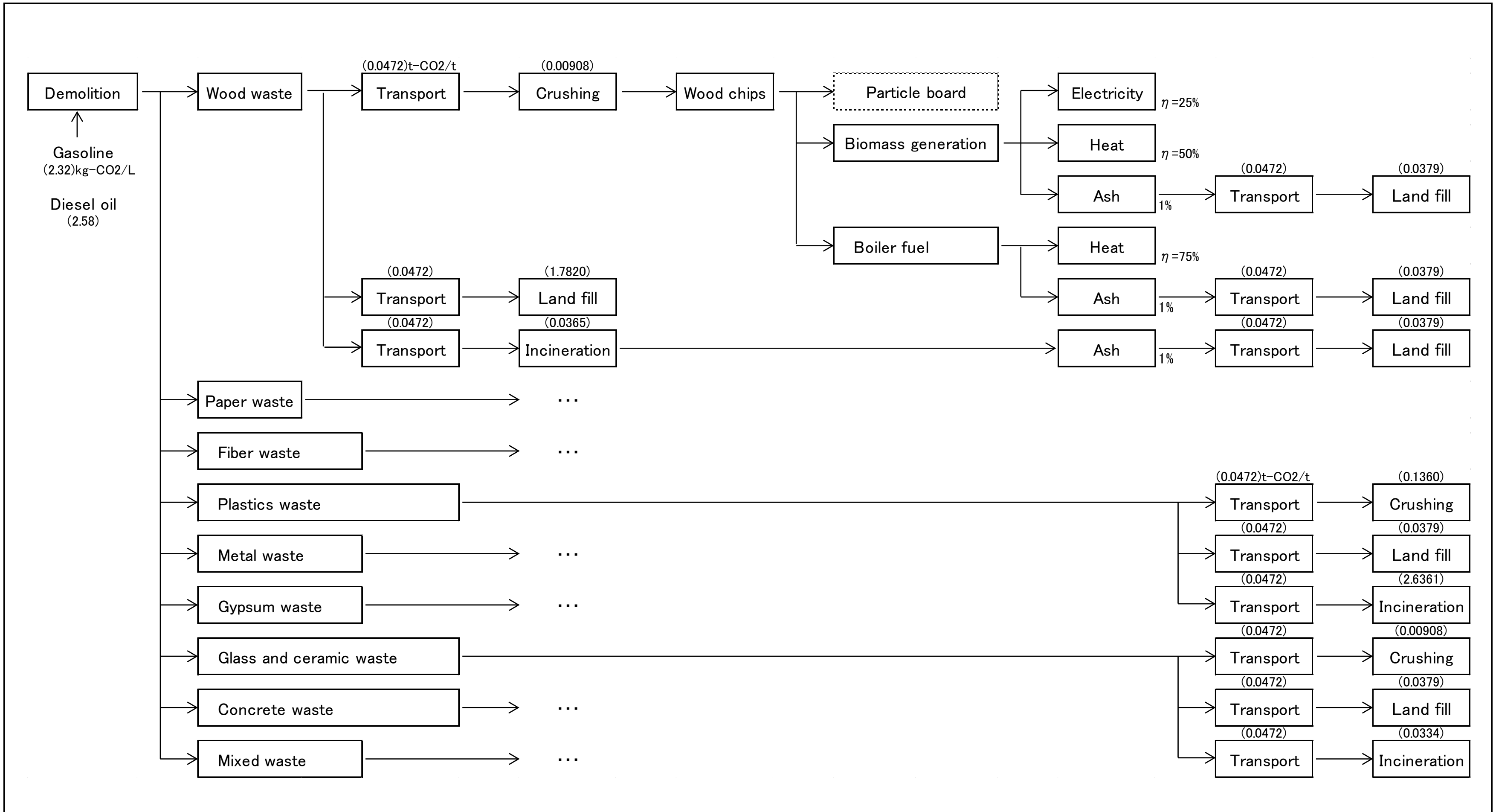
Building life cycle stages included in the study, according to EN15978

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	X	X				X	X			X	X	X	X	X

LCA BACKGROUND

Reference study period: 60 years
LCIA methodology: AIJ-LCA&LCW (Detached Houses) ver. 2.00 (Architectural Institute of Japan 2013)
Databases used: AIJ-LCA&LCW (Detached Houses) ver. 2.00 (Architectural Institute of Japan 2013)
Emission Intensity Database for Calculation of Organizational GHG Emissions Including Supply Chains ver.2.2 (Ministry of the Environment, Ministry of Economy, Trade and Industry 2015 Japan)
Carbon Footprint of Products Communication Program –Basic database ver.1.01 (Japan Environmental Management Association for Industry)
Energy supply: Electricity from Tokyo Electric Company／LNG from Tokyo Gas Company

FLOW CHART OF THE BUILDING DEMOLITION/DISPOSAL PROCESS



THE BUILDING

The house is erected by the wood-frame construction method. The Kizure Panel, which is a lattice consisting of narrow strips of wood, is used as the exterior wall substrate. While the Kizure Panel is a load-bearing wall surface material, it also releases intra-wall moisture functioning as a ventilation layer. Effective use of thinnings contributes to recycling of forest resources. Wood building materials are also used for key structures such as the interior wall, floor substrate, floor finish, staircase, and interior parts.

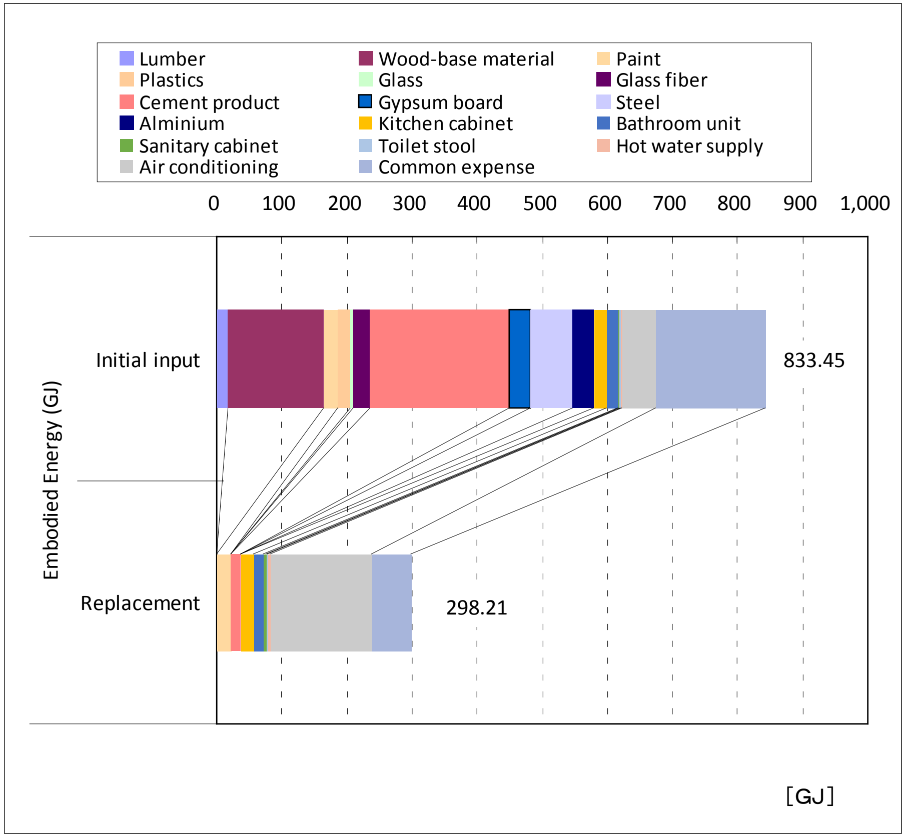
©Sumitomo Forestry Co.,Ltd.

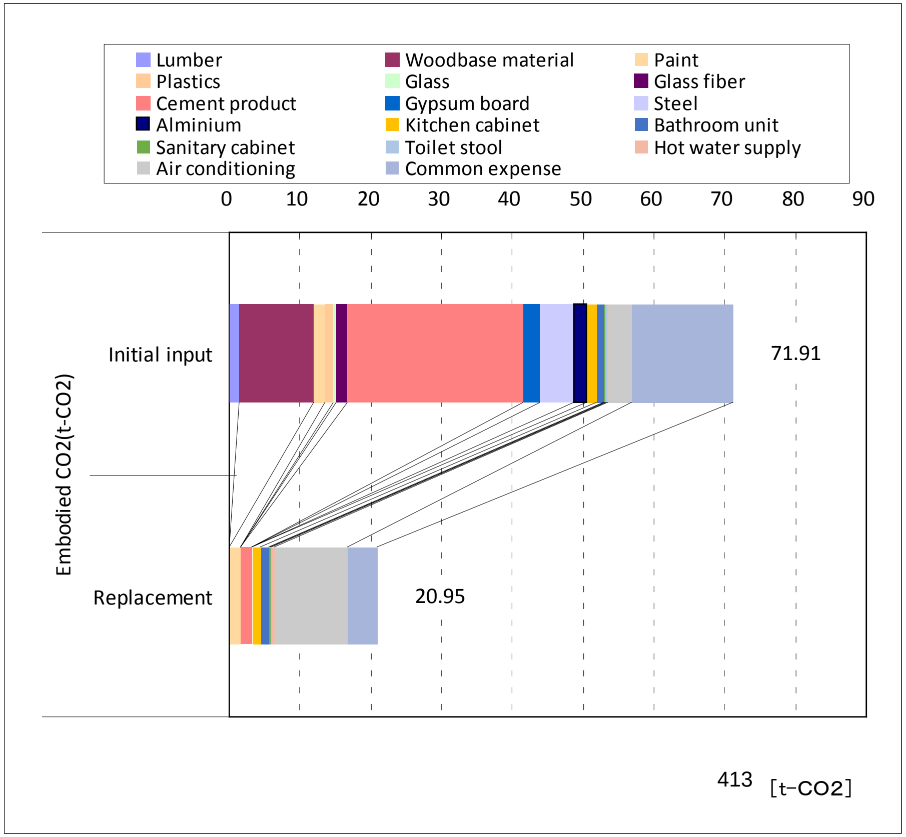
MATERIAL USE AND QUANTITIES

Building elements		Materials	Material division	Input /Initial [tons]	Replace met cycle [years]	Input /Replace ment [tons]	Input /60years [tons]
Foundations	—	Concrete	Cement product	47.00	60	0.00	47.00
		Steel rod	Steel	1.84	60	0.00	1.84
Structural parts	Wood	Lumber	Lumber	5.13	60	0.00	5.13
		Laminated lumber	Woodbase material	5.38	60	0.00	5.38
		Plywood	Woodbase material	3.63	60	0.00	3.63
	Steel	Steel	Steel	1.26	60	0.00	1.26
	Insulation	Glass fiber	Glass fiber	0.59	60	0.00	0.59
		Polysthylane board	Plastics	0.58	60	0.00	0.58
Exterior parts	Roofing	Slate tile	Cement product	3.06	30	3.06	6.12
	Eaves	Calcium silicate board	Cement product	0.40	30	0.40	0.80
	Exterior	Mortar	Cement product	3.02	60	0.00	3.02
	Wall	Paint	Paint	0.71	30	0.71	1.41
	Window	Alminium	Alminium	0.21	60	0.00	0.21
		Glass	Glass	0.47	60	0.00	0.47
		Plastics	Plastics	0.10	60	0.00	0.10
Interior parts	Wall・Ceiling	Gypsum board	Gypsum board	6.31	60	0.00	6.31
	Floor	Flooring	Woodbase material	0.77	60	0.00	0.77
Equipments	Kitchen cabinet	(complex)	Equipments	0.25	30	0.25	0.50
	Bathroom unit	(complex)	Equipments	0.23	30	0.23	0.46
	Sanitary cabinet	(complex)	Equipments	0.12	30	0.12	0.23
	Toilet stool	(complex)	Equipments	0.09	30	0.09	0.17
	Hot water supply	(complex)	Equipments	0.03	15	0.09	0.12
	Air conditioning	(complex)	Equipments	0.36	15	1.08	1.44
Others	Glavels, Tiles, Interior door,Interior cabinets, Nails, Sheets, Sealing, Ventilation equipment, Lightings, Electlic wires, Water pipes, Wall paper,Tatami-floor,Packing and protect items,others.			—	—	—	—
			Total	81.52	—	6.01	87.54

EE-EG OF INITIAL INPUT AND REPLACEMENT

EE-EG estimation results in relation to the initial input for new construction and the replacement for renewal
EE for new construction is 843 GJ (74%), while EE for renewal is 298 GJ (26%). The total EE is 1,141 GJ.
EG for new construction is 71 t-CO2 (77%), while EG for renewal is 21 t-CO2 (23%). The total EG is 92 t-CO2.Cement products (for foundation and exterior wall substrates) constitute the largest proportion of the initial input, followed by lumber.
The EE-EG arising from replacement is approximately one third of the EE-EG of new construction. Air conditioning makes up the largest proportion of the replacement.





CASE-STUDY CONDITION

	Case1: Past	Case2: Present	Case3: Measures
Recycling rate	2000year	2012year	2012year
Use case	Thermal use =Boiler use	Thermal use =Boiler use	Recycled =Cogeneration
Effect	Gas reduction	Gas reduction	Gas and electricity reduction

FUEL CONSUMPTION FOR DEMOLITION

Gasoline	150.0	L
Diesel oil	94.1	L

WEIGHT OF THE WASTE

	Weight of the waste [t]		
	Initial imput	Replace -ment	60years total
Glass and ceramic waste	1.06	0.00	1.06
Concrete waste	53.48	3.46	56.94
Metal waste	3.31	0.00	3.31
Paper waste *1	0.00	0.00	0.00
Wood waste	14.91	0.00	14.91
Fiber waste *2	0.00	0.00	0.00
Mixed waste	1.07	1.85	2.91
Gypsum waste	6.31	0.00	6.31
Plastics waste	1.39	0.71	2.09
Total	81.52	6.01	87.54

*1 Paper wastes by wall paper, packing and protect items are not included.

*2 Fiber wastes by Tatami floor are not included.

WEIGHT OF THE WOOD WASTE FOR RECYCLING

	Case1	t	Case2,3	t
Total	100%	14.91	100%	14.91
Recycled	38.0%	5.67	89.2%	13.30
Incineration	17.7%	2.64	5.2%	0.78
Land fill	44.3%	6.61	5.6%	0.84
Thermal use	14.7%	2.19	34.5%	5.15
Material use	23.3%	3.47	54.7%	8.15

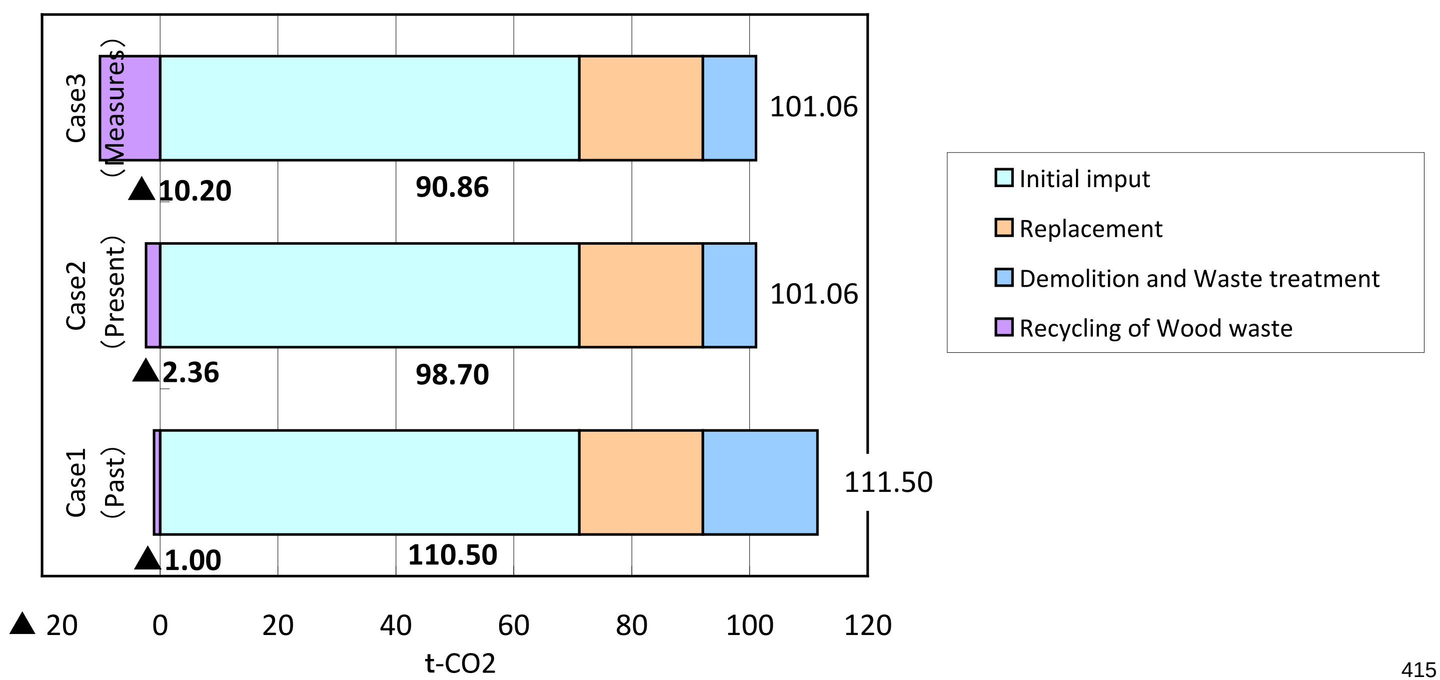
RECYCLING RATE OF EACH CASE AND MATERIAL

	Case1（Past: 2000）			Case2（Present: 2012）,Case3（Measures）		
	Incineration	Land fill	Recycle	Incineration	Land fill	Recycle
Glass and ceramic waste	2.3%	56.2%	41.5%	4.6%	24.8%	70.6%
Concrete waste	0.0%	3.8%	96.2%	0.0%	0.7%	99.3%
Metal waste	1.3%	16.0%	82.6%	1.0%	2.3%	96.7%
Paper waste	41.7%	8.7%	49.7%	40.8%	4.3%	54.9%
Wood waste	17.7%	44.3%	38.0%	5.2%	5.6%	89.2%
Fiber waste	62.6%	25.3%	12.2%	33.5%	12.0%	54.5%
Mixed waste	31.7%	63.4%	4.9%	0.9%	41.8%	57.3%
Gypsum waste	0.0%	78.0%	22.0%	0.0%	78.0%	22.0%
Plastics waste	30.6%	44.8%	24.6%	27.9%	17.0%	55.1%

TOTAL EG -RESULTS

Total EG including demolition ,waste treatment and recycling of wood waste

Total EG of Case 1 (past) is 110.3 t-CO2.
Total EG of Case 2 (present) is 98.3 t-CO2.
Total EG of Case 3 (with implemented measures) is 89.8 t-CO2.
When comparing with Case 1, Case 2 shows an EG decrease of 12.0 t-CO2 (10.9%).
This is considered to be the effect caused by the improved recycling rate.
When comparing with Case 2, Case 3 shows an EG decrease of 8.5 t-CO2 (8.7%).
This effect can be attributed to the expanded energy utilization by the assumption of maximum thermal utilization and cogeneration.



Case study JP4
Library in Japan

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The EEC was calculated with a Reference Study Period (RFS) of 60 and 100 years respectively.

In the study, to increase the building life time from 60 years to 100 years, the covering thickness of concrete for reinforcing rod is increased and the increase in earthquake-resistant strength.

Embodied Energy (EE) and Embodied GHG (EG) was evaluated. The length of RFS is an important factor for the results.

REFERENCE STUDY PERIOD

	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

(50):Earthquake-resistant strength +50%
(25):Earthquake-resistant strength +25%

Evaluation of additional cost for prolongation of life time, the additional cost is 3 to 9% of total construction cost of building.

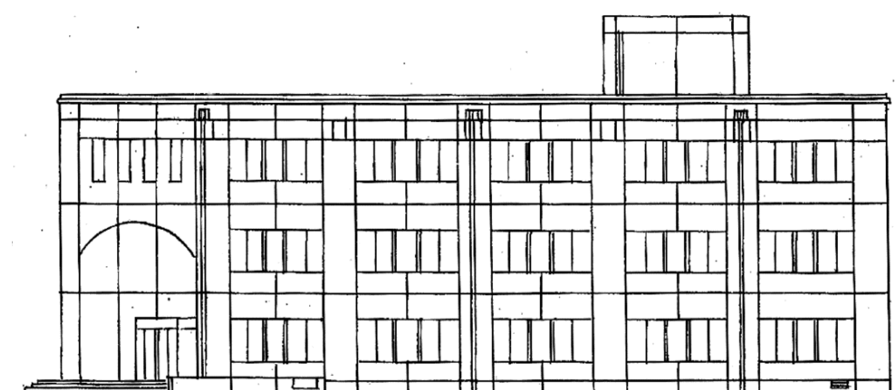
OBJECTIVES OF CASE STUDY

To perform a embodied energy and greenhouse gas (EE-EG) for prolongation of building life time to evaluate the use of Primary Energy (PE) and Global Warming Potential (GWP) related to a new library building in Japan. The study evaluates:

- The Embodied Energy (EE) and Embodied GHG (EG) at construction period
- The impacts related to different building life time

BUILDING KEY FACTS

Intended use: Library
Size: 2,412 m^2 GFA
Location: Tokyo, Japan
Building year: Designed in 2004 (Design only)



Source: [4]

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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														

Production and construction stage modeling: 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.

LCA BACKGROUND

Reference study period: 60 and 100 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: 2005 I-O table in Japan
Energy supply: not applicable
Standards/guidelines: not applicable

REFERENCES

[1] The basic transaction table of 2005 input–output table in Japan

[2] Principal Guide for Service Life Planning of Building, 1988, Architectural Institute of Japan, 1988, Architectural Institute of Japan.

[3] General earthquake proofing, anti-tsunami plan standard of government office facilities, 2013, Ministry of Land, Infrastructure and Transport

[4] Building cost information, 2004 summer, 2004, Construction Research Institute

[5] Yokoyama, et. al., Study on impact of embodied energy and greenhouse gas emissions for prolongation of building life time: Case Study in Japan, Journal of Civil Engineering and Architecture, Volume 9, Number 3, 2015,

BUILDING DESCRIPTION - INVENTORY

Annex 57

THE BUILDING

The case study was conducted for the library which is the steel reinforced concrete construction as drawings shown in right [4].

MATERIAL USE AND QUANTITIES

Capacity and weight of building structure are obtained from cost data [4] and shown in Table below.

Table 1 Capacity and weight of building structure

	Concrete		Reinforcing bar	
	m3	Ratio	kg	kg/m3
Column	208	12%	41,007	197
Beam	402	23%	69,656	173
Floor	379	22%	24,957	66
Wall	235	14%	25,279	108
Foundation	505	29%	50,800	101
Total	1,729	100%	211,700	122
Weight of building structure			4,016	ton

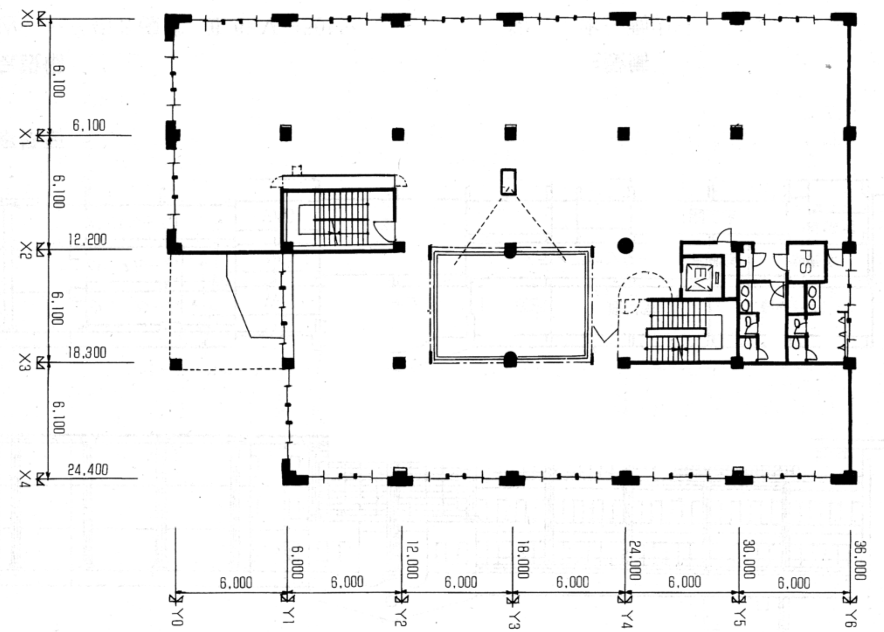


Figure 1: Plan of 2nd floor Source: [4]

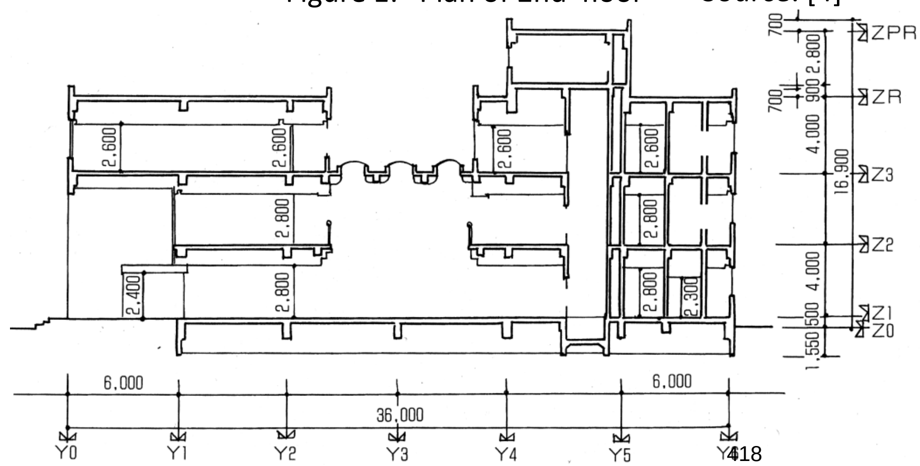


Figure 2: Section of the building Source: [4]

METHODS

we take up the increasing durability of structure as one of the methods to extend the life of a building. To increase the life of building from 60 years to 100 years, the covering thickness of concrete for reinforcing rod is increased and the increase in earthquake-resistant strength.

1. Increasing durability of the covering thickness of concrete for reinforcing rod

For the service life of the structure of the reinforced concrete construction, degradation caused by the rust of a reinforcing rod of concrete is a big factor. The time to progress of neutralization of concrete to certain depth is a relationship to be almost proportional to square of the depth.

2. Extension of life-span by increase of earthquake-resistant strength

In the earthquake-resistant plan of the building of government offices in Japan; even if a major earthquake is generated, the structure is recommended to increase earthquake-resistance strength with 50% or 25% of standard values to continue use.

3. The total increase rate of material

The total increase rate of material is shown in Table 1.

4. EEC increase by extension of life-span

Intensities of energy consumption and greenhouse gas emission are calculated from 2005 input-output table in Japan as shown in Table 2. The intensities of concrete and reinforced rod per unit become table 3 based on table 2.

Table 2 Increasing rate of material for each element by synthetic extension of life span

Element	Earthquake-resistant strength +50%		Earthquake-resistant strength +25%	
	Concrete	Reinforcing bar	Concrete	Reinforcing bar
Column	+54%	+54%	+26.8%	+26.8%
Beam	+54%	+54%	+26.8%	+26.8%
Floor	+11%	+11%	+11%	+11%
Wall	+11%	+11%	+11%	+11%
Foundation (equivalent to a pillar and a beam)	+54%	+54%	+26.8%	+26.8%

Table 3 Intensities of energy consumption and greenhouse gas emission of major material (part of 401sectors)

No	Industrial No	Industrial Sector	Energy (MJ)	CO_2(kg-CO_2)	Unit/Mil. Yen
			Per Consumer price of Mln. Yen	Per Consumer price of Mln. Yen	Quantity of Material for Consumer Price of Mln. Yen
10	150	Ready mixed concrete	81,093	16,745	62.60 m3
13	162	Hot rolled steel	189,779	18,271	13.47 t
25	276	Residential construction (wooden)	19,921	1,707	6.318 m2
26	277	Residential construction (non-wooden)	29,055	2,704	5.527 m2
27	278	Non residential construction (wooden)	21,103	1,835	7.749 m2
28	279	Non residential construction (non-wooden)	29,644	2,704	6.844 m2

Table 4 Intensity of concrete, reinforced bar and non-residential construction

No	Industrial No	Industrial Sector	Energy (MJ)	CO_2(kg-CO_2)	Unit
			Per Unit	Per Unit	
10	150	Ready mixed concrete	1,295	267	m3
13	162	Hot rolled steel	14.1	1.36	kg
28	279	Non residential construction (non-wooden)	4,331	395	419 m2

RESULTS OF STUDY

Importance of the reference study period (RSP)
Using a 100 year RSP instead of 60 years lowers the embodied energy (total primary energy) from 72 to 52 or 48 MJ/m$^2_{GFA}$/year and the embodied greenhouse gas from 6.6 to 5.2 or 4.6 kg CO_2 equiv. /m$^2_{GFA}$/year. The study showed that the additional cost is 3 to 9% add from original cost of building.

Table 5 Increase of material by prolongation of building life time

	Earthquake-resistant strength +50%				Earthquake-resistant strength +25%			
	Concrete		Reinforcing bar		Concrete		Reinforcing bar	
	Increasing rate %	m3	Increasing rate %	kg	Increasing rate %	m3	Increasing rate %	kg
Column	54	113	54	22,144	27	56	27	11,072
Beam	54	217	54	37,614	27	108	27	18,807
Floor	11	42	11	2,745	11	42	11	2,745
Wall	11	26	0	0	11	26	0	0
Foundation	54	273	54	27,432	27	136	27	13,716
Total (Increasing rate)		670 (39%)		89,936 (42%)		369 (21%)		46,340 (22%)
Increasing weight			1,563	ton			857	ton

Table 6 EEC increase by prolongation of building life time

Earthquake-resistant strength +50%				
	Quantity	Unit	Energy (MJ)	CO2 (t-CO2)
concrete	670	m3	867, 928	179
reinforcing bar	89, 936	kg	1, 267, 109	122
Total			2, 135, 038	301

Earthquake-resistant strength +25%				
	Quantity	Unit	Energy (MJ)	CO2 (t-CO2)
concrete	369	m3	478, 008	99
reinforcing bar	46, 340	kg	652, 885	63
Total			1, 130, 893	162

Table 7 Annual EE-EG by prolongation of building life time

Type of building	Building Life	EE-EG per annual			
	year	Energy (MJ)	Ratio %	CO2 (t-CO2)	Ratio %
Reference Building	60	72.2	100%	6.59	100%
Long-life building Earthquake-resistant strength +50%	100	52.2	72%	5.20	79%
Long-life building Earthquake-resistant strength +25%	100	48.0	66%	4.62	70%

Case study JP5
Office - Japan

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The EG was calculated how much the EG is affected by fluorocarbon gases, which are used in building materials, equipment and device.

In the study, the total EG is 1093 (kg-CO_2/m^2).

EG due to fluorocarbon gases contained in insulators is 26 (kg-CO_2/m^2), 2% of the building's EG.

EG due to fluorocarbon gases contained in refrigerants is 135 (kg-CO_2/m^2), 12% of the building's EG.

Embodied GHG (EG) was evaluated. The reduction of fluorocarbon gases contained in refrigerants is an important factor for the results.

Embodied GHG (EG) [1]

	EG		
Construction	666	(61%)	
Renewal	355	(32%)	
Demolition	73	(7%)	
Insulators	26	(2%)	HFC-245fa
Refrigerants	135	(12%)	Air-source HP (R410A)

Duration of use of building is calculated as 60 years.

OBJECTIVES OF CASE STUDY

To perform an embodied GHG(EG) with CO_2 equivalent from fluorocarbon gases which are used in building materials, equipment and device to evaluate the Global Warming Potential (GWP) related to an office building in Japan. The study evaluates:

-The Embodied GHG (EG) at construction, renewal/repair and demolition
-The impacts related to fluorocarbon gases released

BUILDING KEY FACTS

Intended use: Office building
Size: 11,015 m^2 GFA
Height: 6 stories and 1 basement
Location: Tokyo, Japan

Building life cycle stages included in the study, according to EN15978

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	X	X	X		X	X	X			X				

LCA BACKGROUND

Reference study period: 60 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: 2005 I-O table in Japan
Energy supply: not applicable
Standards/guidelines: not applicable

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[5] Research regarding the impact of insulators on the global warming, New Energy and Industrial technology Development Organization, March 1998
[6] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.3, Table 7.9, 2006
[7] Review of Emission Factors for Refrigerators and Air-Conditioning Equipment in Use, Ministry of Economy, Trade and Industry, 2009
[8] Status of Fluorocarbons Recovery from Commercial Refrigeration and Air Conditioning Equipment based on the Fluorocarbons Recovery and Destruction Act, Ministry of Economy, Trade and Industry, December 2013

Production and construction stage modeling: 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 [2].

Operation stage modeling: EG in the renewal phase (including repair) is calculated using at the renewal ratio which represents the ratio of EG at the renewal stage to EG at the construction stage.
The renewal ratio is obtained by multiplying “Renewal/Repair factor of each component” by “Number of renewals/repairs”. The renewal/repair factor respectively represent a ratio of the expense for an one-time renewal/repair to the expense at the construction stage.
The Number of renewals/repairs is calculated by the renewal/repair cycle. The renewal/repair cycle indicates the number of years until the next renewal/repair. When determining the number of renewals/repairs, the duration of use of a building is calculated as 60 years. Repair work can be disregarded when the number of years until the next scheduled renewal or the expiry of the duration of use is less than half of the repair cycle. Similarly, when the number of years until the expiry of the duration of use is less than half of the renewal cycle, the renewal work can be disregarded [3].

End of life stage : EG at the demolition stage is calculated as 73 (kg-CO_2) per total floor space (m^2) [4].

Other : The impact from fluorocarbon gases contained in insulators are included. In the calculation, all fluorocarbon gases are released into the atmosphere. In addition, the impact from fluorocarbon gases as refrigerants used to electric refrigerators are included too. Fluorocarbon gases from electric refrigerators are released when there is a leak in devices or pipes during operation, renewal and demolition [5] [6] [7] [8].

THE BUILDING

The case study was conducted for the office building which is steel construction as drawings shown in right.

MATERIAL USE AND QUANTITIES

<Structure>

Steel frames : 784 ton

Reinforcing bars : 522 ton

Concrete : 4,791 m^3

<Finishing>

Tiles : 3,511 m^2

Glass : 1,092 m^2

<Equipment>

HVAC : 998 kW (Air-source HP chiller)

Water supply : 83 m3/day

Power receiving capacity : 1700kVA

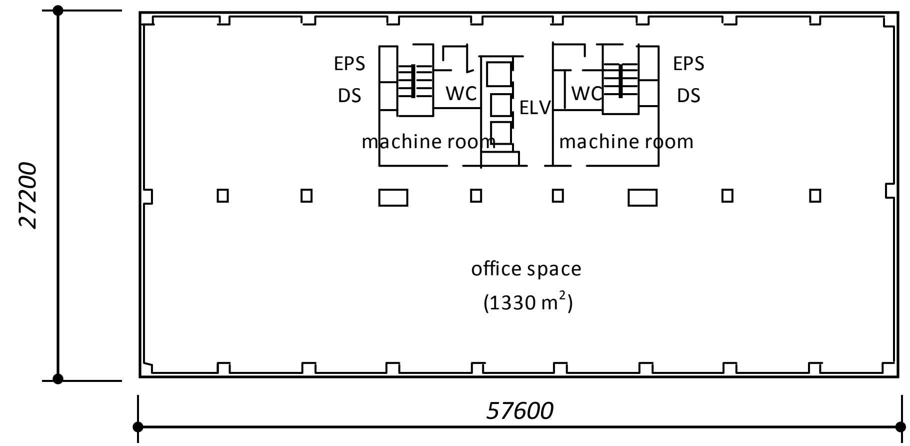

Fig.1 basic floor plan [4]

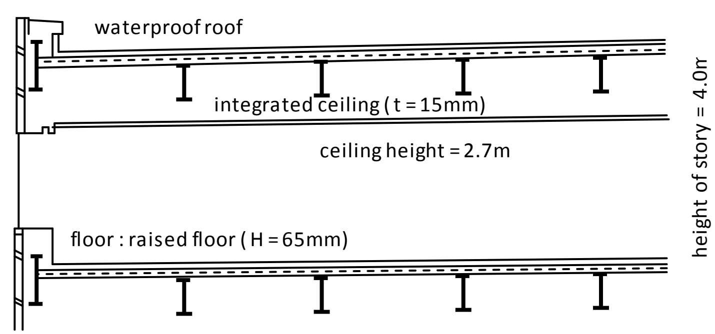

Fig.2 basic plan [4]

METHODS

In this case study, We calculated the embodied GHG in each phase during the life-cycle of the office building, such as construction, renewal and demolition. Additionally, we also calculated how much the embodied GHG (EG) is affected by fluorocarbon gases which used in building materials, equipment and devices.

1. Embodied GHG

(1) Construction phase

EG is calculated either by multiplying the quantity (unit) by the greenhouse gas emission intensity (kg-CO_2/unit), or by multiplying the construction expense (JPY) by the greenhouse gas emission intensity (kg-CO_2/Mil JPY).

(2) Renewal phase

EG is calculated using the renewal ratio which represents the ratio of EG at the renewal stage to EG at the construction stage (Table 1).

(3) Demolition phase

EG is calculated as 73 (kg-CO_2) per total floor space (m^2).

Table 1 Renewal ratio [1]

Construction item	Material item	Factor[3] Repair	Factor[3] Renewal	Cycle(year)[3] Repair	Cycle(year)[3] Renewal	Number of times*1 Repair	Number of times*1 Renewal	Renewal ratio
Structure	Steel frame	0	0	-	-	0	0	0
	Concrete	0	0	-	-	0	0	0
	Reinforcing bar	0	0	-	-	0	0	0
	Metal fitting	0.04	1	5	30	10	1	1.4
	Interior wall	0.05	1	10	30	4	1	1.2
	Tile	0.015	1	10	-	5	0	0.075
Air conditioning	Refrigerator (Air-source heat pump)	0.23	1.1	10	15	4	3	4.22
	Plumbing	0	1.2	-	25	0	1	1.2
	Duct	0	1	-	30	0	1	1
Sanitary	Pumping	0.36	1.1	7	20	6	2	4.36
	Plumbing	0	1.2	-	25	0	1	1.2
	Sanitary fitting	0.243	1.1	5	30	10	1	3.53
Electric	Receiving and transforming	0.2	1	10	30	4	1	1.8
	Wiring	0	1	-	30	0	1	1
	Lighting	0.347	1	10	20	3	2	3.041

**The renewal ratio is obtained by multiplying "Renewal/Repair factor of each component" by "Number of renewals/repairs".*

**Duration of use of the building is calculated as 60 years.*

2. Impact of fluorocarbon gases from insulators and refrigerants

(1) Insulators

EG from insulators is expressed in the following equation.

$EG = A_{ins} \times L_{ins} \times e \times f \times GWP$

A_{ins} : Area covered by insulators (m^2), L_{ins} : Thickness of insulators (m), e :Density of insulators (kg/m^3), f :Initial content of fluorocarbon gases (%), and GWP : Global Warming Potential.

(2) Refrigerants

EG from refrigerants is expressed in the following equation.

$EG = [(W \times h_0 \times t) + \{W \times (1 - h_d / 100)\}] \times GWP$

W : Initial filling amount of refrigerants (ton), h_0 : Leak rate of refrigerants (%), h_d : Collection rate at the disposal (%), and t : Number of years used (year).

Table 2 Characteristics of insulators [1]

	Thermal conductivity W/(m*K)	Density kg/m^3	Type of fluorocarbon gas	GWP (-)	Content rate (%)
Urethane foam (foamed on-site)	0.028	30	HFC-245fa	1030	7.3

Table 3 Characteristics of refrigerants [1]

Sub-application	CO_2 emission factor IPCC[6] Guideline	CO_2 emission factor Reference Japan[7]	Recovery efficiency Japan[8]
Chillers	2-15%	6-7%	30%
Medium & Large Commercial Refrigeration	10-35%	12-17%	
Residential and Commercial A/C, including Heat Pumps	1-10%	2-5%	

RESULTS OF STUDY

1. Total EG : 1,093 (kg-CO_2/m^2) (Fig.3)
(1) Construction stage : 666 (kg-CO_2/m^2)
- Construction site : 7%, - Structure : 58%, - Finishing : 17%,
- Equipment : 18%

(2) Renewal stage : 355 (kg-CO_2/m^2)
- Structure : 3%, - Finishing : 35%, - Equipment : 62%

(3) demolition stage : 73 (kg-CO_2/m^2)

EG for the renewal stage is equivalent to 53% of the EG for the construction stage. Particularly, in terms of equipment, the EG for the renewal stage is 1.8 times as the EG for the construction stage. This is because equipment has a short renewal cycle compared to structure and finishing. Therefore, a life-cycle extension of equipment would be important.

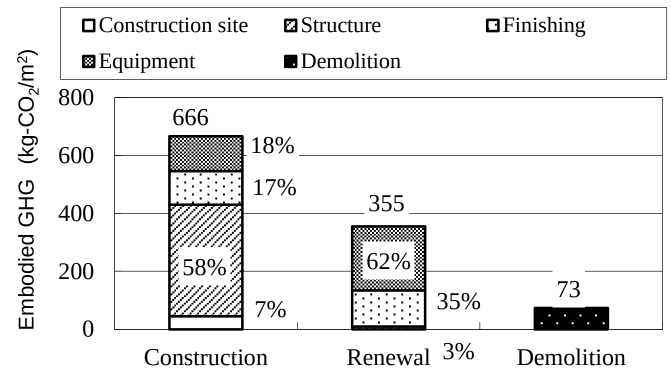

Fig.3 Embodied GHG (60 years) [1]

2. Impact of fluorocarbon gases from insulators and refrigerants (Fig.4)
(1) EG (Insulators) : 26 (kg-CO_2/m^2)
(2) EG (Refrigerants) : 135 (kg-CO_2/m^2)

EG due to insulators (HFC-245fa) is equivalent to 2% of the building's EG.
EG due to refrigerants (R410A) is equivalent to 12% of the building's EG.
It is important to keep reducing emissions of fluorocarbon gases into the atmosphere by improving quality during manufacture, construction, operation (leakage from the pipes or devices), maintenance and demolition.

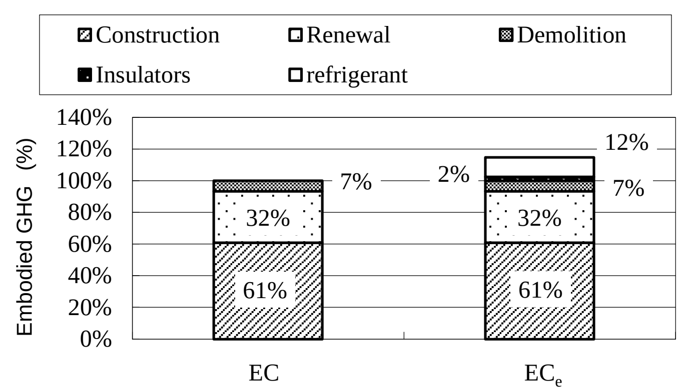

Fig.4 Embodied GHG due to insulators and refrigerants (Chillers) [1]

Key issues related to Annex 57:
1.3 Prolongation of building life time
2.2 which elements in the building?
3.3 Completeness of building data

Case study JP6
Long life and Low Carbon building

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The EEG was calculated with a Reference Study Period (RFS) of 50 and 100 years respectively.

To increase the building life time from 50 years to 100 years, the covering thickness of concrete, the steel frames, oil dumpers are considered. Embodied Energy (EE) and Embodied GHG (EG) was evaluated. The length of RFS is an important factor for the results.

REFERENCE STUDY PERIOD

	50	100	years
EE	240	125	MJ/m^2_{GFA}/year
EG	22	12	kg CO_2 equiv. /m^2_{GFA}/year

OBJECTIVES OF CASE STUDY

This case study perform two themes relating to embodied energy and greenhouse gas. The first one is that the embodied energy and greenhouse gas for prolongation of building life time, second compare detail analysis and simple analysis of embodied energy and greenhouse gas.

The study evaluates:

- The Embodied Energy and Embodied greenhouse gas at construction period
- The impacts related to different building life time
- Evaluation all building elements and part of building elements

BUILDING KEY FACTS

Intended use: Office (Prefectural office), Long life and low carbon office
Size: 63,839 m^2 GFA （Main building)
Location Tochigi, Japan
Architect: Nihon Sekkei
Building year: 2007

© Kobayashi Kenji Photograph Office

Building life cycle stages included in the study, according to EN15978

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	X		X											

Production and construction stage modeling:
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.

Operation stage modeling:
Actual annual energy consumption data are obtained and referred.

LCA BACKGROUND

Reference study period: 50 and 100 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: 2005 I-O table in Japan
Energy supply: not applicable
Standards/guidelines: not applicable

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[4] Y.Kawazu, N.Yokoo, T.Oka, H.Ishikuro, A Study on the transition of materials about the energy consumption and CO2 emission associated with building construction, J. Environ. Eng., AIJ, Vol.73, No.629 (2008) 931-938

[5] T.Takebe, S.Hoshino, et al, Design and Implementation of the Environmental, HVAC and Plumbing System on Tochigi Prefectural Office Building, J. SHASE, 2010

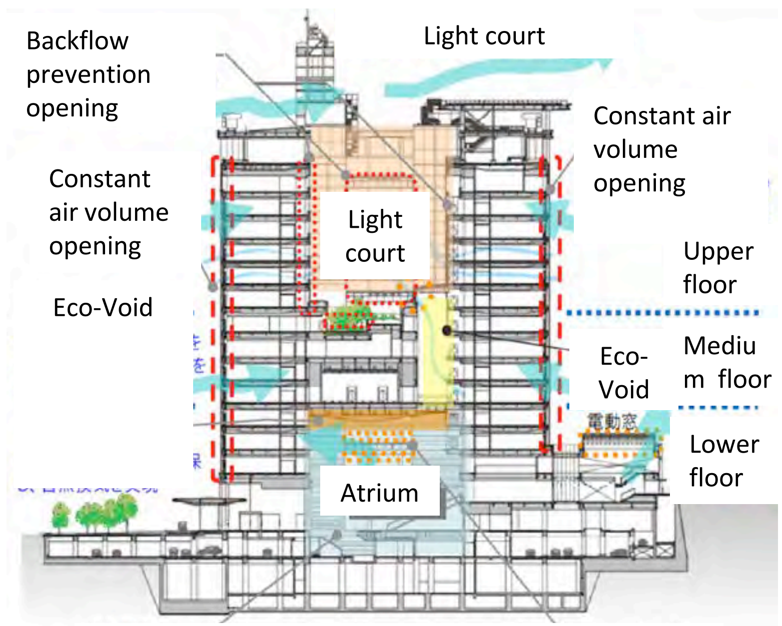
THE BUILDING

The building is a prefectural government office and it introduces various energy saving strategies and long life strategies to achieve low carbon building. Main energy saving designs s are passive design, natural ventilation, double skin façade, day-lighting, high efficiency mechanical system, PV panel, thermal storage, active control earthquake.

MATERIAL USE AND QUANTITIES

Main building materials are follows;

Concrete:	49,000 m3
Reinforce bar:	6,581 t
Steel frame:	3,026 t
Aluminum panel:	780 t
Single glazing:	4,736m2
Double glazing:	2,363m2
Glass wool insulation:	17,427m2
Carpet tile:	22,612m2
Tiles and ceramics:	16,057m2



Natural ventilation in underground parking
Source: Nihon sekkei, inc

CALCULATION METHODS

The calculation methods is as follows;

- The embodied energy /CO2 is obtained from the analysis 2005 Input/Output tables in Japan. The IO tables of Japan consist of 400 industrial sectors.
- Building materials and quantities data are obtained by using building cost data.
- Reference building are assumed based on standard design.
- Long life and low carbon office considers design strategies shown in Table 1 and compare long life/Low carbon office and reference building.
- Embodied energy and Embodied GHG of all element of building, part of elements of building and of skeleton.

Table 1 Long life and low carbon design strategies and standard design strategies

	Long life/Low Carbon Office	Reference building
Earthquake resistant strength	Increase steel frame Oil dumper to reduce earthquake response acceleration	Standard No dumper
Longevity	Increase covering depth of concrete Tile exterior walls Stainless steel piping for water works	Standard covering depth Paint finishing exterior walls Steel piping
Reduce heat loads	Double skin façade, Low-e glazing	Single glazing
Passive	Atrium and light court for natural ventilation and daylight	No atrium, no light court
Peak shift	Thermal storage tank	no
Maintenance	Catwalk for maintenance rout	no
Renewable energy	PV panel	no

Embodied energy

Embodied energy of LC office is about 7 % larger than the reference building(Fig.2). Introducing various energy saving and long life design strategies effects building materials uses and quantities. The life time of LC Office is 100 years and of the reference building is 50 years. Embodied energy with considering building life time shown in Fig.3.

Fig.4 and Fig.5 show the embodied energy and embodied greenhouse gas and operating energy and operating greenhouse gas.

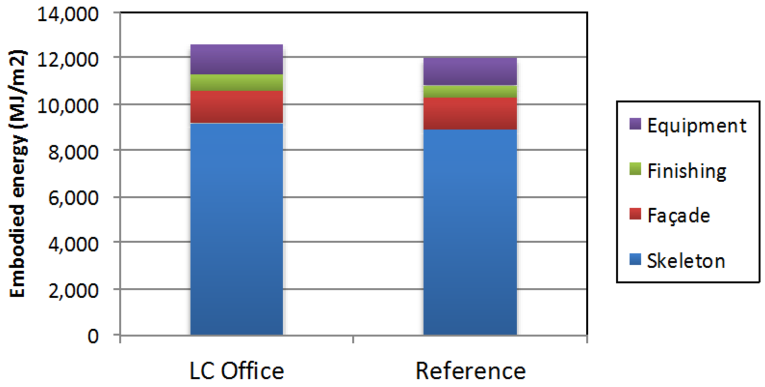


Fig2 Embodied energy

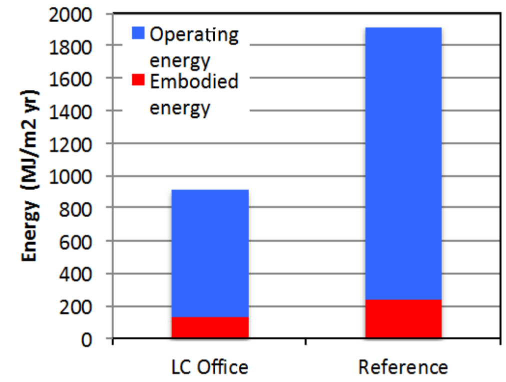


Fig4 Embodied energy and operating energy

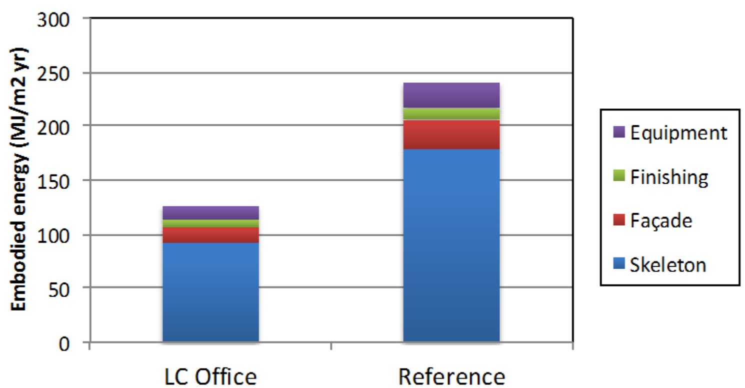


Fig 3 Embodied energy
Building life: 100 years for LC Office,
50 years for reference

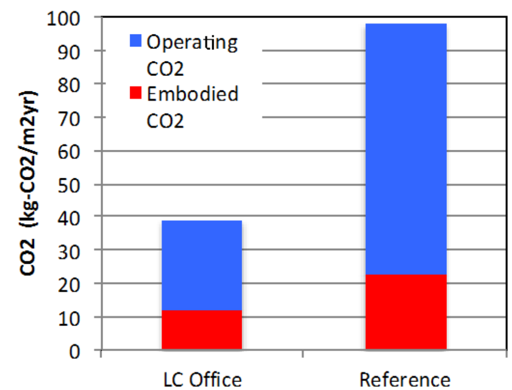


Fig 5 Embodied GHG and Operating CO_2
Building life: 100 years for LC Office,
50 years for reference

Fig.6 and Table 2 show EE and EG of all building elements, part of building elements and skeleton.

Based on building cost estimation data, complete building data are used to calculate EE and EG of all building elements.

EE and EG of Skeleton are about 62-72% of EE and EC of all element, and EE and EG of part of elements are about 78-89% of all elements.

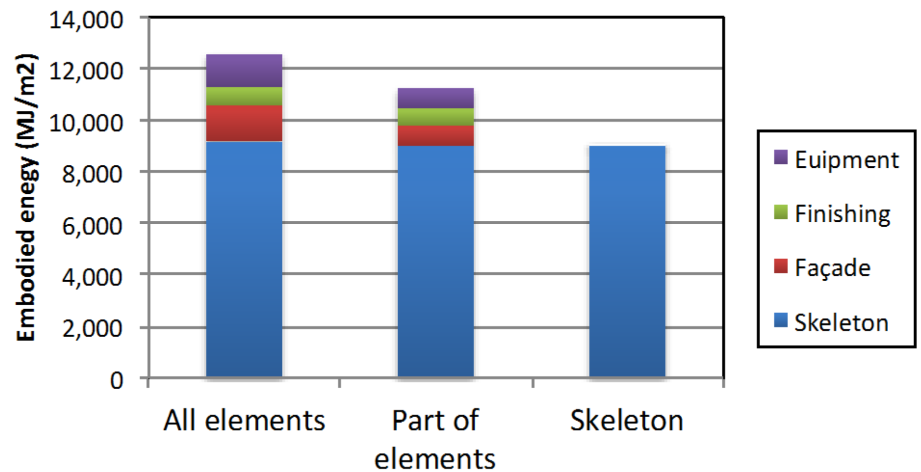


Fig. 6 Embodied energy

Table 2 Embodied energy and greenhouse gas

	All elements	Part of elements	Skeleton
Number of building elements	284	47	25
Embodied energy (MJ/m2)	12,573 (100%)	11,254 (89%)	9,000 (72%)
Embodied GHG (kg-CO2/m2)	1,182 (100%)	921 (78%)	744 (62%)

Importance of Prolongation of building life time and completeness buidling data

Prolongation of building affects EE and EG. EE and EG of LC office increases 5-7% larger than reference building. When EE and EG are normalized annually, EE and EG of LC office reduced to 50% compare to the reference building.
Building data completeness also affects EE and EG. When it accounts skeleton of building, its value evaluates 60-70% of EE and EG of all building elements.

Key issues related to Annex 57:
5.1 LCA/EE+EG integrated into the design process, different steps and different decisions
5.2 Development work to facilitate the consideration of LC thinking/EE/EG in the design process

Case study JP7
Renovation Office Building

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

There are clearly large differences of energy use and energy intensity between renovation and reconstruction project. As such, the decision whether an existing building should be upgraded or replaced by new one based on the environmental and economical point of view requires careful consideration at the planning phase.

With the renovation case, the total amount of energy use and greenhouse gas emissions were approximately 3.8 GJ/m2 and 306kg-CO2/m2 respectively. With the reconstruction case, the total amount of energy use and greenhouse gas emissions were approximately 11.2GJ/m2 and 966kg-CO2/m2 respectively.

REFERENCE STUDY PERIOD

	Renovation	Reconstruction	
EE	3.8	11.2	GJ/m^2_{GFA}
EG	306	966	kg CO_2 equiv. $/m^2_{GFA}$

OBJECTIVES OF CASE STUDY

This study quantifies the embodied energy and embodied greenhouse gas associated with upgrading or replacing an existing office building, and provides reference data for project planning of renovation or reconstruction projects. To compare the environmental loadings of renovation and reconstruction alternatives, two office buildings of the same size were selected as case study.

The study evaluates:

- The Embodied Energy and Embodied greenhouse gas from product stage to construction stage, demolition, transportation of waste and disposal of wastes.
- The impacts related to renovation and new construction
- Evaluation all building elements

BUILDING KEY FACTS

Intended use: Office, energy saving building
Size: 1,1187 m^2 GFA
Location Tokyo, Japan
Architect: Obayashi Corporation
Building year: Constructed in 1961 and renovated in 1999

Before renovation

After renovation

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	X	X				X	X			X	X			

Production and construction stage modeling:
All impacts from the raw material extraction and the manufacturing of the building materials are included, because the calculation is based on intensity of 1995 I-O table in Japan.

Renovation and construction data were analyzed to obtain the embodied energy use and embodied greenhouse gas emissions associated with each case study building. The analysis was extended to includes the energy use and greenhouse gas emissions associated with demolition, transportation of waste and disposal of wastes.

LCA BACKGROUND

Reference study period: not applicable
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: 1995 I-O table in Japan
Energy supply: not applicable
Standards/guidelines: not applicable

REFERENCES

[1] Yamaguchi, T.Ikeda, N. Yokoo, T.Oka, Study on the Effects to the Environment due to Retrofit or Reconstruction of an Existing Office Building, J. Environ. Eng., AIJ, No.566 (2003) 1-7

[2] N. Yokoo, K.Yamaguchi, T.Oka, R.Cole, A study on the environmental loads associated with upgrading or replacing an existing office building, Proceedings of CIB World Building Congress 2004, Toronto

THE BUILDING

The renovation project (Bldg. A) was built in 1961 and renovated to improve its energy performance in 1999. The main renovation features, shown in Figure 1 and Table 2, were the replacement of all external and interior finishing and its heating and cooling distribution system and electrical systems. The reconstruction project is an office building (Bldg. B) was constructed in 2000. The size and structure of the reconstruction building are similar to the renovated building.

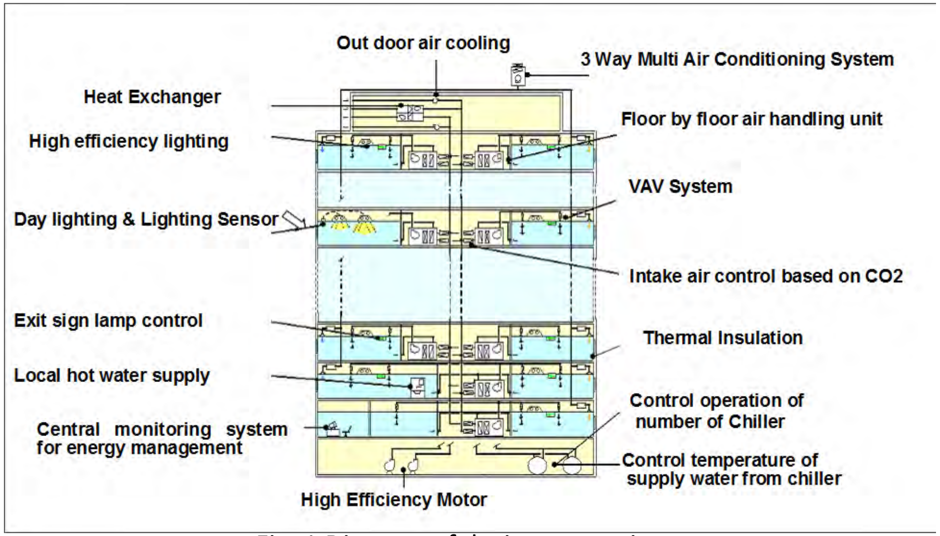


Fig. 1 Diagram of design strategies
Source: K.Yamaguchi, 2004

MATERIAL USE AND QUANTITIES

Main building materials are follows;

	Building A	Building B
Concrete (m3/m2):	0.06	0.82
Steel (kg/m2):	0.38	115.01
Aluminum(kg/m2):	4.05	1.26
Glass (kg/m2):	3.09	11.47

© Obayashi Corporation

Table 1 Main feature of renovation in Building A

			Before renovation	After renovation
Exterior			Aluminum panel, Double sliding sash	Aluminum CW, Vertical rotating band window
Interior	EV hall	Floor	Vinyl Tile	Double floor, Tile carpet
		Wall	Marble, Vinyl cloth	Cleaned Marble, Vinyl cloth
		Ceiling	Integrated ceiling	Rock wool sound absorbing board
	Office	Floor	Vinyl Tile	Double floor, Tile carpet
		Wall	Paint	Vinyl cloth
		Ceiling	Sound absorbing textile finishing	Rock wool sound absorbing board
	Lavatory	Floor	Mosaic tile	Homogeneous tile
		Wall	Tile	Steel panel
		Ceiling	Painted flexible board	Rock wool sound absorbing board
Electric equipment			All equipments are replaced new one	
Water supply equipment	Water supply		Elevated tank feed system	Pressurized water supply
	Water receiving Tank		Underground pit	FRP water tank
	Water supply pipe		All equipments are replaced new one	
Drainage equipment, Hot water supply, Sanitary fixture			All equipments are replaced new one	
Fire suppression equipment			Use of existing equipment	
Heating and cooling plant			Use of existing equipment	
Air Conditioning Equipment			Central 2 way single duct system	Interior: Floor by floor 2 way air handling +VAV
			Building Multi system partly	Perimeter: Packaged air conditioning
Transportation equipment			All equipments are replaced new one	

The calculation methods is as follows;

- The embodied energy /greenhouse gas is obtained from the analysis 1995 Input/Output tables in Japan. The IO tables of Japan consist of 400 industrial sectors.
- Building materials and quantities data are obtained by using building cost data.
- Reference building are assumed based on actual building data.

Renovation work

The renovation work on Bldg. A was extensive in nature and the majority of the building components were replaced except for the building structure, heating and cooling plant and fire suppression equipment. The energy and greenhouse gas emissions figures associated with the renovation includes refurbishments, transport of wastes and disposal wastes.

Reconstruction work

Reconstruction work in Bldg. B includes demolition work, transport waste and disposal waste, and new construction work. The environmental loads associated with demolition of existing building, transport of wastes and disposal of wastes were calculated based on the estimation documents of each works and a questionnaire survey administered to disposal facilities staff:

•The total amount of demolished concrete was derived by referencing data from similar demolition projects.

•The total amount of fuel consumption required in the concrete demolition and intermediary disposal facility was calculated.

•The energy consumption of transportation between construction site and intermediary disposal waste facility, and subsequently to the final disposal facility were calculated base on the fuel consumption, haulage distances and frequency of trips.

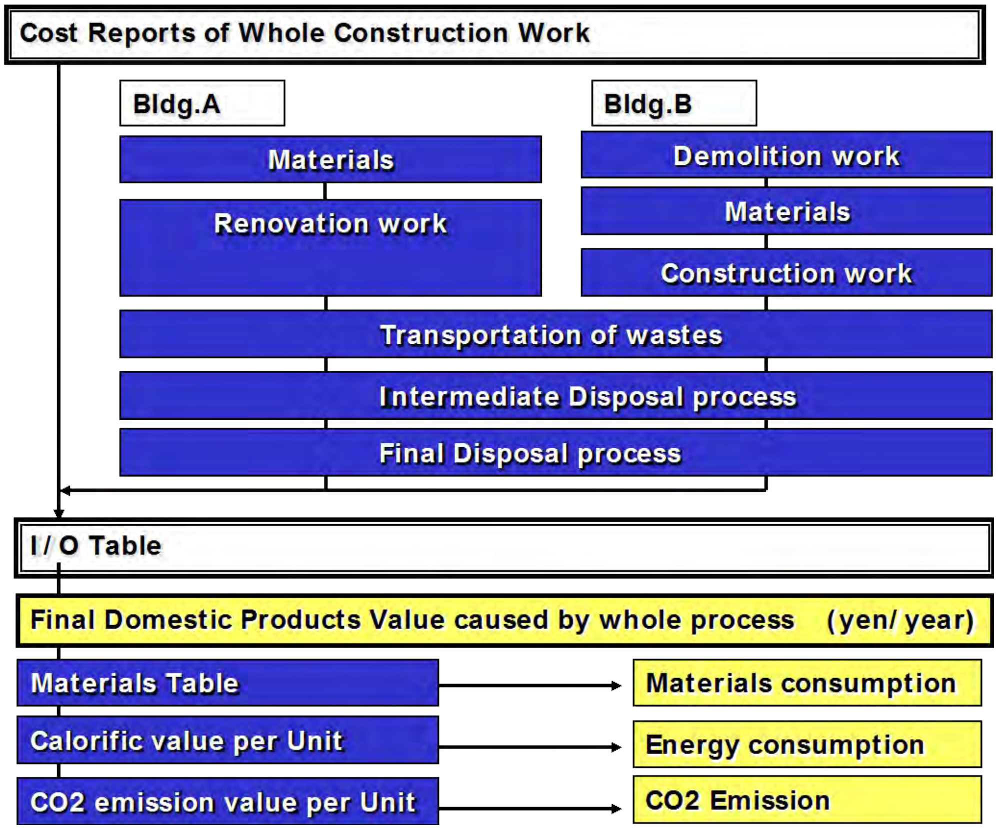


Fig.2 Evaluation flow

Embodied energy

Fig. 3 shows the energy use of renovation of Bldg. A and reconstruction of Bldg. B:

•The energy use associated with renovation is about 3,769 MJ/m2 and reconstruction is approximately 14,697 MJ/m2.

•The energy use associated with structural work of reconstruction is 5,422 MJ/m2, which is larger than the total embodied energy use of the renovation.

•The energy use associated with finishing of Bldg. B is larger than Bldg. A. This is because Bldg. B used more materials with higher embodied energy content than Bldg. A.

•If the quality of finishing of Bldg. B is equivalent to Bldg. A, energy use associated with reconstruction of Bldg. B is approximately 1,1230 MJ/m2.

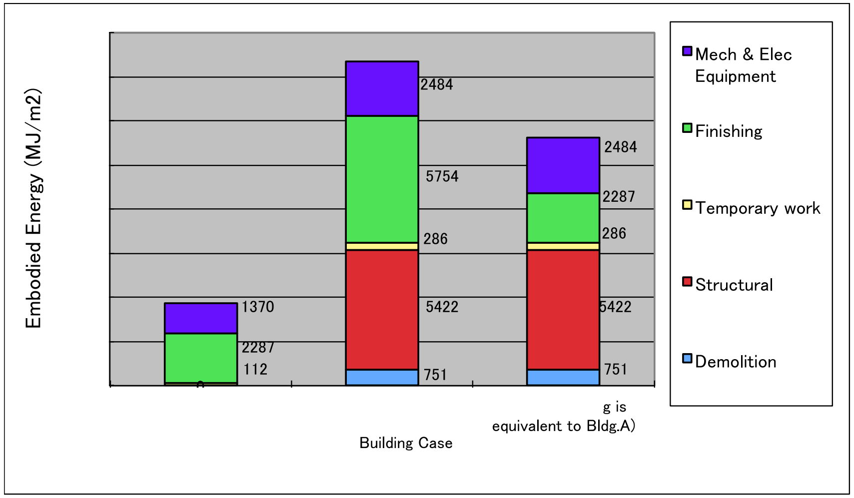


Fig.3 Embodied energy

Embodied greenhouse gas

Fig.4 shows greenhouse gas emissions due to renovation of Bldg. A and reconstruction of Bldg. B:

•The overall trend of greenhouse gas emissions of Bldg. A and Bldg. B shows similar trends to energy consumption.

•Total greenhouse gas emissions associated with the renovation is approximately 306 kg-CO2/m2 and reconstruction is about 1,233 kg-CO2/m2.

•If the finishing of Bldg. B is equivalent to Bldg. A, greenhouse gas emissions due to reconstruction work of Bldg. B are approximately 966 kg-CO2/m2.

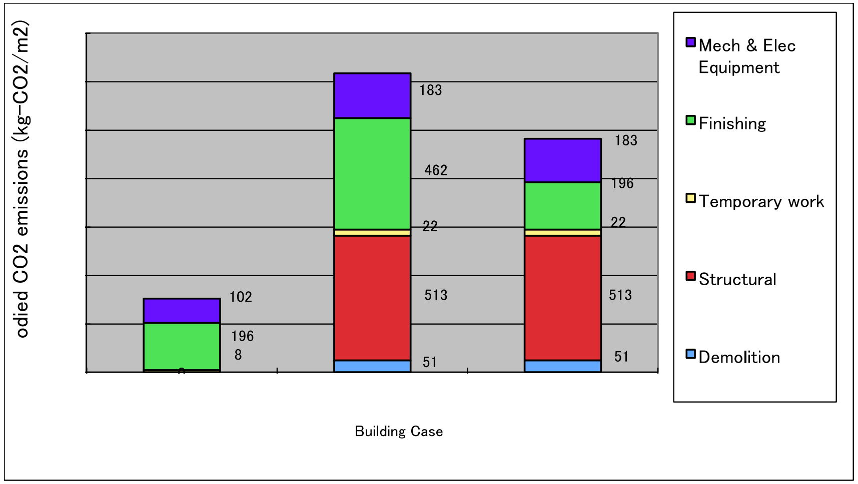


Fig. 4 Embodied greenhouse gas

South Korea

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials
3.1 Length of reference study period

Case study KR1
Traditional House(Han-ok) - Korea

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was performed with a Reference Study Period (RFS) of 30 years. The study showed that the building materials in a traditional building contributed with **11.4%** of Global Warming Potential (GWP) with RFS of **30 years**.

Due to natural materials like mud, sand and wood, the building's EE and EG seem to be very low compare to other conventional buildings, but the energy performance of the building is very poor to maintain indoor temperature as up to 20℃. This makes the building require more heating energy.

Evaluation of building components showed that the majority of EE and EG are covered by few materials like Korean roof tiles(39.1%), cement (32%) and lumber (27%) during production stage, while riprap, sand, mud and granite stone are used by a large amount by weight.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate Global Warming Potential (GWP) related to the life cycle of a Han-ok in Korea. The study evaluates:

- The significance of different life cycle stages and processes
- The materials contribution to the impacts compared to the total impacts
- The Embodied Green House Gases (EG)
- The impacts related to different building components
- The impacts related to different building materials

Additionally the study evaluates:
- The length of the reference study period on the results of the study

BUILDING KEY FACTS

Intended use: Han-ok for residential life
Size: 85.07m^2 GFA
Location: 11-22 Gahoe-Dong, Seoul, Republic of Korea
Building year: 1930's and remodeling(Refurbishment)

KICT 한국건설기술연구원

Building life cycle stages included in the study, according to EN15978

A 1-3 Product stage			A 4-5 Construction process stage		B 1-7 Use stage							C 1-4 End-of-Life				D Next pro duct syst em
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 recyclin g potential
X	X	X	X					X		X				X	X	

LCA BACKGROUND

Reference study period: 30 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Korean LCI Database, Process database from site
Energy supply: Thermal energy from LNG, electricity from KEPCO
Standards/guidelines: ISO 14040, Korean LCA guideline

REFERENCES

Ministry of Land and Infrastructure, The study on activation policy and environmental assessment on traditional housing, Han-ok, 2011

Production and construction stage modeling:
All impacts from the raw material extraction and the manufacturing of the building materials are included. The data were collected by LCA for building materials in production and construction.
In construction stage, the data of power energy and construction equipment in site were evaluated with the amount of building materials or a sector of material freight by field survey or reference data, including transportation to the site. However, collecting accuracy data for energy and water consumption of installation work is excluded due to the difficulties of searching data sources. Those are remained as data gap.

Use stage modeling: The energy consumption in the ´building's operation stage is modeled with Eco2 which is an nhenergy simulation program developed by KICT.
The assessment period is 30 years including use, replacement, and operational energy use. Replaced materials are calculated by replacement scenario on the basis of Korean Housing Management Regulation.

End of life stage and next product system modeling:
Total amount of waste resources from disposal of the Han-ok are calculated by adding total amount of building materials for the initial construction with refurbished materials, classifying them by groups of same materials.
Because it is difficult to get information on real recycling methods for construction waste, statistical data are used to calculate for recycling process of construction wastes, as adopting recycle rate(96.7%), reclamation rate(2.6%), incineration rate(0.7%). These ratio are provided by the Ministry of Environment, and in this study 2005 data are adapted for the modeling.

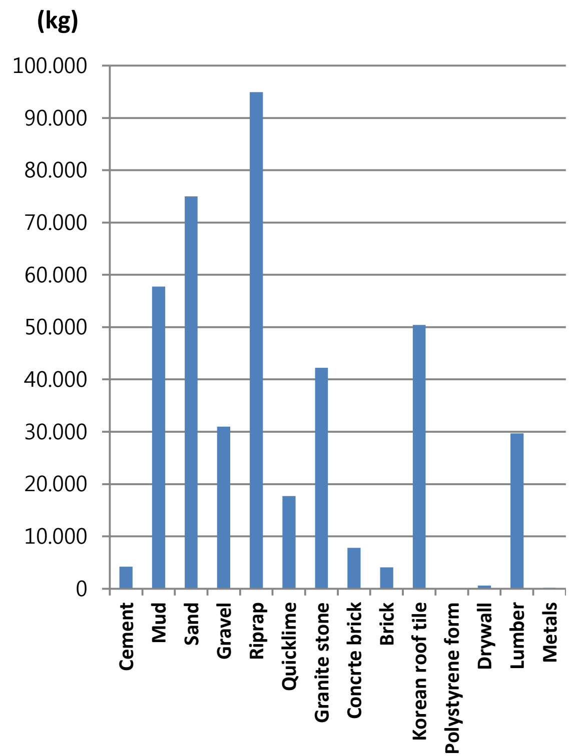
THE BUILDING

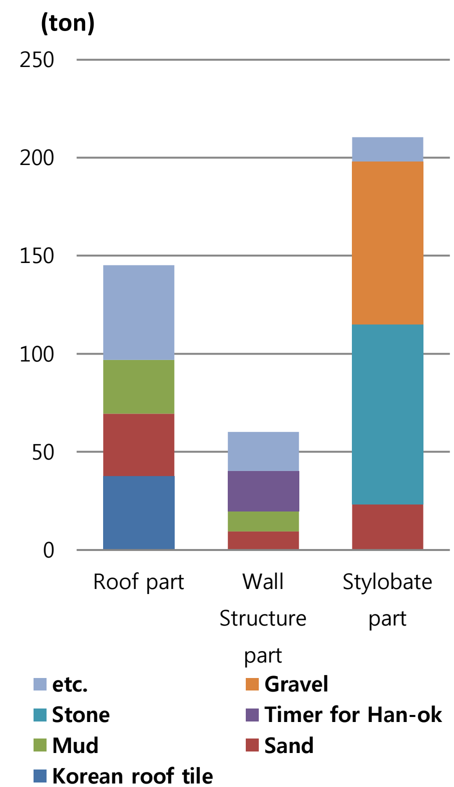
- Was built in 1930’ and totally reconstructed in early 2000 to fit the lifestyle of contemporary housing. Building products and materials used for the building are mainly from nature, but roof tiles are manufactured in a factory while traditional one are hand-made and sundried.
- Han-ok in Gahoe-Dong was constructed following a traditional process and using traditional building materials as possible as they can except glasses, kitchen furniture, lighting and so on.

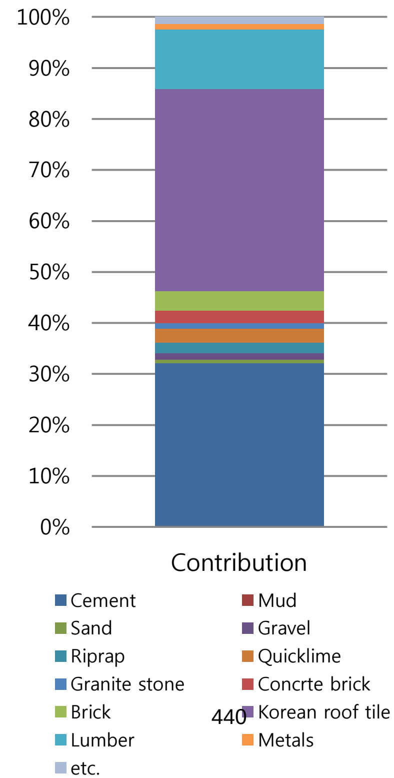
MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 417 tons or 4,886 kg/m$^2_{GFA}$

Riprap: 94,962 kg(22.8%)
Sand: 75,024.54 kg(18.1%)
Mud: 57,742.08 kg (13.9%)
Korean roof tile: 50,418.52 kg(12.1%)
Granite stone: 42,245.7 kg(10.2%)
Gravel: 30,954.79 kg(7.4%)
Lumber: 29,715.17 kg(7.1%)
Quicklime: 17,698.31 kg(4.3%)
Concrete brick: 7,817.33 kg(1.9%)
Cement: 4,195.33 kg(1.0%)
Brick: 4,607.83 kg(1.0%)







RESULTS OF STUDY PERIOD = 30 YEARS

Global Warming Potential

142.2 kg CO_2 equiv. /m^2_{GFA}/year

- construction materials: 11.4% (included replacement)
- operational energy: 85.67%

Embodied Green House Gases:

10.7 kg CO_2 equiv. /m^2_{GFA}/year

Impact categories evaluated

GWP: Global warming potential

Stage	[kg-CO2eq.] Han-ok
Production	24,784.78
Construction	3,548.17
Use	294,576.62
Disposal	6,091.84
Total	329,001.41

Stage	[kg-CO2eq./m2] Han-ok
Production	321.34
Construction	46.00
Use	3,774.62
Disposal	78.98
Total	4,265.54

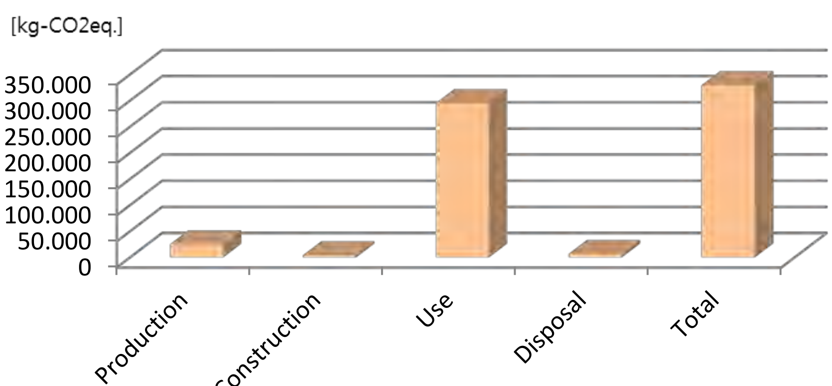


Figure 3: LCCO2 emission of Han-ok

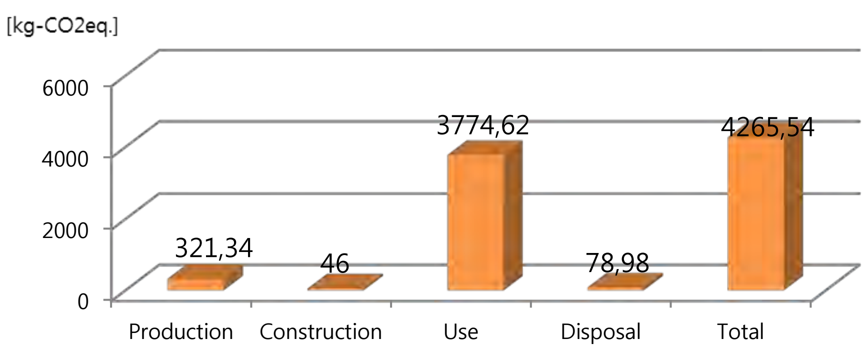


Figure 3: LCCO2 emission of Han-ok(per unit area)

Conclusion

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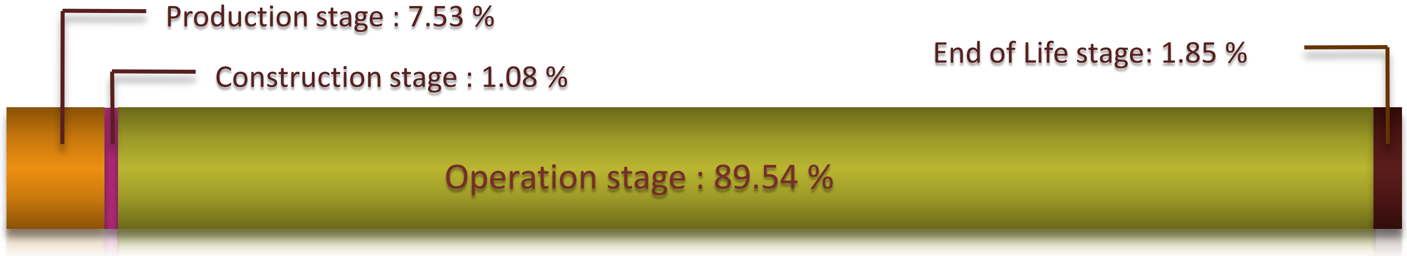
Using period: 30 years



Conclusion:

As a result of LCCO2 assessment on Han-ok in Gahoe-Dong,
the contribution from life cycle is divided into four stages which are production stage(7.53%), construction stage(1.08%), operation stage(89.54%) and end of life stage(1.85%).

During production stage, the impact of Korean roof tile contributes by 39.61% and cement by 32.08%. Operational stage contributes by 89.5% during the total life cycle stage of Han-ok and this means that the EE and EG of a traditional building to be low due to the use of natural materials, but it needs to enhance their energy performance to reduce total greenhouse gas emission.

To reduce the EG of Han-ok, replacement of Korean roof tiles to other less greenhouse gas emission material are needed and to reduce total emission it requires to improve energy performance of the building.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials
3.1 Length of reference study period

Case study KR2
Multi-family residential building- Korea

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was performed with a Reference Study Period (RFS) of 30 years. The study building was constructed with reinforced concrete structure and the total amount of assessment result was divided by one unit including 3 rooms, 1 living room, 1 kitchen and dining.

The study showed that the building materials contributed with **19.2%** of Global Warming Potential (GWP) with RFS of **30 years**.

Embodied Green House Gases (EG) was evaluated . The length of RFS is an important factor for the results, because more RFS means less EG.

Evaluation of the different building materials showed that for EG, concrete contributed with 72.31% and cement(brick) with 8.55% and this means that in reinforced concrete structure concrete and concrete products should be main consideration for Design for Environment.

OBJECTIVES OF CASE STUDY

Multi-family residential housing is a very popular type among residential buildings in Korea. Over 50% of population are living there. This study is to clarify the greenhouse ga s emission from the building and analyze the EE and EG related to the life cycle o f the building. The study evaluates:

- The significance of different life cycle stages and processes
- The materials contribution to the impacts compared to the total impacts
- The Embodied Green House Gases (EG)
- The impacts related to different building materials

Additionally the study evaluates:
- The length of the reference study period on the results of the study

BUILDING KEY FACTS

Intended use: Multi-family residential building(Typical)
Size: 85 m^2 GFA/1 family (60 family, 5,040 m^2/study building)
Location: Seoul, South Korea
Building year: Completed 2005

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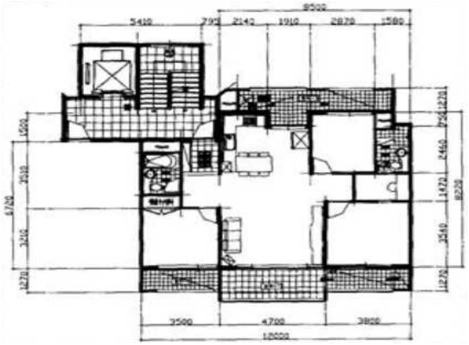

Floor plan for a single unit

Source: LH Corp, Korea

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						X		X				X	X	

Production and construction stage modeling: All impacts from production stage are included. The Korean LCI DB were applied to calculate the EG of the stage. In construction stage, the data of power energy and construction equipment in site were evaluated with the amount of building materials including transportation to the site.
However, collecting accuracy data for energy and water consumption of installation work is excluded due to the difficulties of searching data sources. Those are remained as data gap.

Operation stage modeling: The energy consumption in the building's operation stage is modeled with Eco2 which is an energy simulation program developed by KICT.
The assessment period is 30 years including use, replacement, and operational energy use. Replaced materials are calculated by replacement scenario on the basis of Korean Housing Management Regulation. The regulation is a kind of recommended guideline for maintenance engineers and companies.

End of life stage and next product system modeling: The majority of materials used in this study building are concrete work related and more than 90% of waste concrete are recycled as aggregate. Statistical data from the Ministry of Environment are applied to analyze the EOL stage. In the analysis, equipment operation and transportation of waste are considered, but reuse of waste to other building project are not considered. The possibility of material reuse is excluded and remained as data gap.

LCA BACKGROUND

Reference study period: 30 years
Calculation of Energy: Non-renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: Korean LCI DB
Energy supply: District Heating, KEPCO
Standards/guidelines: ISO 14040, LCA Guideline

REFERENCES

Ministry of Land and Infrastructure, The study on activation policy and environmental assessment on traditional housing, Han-ok, 2011


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THE BUILDING

The study building is built with reinforced concrete structure. The building has 60 households and ea ch household has a net area of 85㎡. The building uses district heating supplied by a public corp and installs air conditioning equipments by the needs of individual households.

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 12,027.9 tons or 2,386.5 kg/m^2_{GFA}.

Among the total amount of materials, concrete was used by 72.3%(8,697 ton) and cement brick by 8.5% (1,028 ton)(8.55%) when calculating by weight of materials. 5 main materials including concrete, cement, aggregate, timber and rebar cover more than 90% of total applied materials by weight.

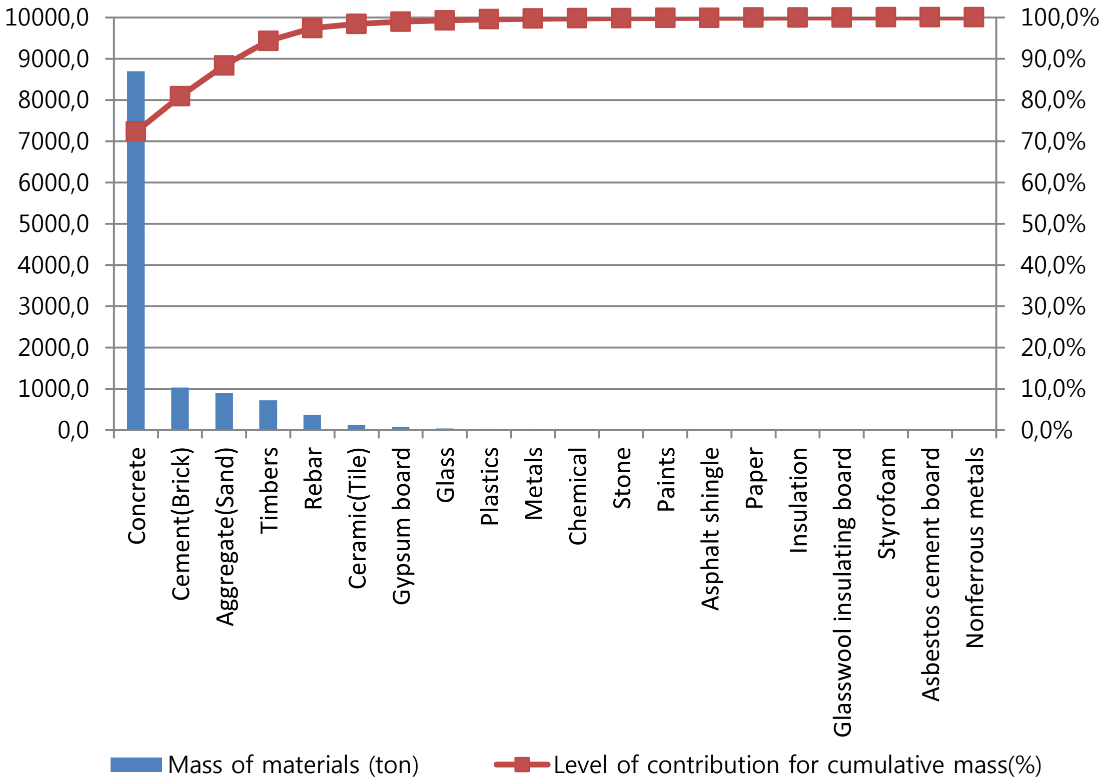


Figure 1: The mass of materials and level of contribution for cumulative mass by in putted materials for multi-family residential building

RESULTS OF STUDY PERIOD = 30 YEARS

Global Warming Potential

87.4 kgCO_2eq./m^2_{GFA}/year

- construction materials:

16.78 kgCO_2eq./m^2_{GFA}/year (19.2%)

- operation :

Electricity 20.62kgCO_2eq./m^2_{GFA}/year,
Heating(LNG) 44.23kgCO_2eq./m^2_{GFA}/year

Embodied Green House Gases:

16.78 kg CO_2 equiv. /m^2_{GFA}/year

Impact categories evaluated

GWP: Global warming potential

	[kg-CO2eq.]
Production	2,566,758
Construction	244,543
Operation	10,260,951
End of life	300,076
Total	13,372,328

	[kg-CO2eq./m^2]
Production	503.28
Construction	47.95
Operation	2,011.95
End of life	58.84
Total	2,622.02

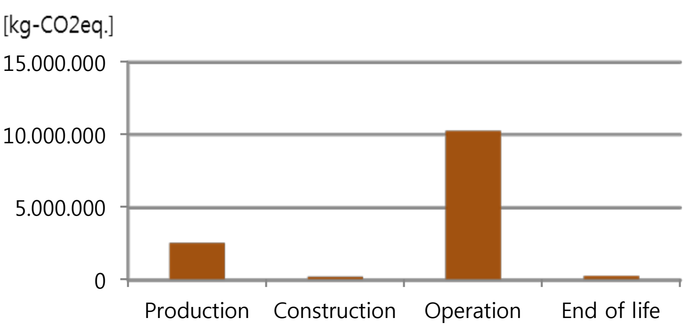


Figure 1: Total amount of CO2eq emission by life cycle sta ge for multi-family residential building

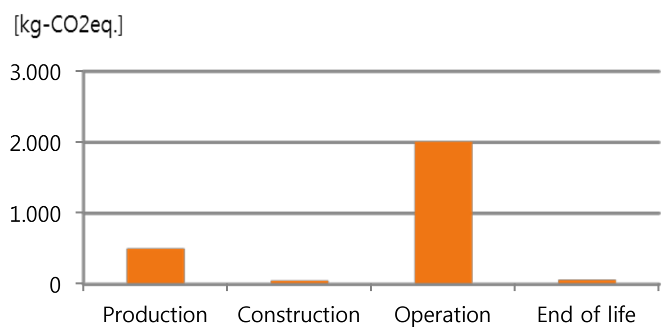


Figure 2: Total amount of CO2eq emissions by life cycle stage for multi-family residential building (per unit area)

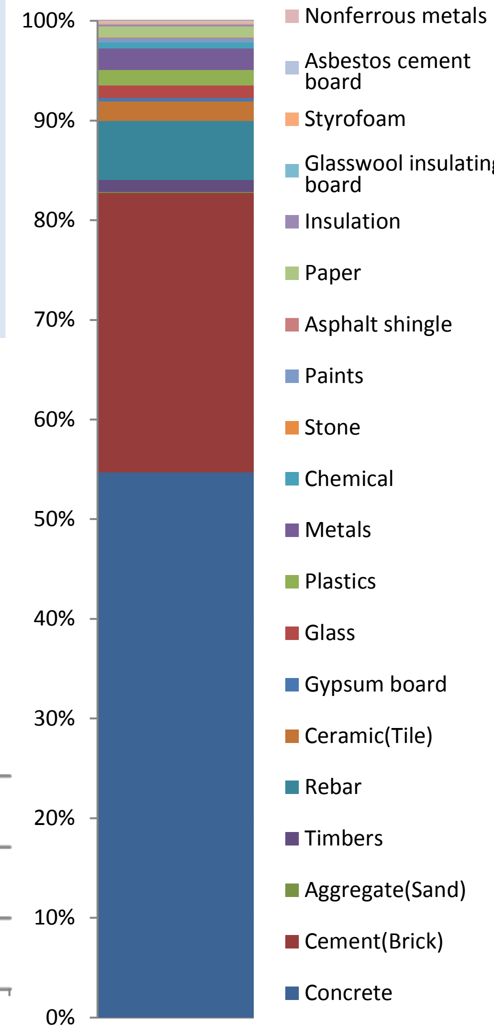
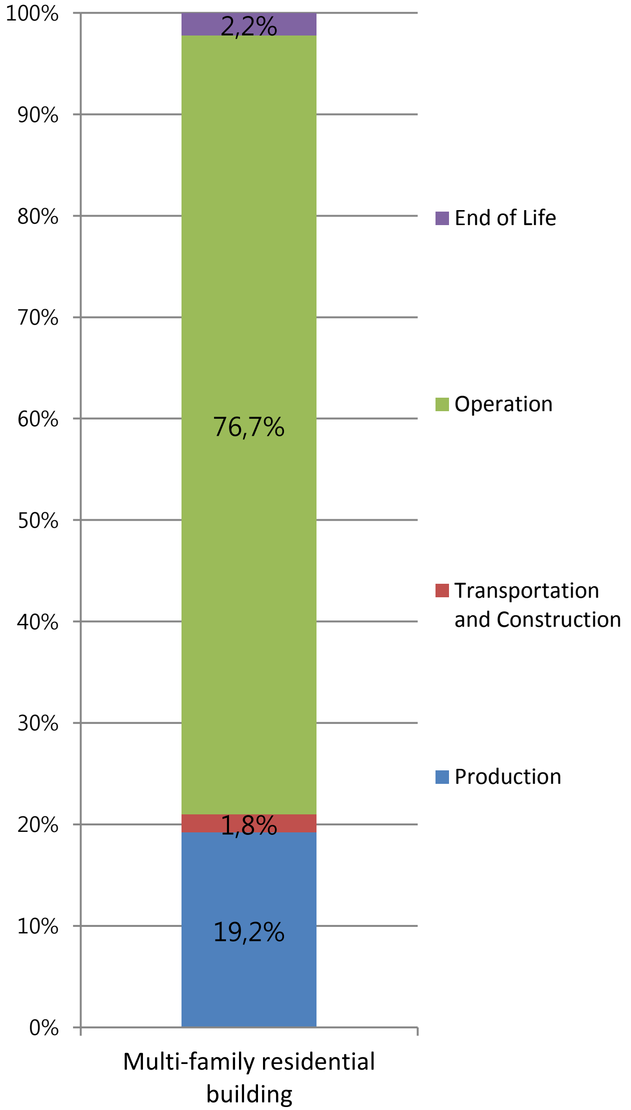


Figure 3: Contribution of CO2eq e mission by building materials

Conclusion



The total emission of greenhouse gas for the building was calculated as 13,372,328kgCO2e and an amount of 222,872kgCO2eq was calculated as for a sing family house. Among the total emission, the operational stage covers 76.7% of total emission by the 30yrs of RFS.

The EG of the study building was calculated by 23.3% including transportation, and the initial EE of the building(production stage) was calculated by 19.2%. During the end of life stage, 2.2% of EG was accounted including deconstruction, recycling and disposal. Reuse of the building component were not considered in the calculation.

During service life(30 years), greenhouse gas emissions from District Heating (LNG) was calculated as 112,791kgCO2eq per household. It covers 66% of the emission from the stage of use and maintenance and 51% from whole life cycle stages.

It is important to reduce energy consumption by improving thermal insulation property, but reduce EE and EG it is needed to replace reinforced concrete structures with low carbon materials to develop less emissive concrete materials.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials
3.1 Length of reference study period

Case study KR3
Posco Green Bulding- Korea

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The POSCO Green Building was built in 2013 as a pilot project to experiment energy performance and durability of steel structure office & residential building. In the building reused beams and plates were applied to reduce EE and EG. The LCA was performed with a Reference Study Period (RFS) of 50 and 100 years respectively.

The study shows that the building materials contributed with 12.86% of Global Warming Potential (GWP) with RFS of 50 years, and in the case of 100years it is decreased to 6.9%. This means reused building products decrease the EG compare to conventional building and durability of building products can reduce EE and EG from a life cycle of building.

Comparison of different building type showed the significance of recycling materials and using renewable energy

Evaluation of the different building materials by different building types showed that steel plate contributed with 65% , slag ready mixed concrete with 21% and damper with 5% to the total greenhouse gas emission of the building.

OBJECTIVES OF CASE STUDY

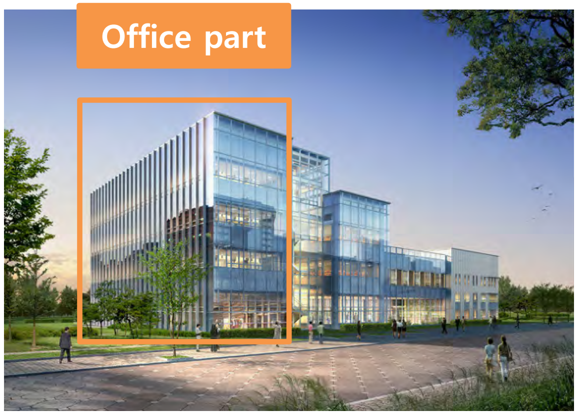
To evaluate the Global Warming Potential (GWP) related to the life cycle of a steel framed of fice building. The study evaluates:

- The significance of different life cycle stages and processes
- The materials contribution to the impacts compared to the total impacts
- The Embodied Green House Gases (EG)
- The impacts related to different building materials

Additionally the study evaluates:
- The length of the reference study period on the results of the study

BUILDING KEY FACTS

Intended use: OFFICE
Structure Type: Steel-frame structure
Size: 3,159.43 m² GFA
Location: Incheon, Korea
Building year: Completed 2013. 11



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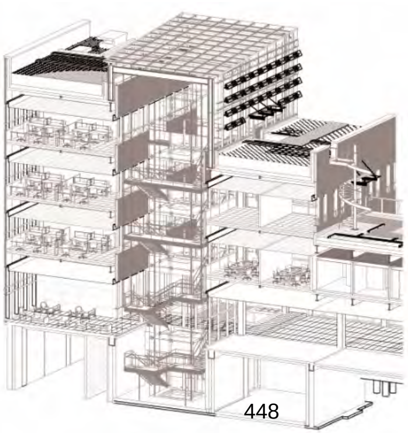


Source: RIST, POSCO

Building life cycle stages included in the study, according to EN15978

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	X	X						X					X	

LCA BACKGROUND

Reference study period: 50 and 100 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP at 100 years: kgCO_2-eq./m².yr (IPCC for 2007)
Databases used: KLCI, Carbon Labeling, IPCC
Energy supply: Thermal energy from electricity, Renewable energy
Standards/guidelines:

REFERENCES

Korea Institute of Construction Technology, The study on GHG reduction and LCA on POSCO GREEN Building, RIST, 2012.

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials in main building elements (structural parts) are included. The 95% cut-off rule was applied to the input materials by weight. The slag ready mixed concrete is manufactured with industrial by-product and the GHG emission unit is separately estimated compare to ordinary ready-mixed concrete.
For construction stage, the data of power energy and construction equipment in site were applied by the amount of building materials used. Reused products such as steel plate, shaped-beam and damping component are calculated just for transportation and installation works.

Operation stage modeling: The service life of building sets 50 years and 100years. The energy consumption of operational stage was calculated by the energy modeling program with given conditions. The consumption of electricity was reduced to 80% by using renewable energy production system.

End of life stage and next product system modeling: The environmental loads are considered from using of equipment in dismantling of components, transportation and processing in recycling or reclaimed to land.

THE BUILDING

The four-story office building having structural component with slag-concrete and steel framed structure was designed to reduce EE and EG, targeting a low carbon building. construction steel. Several components, such as steel plate, shaped steel and damping component are also designed to reuse after 50 years of usage.

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 521 kg/m^2_{GFA} building with recycle and reuse materials.

Materials:

Slag ready mixed concrete: 339 kg (65.1%)

Steel Plate: 132 kg (25.3%)

BH shape steel: 18kg (3.5%)

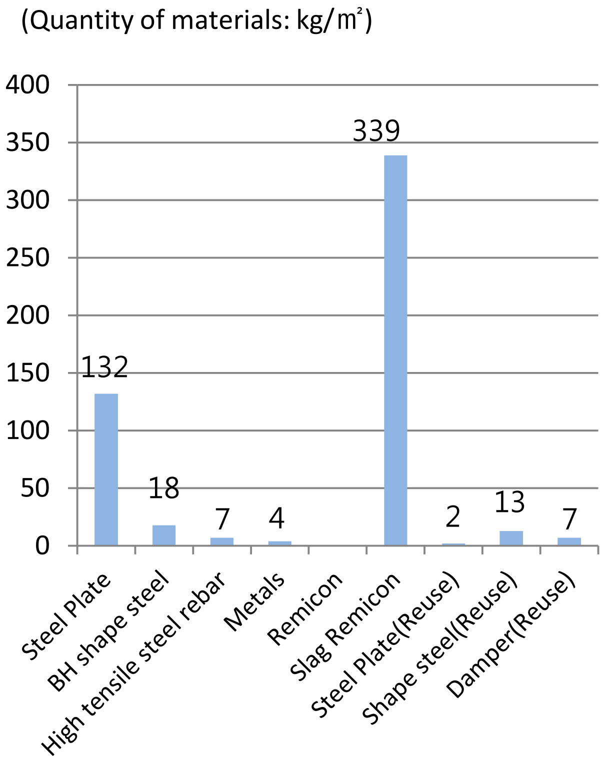
High tensile steel rebar: 7kg (1.3%)

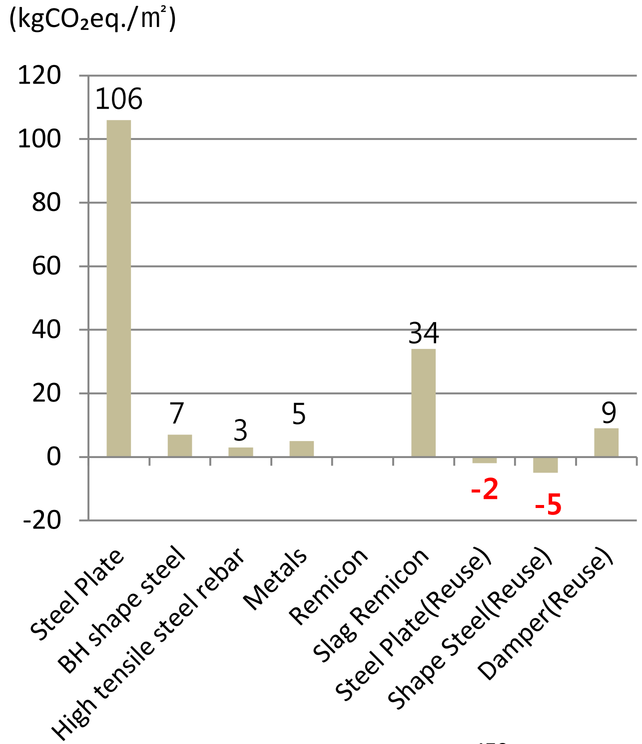
Metals: 0.8%

Reused shape steel: 13kg (2.5%)

Reused damper: 7kg (1.3%)

Reused steel plate: 2kg (0.4%)





RESULTS OF STUDY PERIOD = 50, 100 YEARS

Global Warming Potential (50 yrs)

49.13 kg CO_2 equiv. /m^2_{GFA}/year

- construction materials: 12.86%
- operational energy: 85.53%

Embodied Green House Gases:

6.32 kg CO_2 equiv. /m^2_{GFA}/year

Impact categories evaluated

GWP: Global warming potential

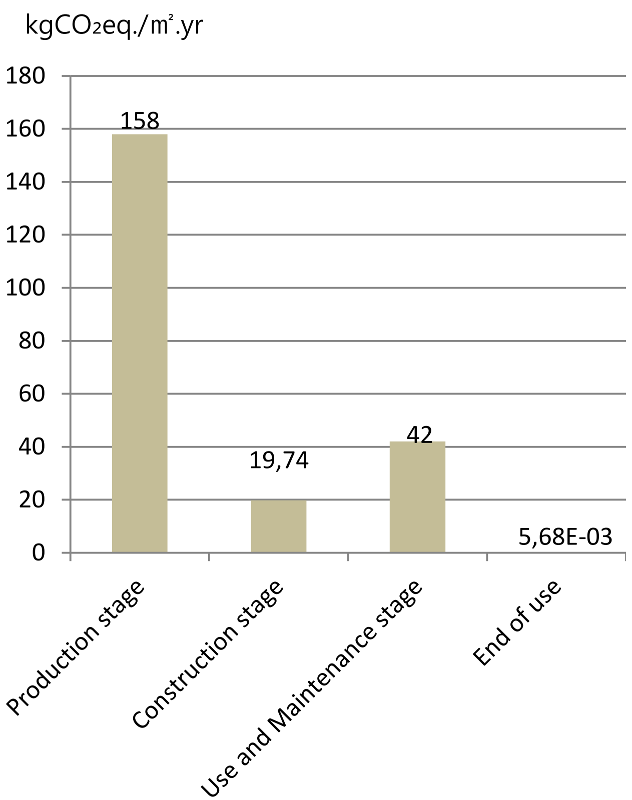


Figure 1: CO_2 emissions from the first project year

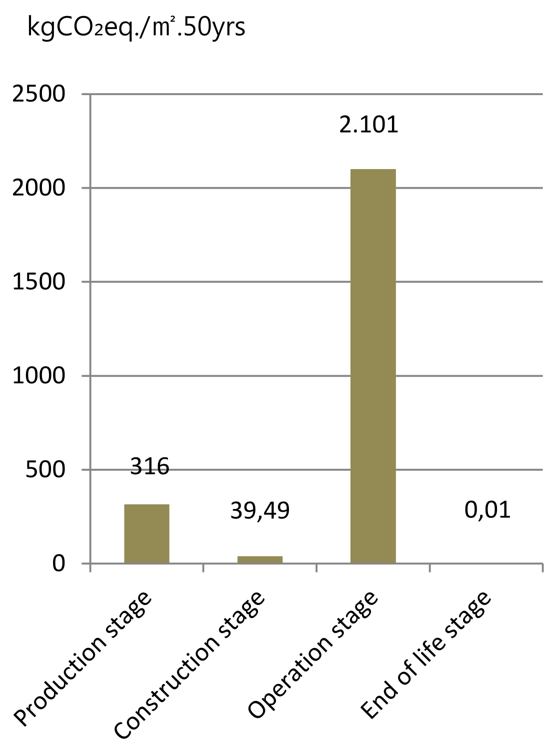


Figure 2: CO_2 emissions during 50years

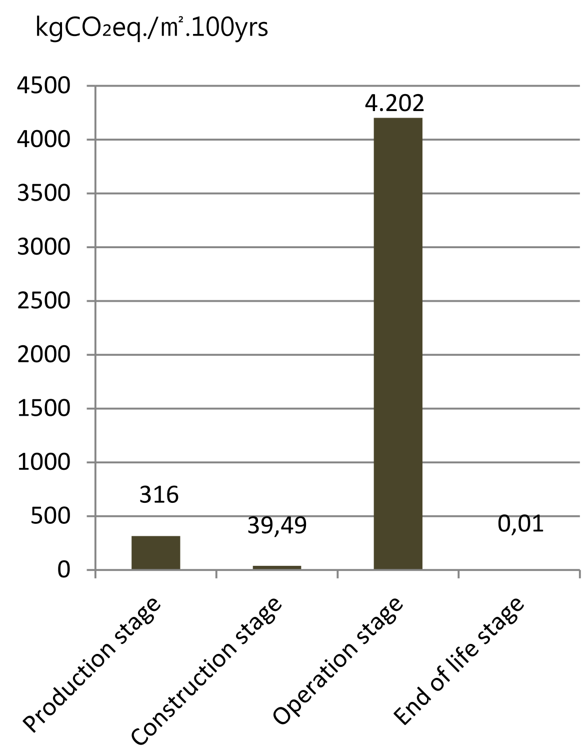
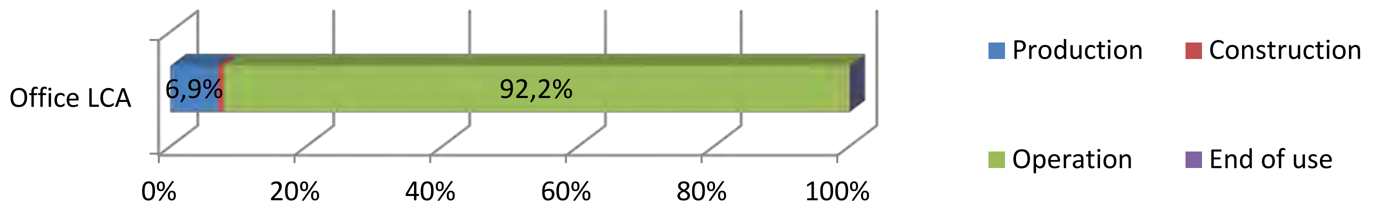


Figure 4: CO_2 emissions during 100years

RESULTS OF COMPARISON



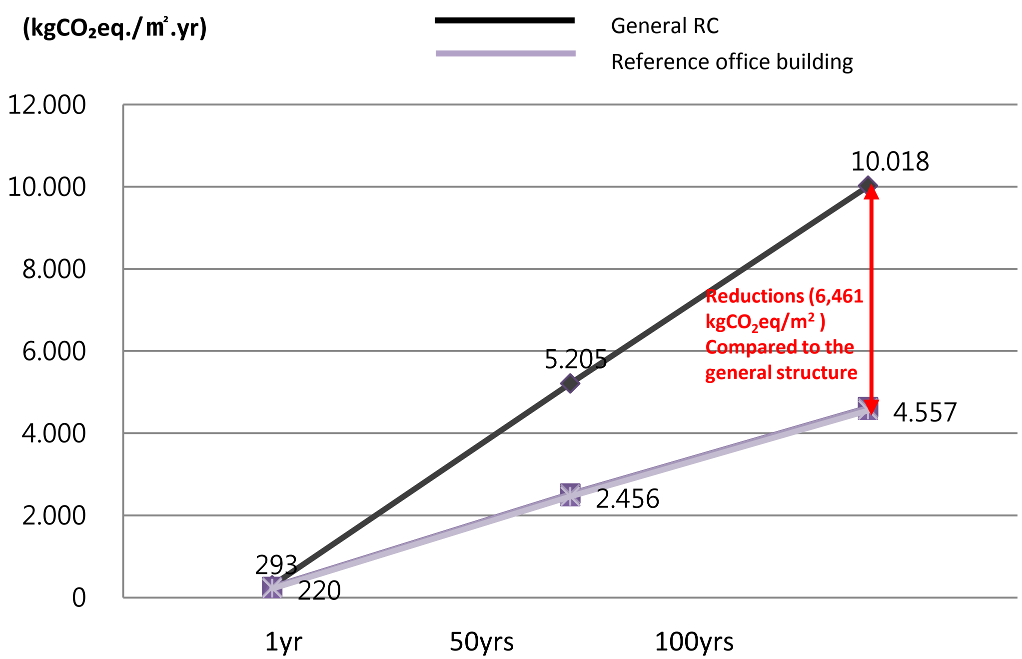


Figure 2: Comparison of CO_2eq emissions between reference study office building and conventional RC structure building

Conclusion:

The avoided impact was applied for reused and recycled materials during the assessment with RFS of 50 and 100 years.
The study on the building shows that the emission of greenhouse gas by the stage of production covers 6.9% of a total emissions, while the stage of operation by 92.2%.
This shows that reuse and recycling can be effective methods to decrease EE and EG of a building due to the avoided impacts. Renewable energy generation is also effective way to reduce total greenhouse gas emissions and energy saving during a life cycle.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
1.1 Selection of building materials
3.1 Length of reference study period

Case study KR4
Timber framed house - Korea

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was performed with a Reference Study Period (RFS) of 30 years.

The study showed that the building materials which could be considered as Embodied Green House Gases(EG), contributed with **12.3%** of Global Warming Potential (GWP) with RFS of **30 years** among all greenhouse gas emissions from the case study**.**

The length of service life is an important factor for reducing EC of a building because operational energy covers the majority of increased greenhouse gas by the increase of RFS.

Evaluation of the different building materials showed that concrete contributed with 67.5% , timbers with 8.8% and rebar with 4.0 % to the embodied greenhouse gases. The amount of concrete use is larger than other timber house because floor heating system is built with concrete. Low carbon products for founding and slabs are needed to reduce EG.

OBJECTIVES OF CASE STUDY

A Life Cycle Assessment (LCA) was performed to evaluate environmental pe rformance of a timber framed house in Korea. The study evaluates:

- The significance of different life cycle stages and processes
- The materials contribution to the impacts
- Embodied Green House Gases(EG)
- The impacts related to different building components
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Detached house (Light weight timber frame

Size: 174m^2 GFA (1F 87.6m^2, 2F 86.4m^2)

Location: Incheon, South Korea

Architect: n/a

Building year: Completed 2008

Source: National Forest Service

KICT 한국건설기술연구원

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

A 1-3 Product stage			A 4-5 Construction process stage		B 1-7 Use stage							C 1-4 End-of-Life				D Next pro duct syst em
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						X		X				X	X	

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included. The data were collected by LCA for building materials in production and construction. In construction stage, the data of power energy and construction equipment in site were evaluated with the amount of building materials or a sector of material freight by field survey or reference data, including transportation to the site.
However, collecting accuracy data for energy and water consumption of installation work is excluded due to the difficulties of searching data sources. Those are remained as data gap.

Operation stage modeling: : The energy consumption in the building's operation stage is modeled with Eco2 which is an energy simulation program developed by KICT.
The assessment period is 30 years including use, replacement, and operational energy use. Replaced materials are calculated by replacement scenario on the basis of Korean Housing Management Regulation.

End of life stage and next product system modeling: Total amount of waste resources from disposal of the house are calculated by adding total amount of building materials for the initial construction with refurbished materials, classifying them by groups of same materials.
Because it is difficult to get information on real recycling methods for construction waste, statistical data are used to calculate for recycling process of construction wastes, as adopting recycle rate(96.7%), reclamation rate(2.6%), incineration rate(0.7%). These ratio are provided by the Ministry of Environment, and in this study 2005 data are adapted for the modeling.

LCA BACKGROUND

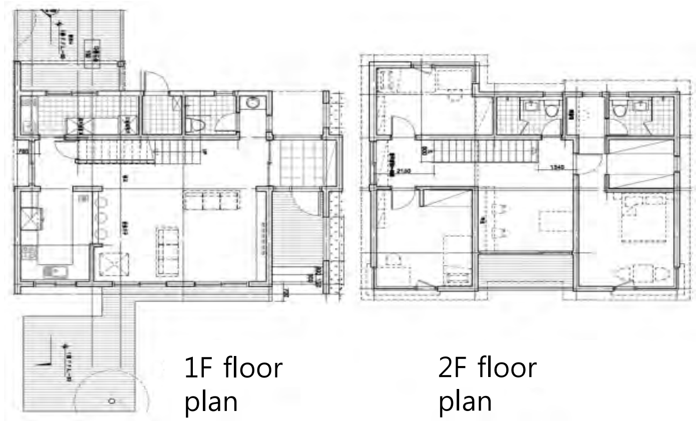
Reference study period: 30 years
Calculation of Energy: non-renewable energy, primary
Calculation of GWP: GWP 100years
Databases used: KLCI
Energy supply: Thermal energy from LNG, electricity from Korean electric
Standards/guidelines: ISO 14040s

REFERENCES

Ministry of Land and Infrastructure, The study on activation policy and environmental assessment on traditional housing, Han-ok, 2011

THE BUILDING

Has timber-framed structure with high performance insulations.



Source: National Forest Service

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 228.1 tons or 1,310 kg/m^2_{GFA}.

Concrete and timber products are used by 187.4 tons (82.2%) and 20.9 ton(9.2%) which covers the majority of materials.

The flooring system is built with wooden ondol-floor (floor heating system)with panel heating with EPS panels.

The wall structure is built with stud and plaster boards system including fiberglass insulation inside. Wallpaper is used for inner wall finishing.

For roof construction, structural plywood panels attached with anti-noise channel including fiberglass insulation are used under asphalt shingle roofing.

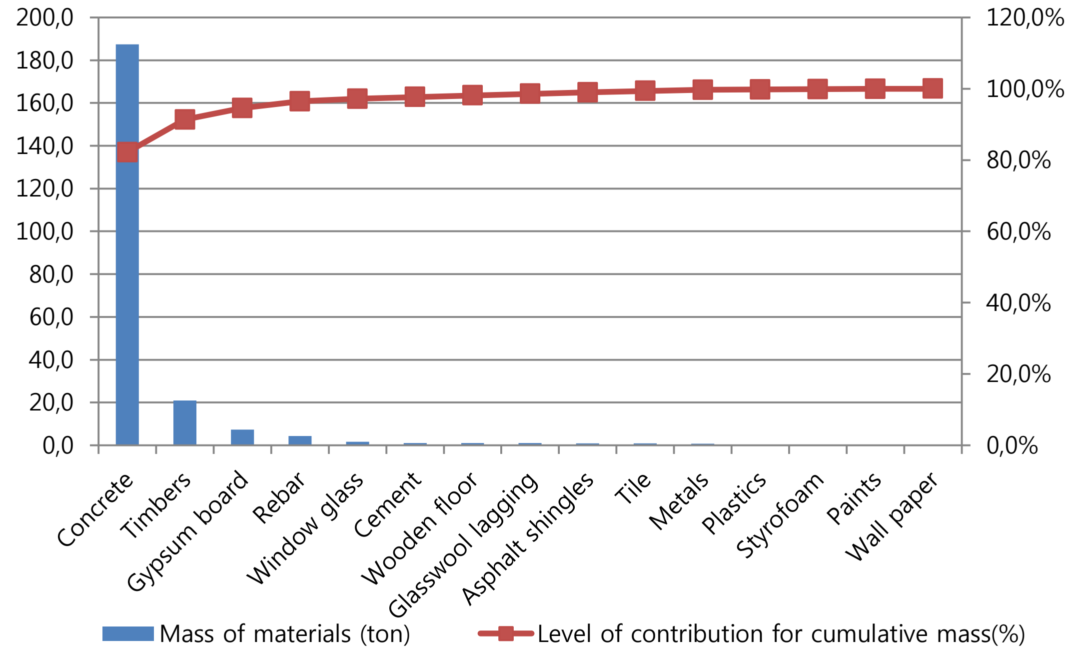


Figure 1: The mass of materials and level of contribution for cumulative mass by inputted materials for timber framed house

RESULTS OF STUDY PERIOD = 30 YEARS

Global Warming Potential

67.7 $kgCO_2eq./m^2_{GFA}/year$

- construction materials:

8.33 $kgCO_2eq./m^2_{GFA}/year$ (12.3%)

- operation :

Electricity 9.2 $kgCO_2eq./m^2_{GFA}/year$,
Heating(LNG) 45.9 $kgCO_2eq./m^2_{GFA}/year$

Embodied greenhouse gases:

8.33 kg CO_2 equiv. $/m^2_{GFA}/year$

Impact categories evaluated

GWP: Global warming potential

	[kg-CO2eq.]
Stage	Timber house
Production	43,480.00
Construction	9,519.00
Use	295,979.00
Disposal	4,538.00
Total	353,516.00

	[kg-CO2eq./m^2]
Stage	Timber house
Production	14,493.33
Construction	3,173.00
Use	98,659.67
Disposal	1,512.67
Total	117,838.67

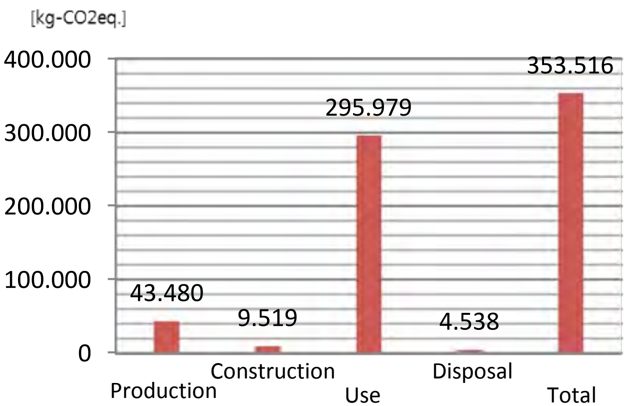


Figure 1: Total amount of CO2eq emission by life cycle stage for Timber framed house

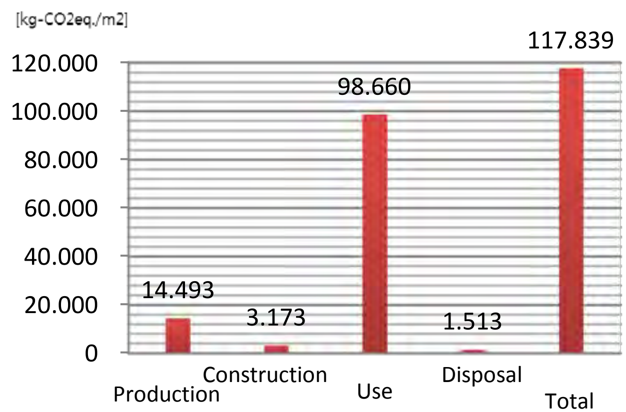


Figure 2: Total amount of CO2eq emissions by life cycle stage for Timber framed house(per unit area)

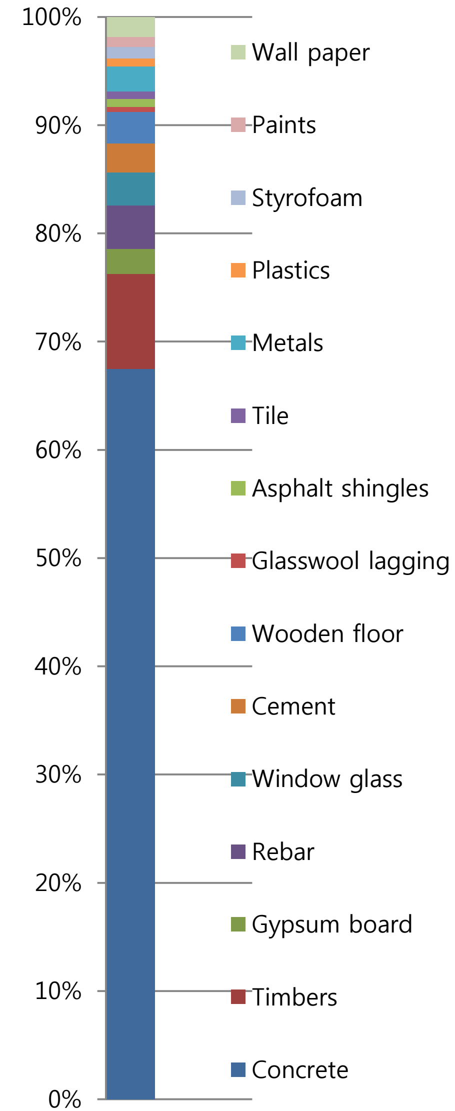
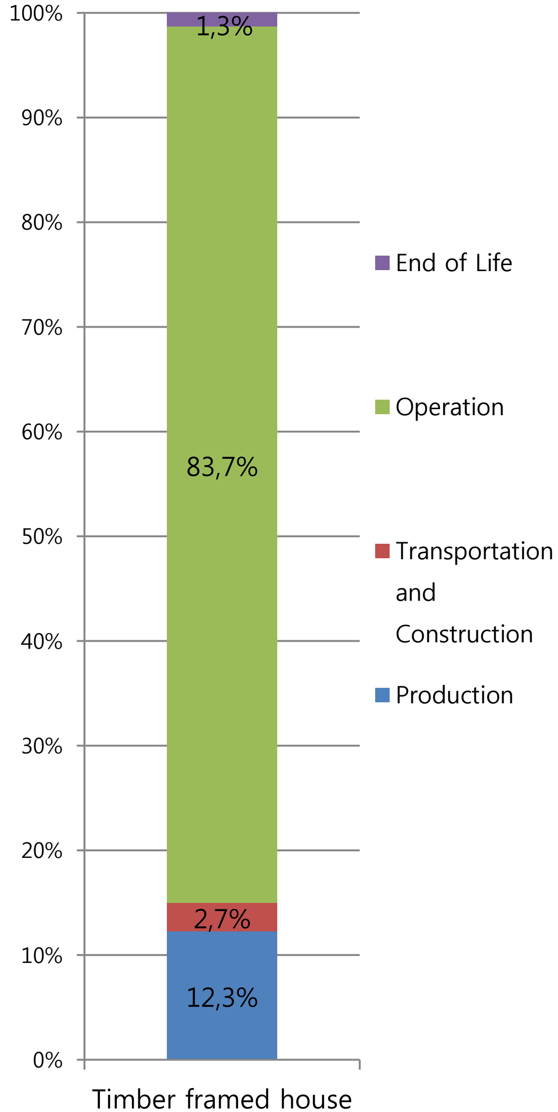


Figure 3: Contribution of CO2eq emission by building materials

Conclusion



Production stage

Wooden house consumes less weight of materials compared to R.C. or Steel structure house. The majority amount of EG are emitted from concrete by 29,345kgCO2eq(67.5%) and timber by 3,811kgCO2eq (8.8%) which were used for foundation and structure.

Transportation and construction stage

The total amount of emission in this stage covers 2.9% among the life cycle emission of the building. Transportation impacts by 85% on this stage and to reduce the emission it is needed to optimize construction schedule concerning transporting building products to the site.

Operation stage

The energy consumption was simulated by ECO2 program and source of energy was considered with LNG and electricity. The emission from operation is counted by 288,318kgCO2eq/30yrs and covers 97.5% of emission from the stage, while the maintenance by 7,661kgCO2eq/30yrs. Even if the building has better energy performance than a conventional house, the operation stage is a key stage to reduce the total emission.

End of life stage

The stage includes demolition, transportation, recycle and waste treatment processes. The scenario for recycling and disposal is adapted from the Statistic of Wastes by Ministry of Environment. The total emission of this stage is calculated by 4,608kgCO2eq and waste treatment process covers about 80% of the stage's total emission.

The LCA on timber framed house shows that the operational stage covers 84% of the life cycle emission while the embodied greenhouse gases is calculated about 14%. Concrete is a key material for the EG and other construction methods are needed to reduce the EG, with application of less EG foundation or floor heating slabs.

Norway

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Building elements contribution
2.3 Material type contribution
5.1 Length of RSL

Case Study NO1
ZEB Single Family House - Norway

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a reference study period of 60 years. Embodied Greenhouse Gases (EG) emissions were calculated for operational energy and for materials. The study showed that the emissions from building materials contributed 44% to total emissions. The PV production is higher than the energy demand and covers 77% of the total Greenhouse Gases emissions.

REFERENCE STUDY PERIOD

	60	years
(EG)	**7.2**	kg CO_2 equiv. /m^2_{HFA}/year

Evaluation of different building parts showed that the emissions from the photovoltaic panels (32%), the concrete (13%) and the EPS insulation (12%) are the largest contributors.

[1] ZEB ambition levels aimed for (ZEB/SINTEF, 2013):

ZEB-O: The building's renewable energy production compensate for greenhouse gas emissions from operation of the building.

ZEB-OM: The building's renewable energy production compensate for greenhouse gas emissions from operation and production of its building materials.

OBJECTIVES OF CASE STUDY

The main aim of this work is to do realistic simulations and calculations of the energy use, embodied emissions and total Greenhouse Gas emissions for a typical residential building in Norway. By doing this the main drivers behind Greenhouse Gas emissions will be revealed, and also what performance is necessary for components and solutions in a Zero Emission Building according to the current ZEB ambition levels[1]. The study evaluates:

- Embodied Greenhouse Gas (EG) and the impact related to different building components and materials.
- The goal of these calculations is to estimate, and thus provide an overview of the materials and components in the ZEB residential concept model, which contribute the most to embodied Greenhouse Gases.
- Can nZEB-O and nZEB-OM be achieved with current technologies?

BUILDING KEY FACTS

Intended use: Residential

Size: $160m^2$ HFA

Location: Oslo, Norway

Building year: N/A

Architect: ZEB / SINTEF

Structure: Timber frame

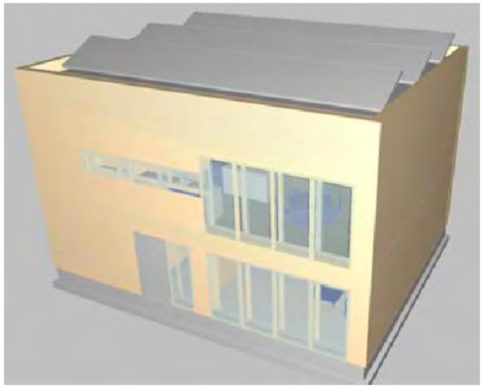


Illustration © Sofie Mellegård (Source: ZEB/SINTEF)

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Building life cycle stages included in the study, according to ISO EN 15978:

A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Next Product System			
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D1: Reuse	D2: Recovery	D3: Recycling	D4: Exported energy / Potential
x	x	x						x		x									

LCA BACKGROUND

Reference study period: 60 years
Calculation of Energy: Non-renewable Primary Energy and Renewable Primary Energy
Calculation of GWP: GWP (100 years)
Databases used: EcoInvent v 2.2, SimaPro 7.3.3
Energy Supply: All electric building. Electricity from grid plus renewable energy systems.
ZEB emission factor used for electricity (operational energy).
EcoInvent average country emission factors used for electricity in country of production (materials)
Standards/guidelines: ISO EN 15978: 2011

Production stage modeling: All impacts from the raw material extraction and the manufacturing of the building materials are included.

Operation stage modeling: The energy consumption in the building's operation stage is modeled with datasets representing average heating technologies and an EU-27 power grid mix. The replacements of building materials and components in the operational stage are only allowed in integers, i.e. a component with a lifetime of 20 years is represented by a tripling of emissions in the environmental accounting because it is replaced 3 times in the building's 60 year life span. (CEN/TC 350,2001).

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THE BUILDING

The concept building is a timber frame, 2 storey, single family home (SFH) with concrete slab on ground. The building has a high performance building envelope achieved by using materials and solutions already on the market. The envelope consists of a well insulated timber frame wall construction with 350 mm mineral wool insulation. The floor construction consists of 500 mm EPS insulation with a 100 mm concrete slab on top. A compact roof construction with 450mm EPS insulation supported on wooden loadbearing trusses/beams has been used in the design.

ENERGY SUPPLY

The energy supply solution for heating, cooling and electricity is an ‘all electric’ solution based on:

- A combined system of an air to air heat pump and solar collectors covering the total heat demand giving a high COP
- The electricity demand is covered by high efficiency PV on the roof

The solution is chosen due to its relatively mature technology and it is a common solution on buildings with high energy ambitions (nearly zero, zero or plus energy houses).

Total Net Annual Energy Demand

70 kWh/m$^2_{GFA}$/year (252 MJ/m$^2_{GFA}$/year)

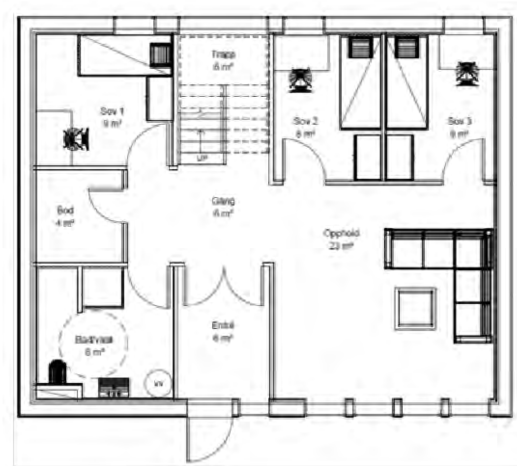
Space heating (30%)

Domestic hot water (34%)

Fans and pumps (4%)

Lighting (11%)

Appliances (21%)



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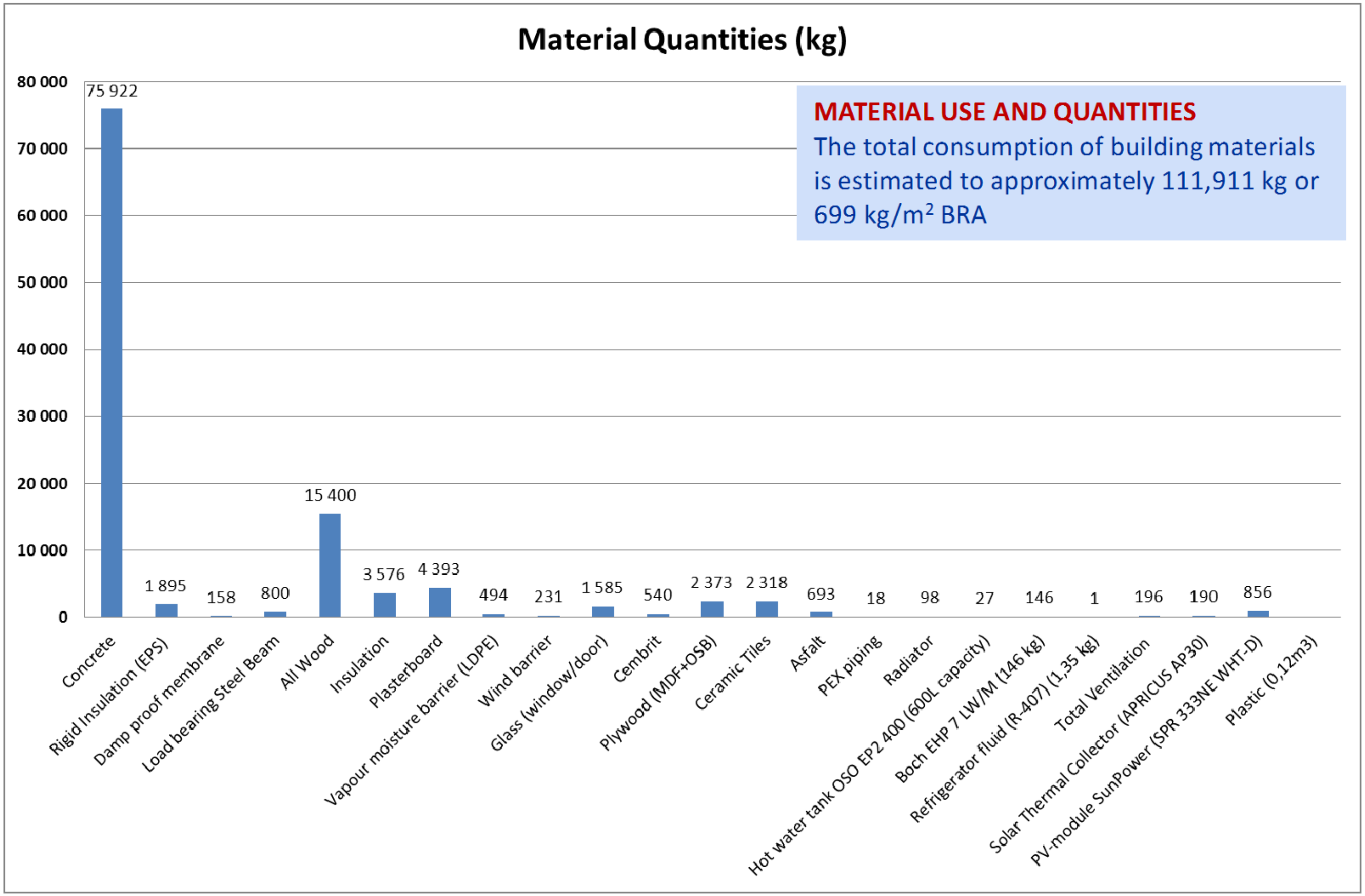
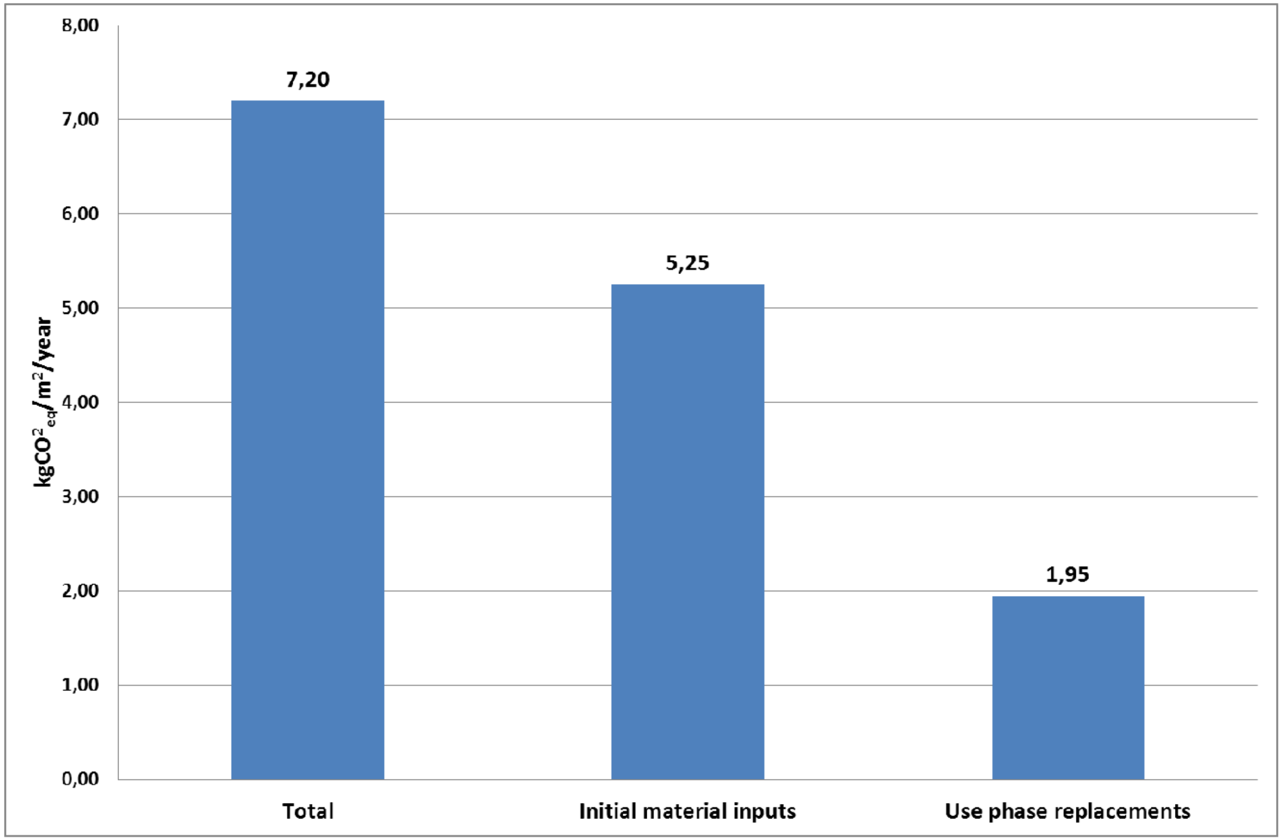


MATERIAL USE AND QUANTITIES

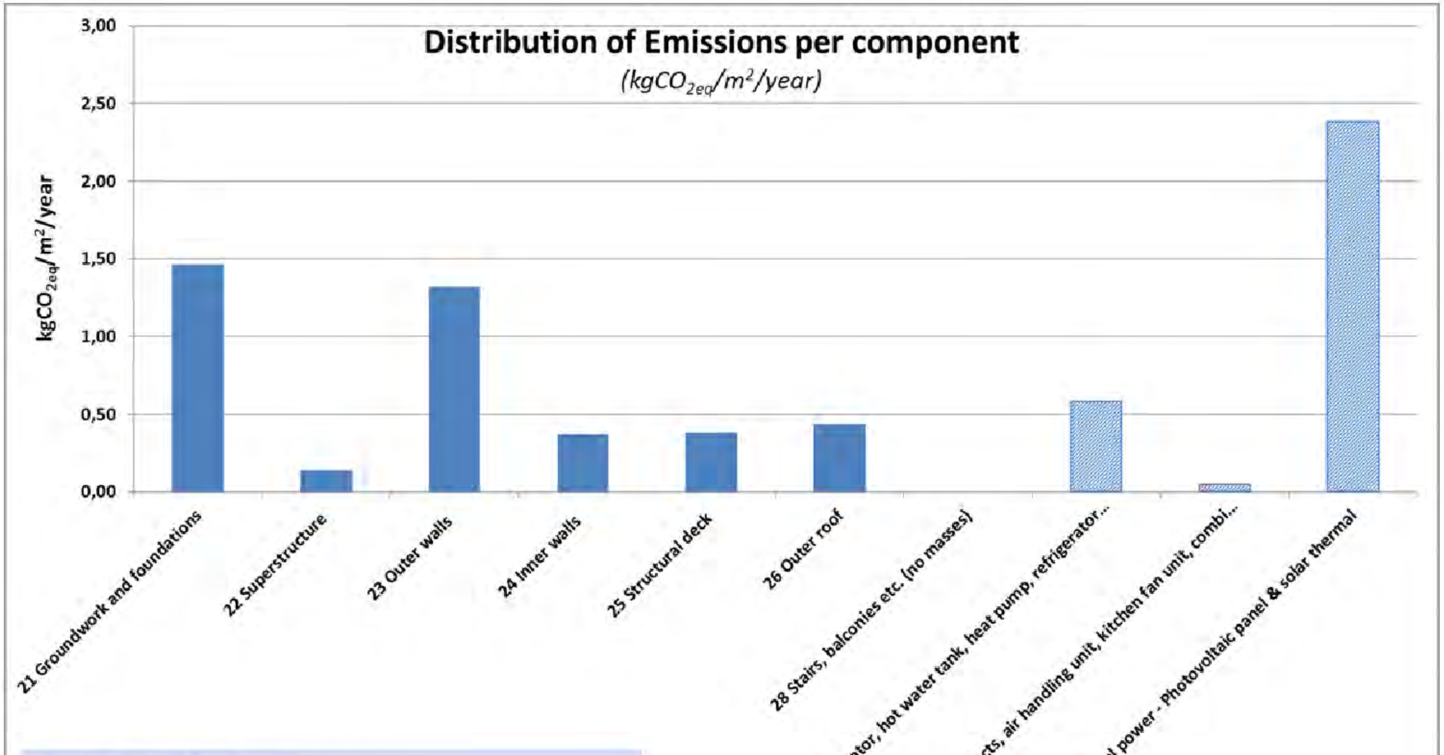
The total consumption of building materials is estimated to approximately 111,911 kg or 699 kg/m² BRA

SERVICE LIFE OF MATERIALS

Material input	Lifetime in years
Concrete	60
Rigid Insulation EPS	60
Load bearing Steel Beam	60
Load Bearing Timber	60
Insulation (mineral wool)	60
Plasterboard	60
Vapour moisture barrier *(PE foil)*	60
Wind barrier	60
Cembrit	30
Wood Pine Cladding	30
Glass pane in door	30
Timber window/doors frame	30
Ceramic Tiles	60
Sponplater (MDF)	30
Wood Flooring *(Parkett 14mm)*	15
Plastic	60
Wood Battons	60
Membrane (Asphalt)	30
Plywood	60
PEX piping	60
Radiator (steel)	60
Hot water tank OSO EP2 400	30
Boch EHP 7 LW/M *(146 kg)*	20
Refrigerator fluid (R-407)	60 (check*)
Total Ventilation (ducts etc)	60
Solar Thermal Collector	20
PV module	30



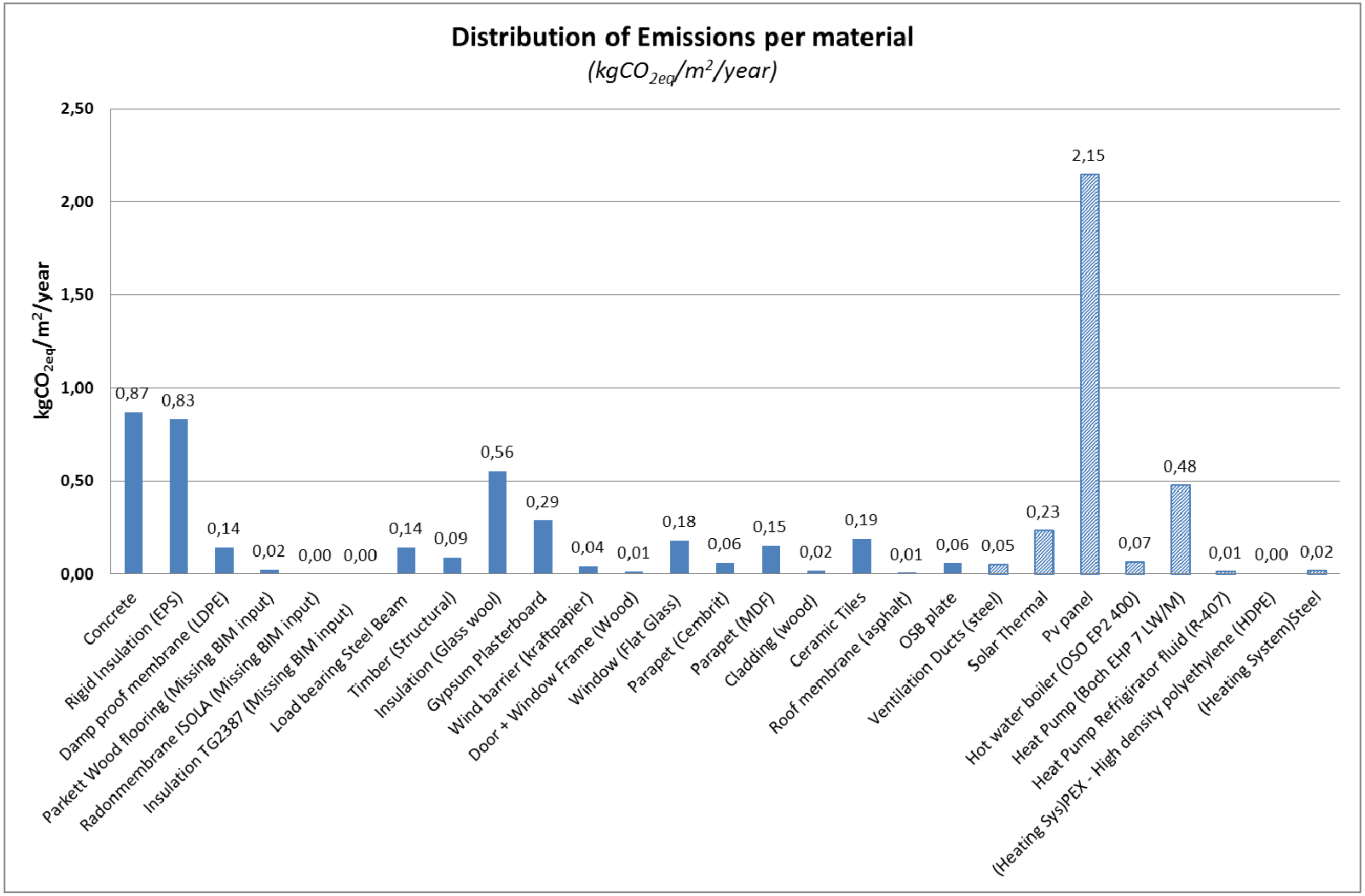
RESULTS FROM STUDY PERIOD OF 60 YEARS



Embodied Carbon:
7,2 kg $CO_{2equiv.}$ /m^2_{BRA}/year
- materials: 58%
- operational energy: 42%

RESULTS

Annex 57



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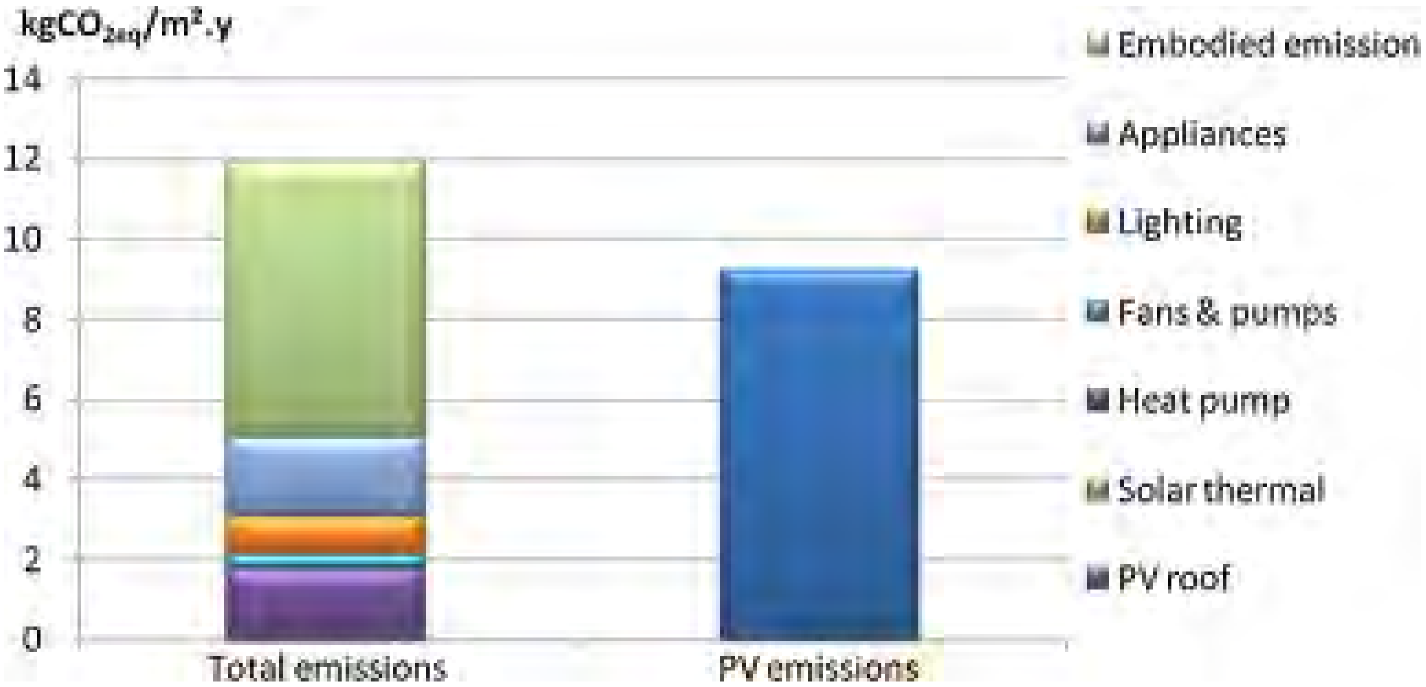
Embodied CO_{2eq} (EG) balance between total emissions *(i.e. embodied and operational)* and embodied emission from PV production.

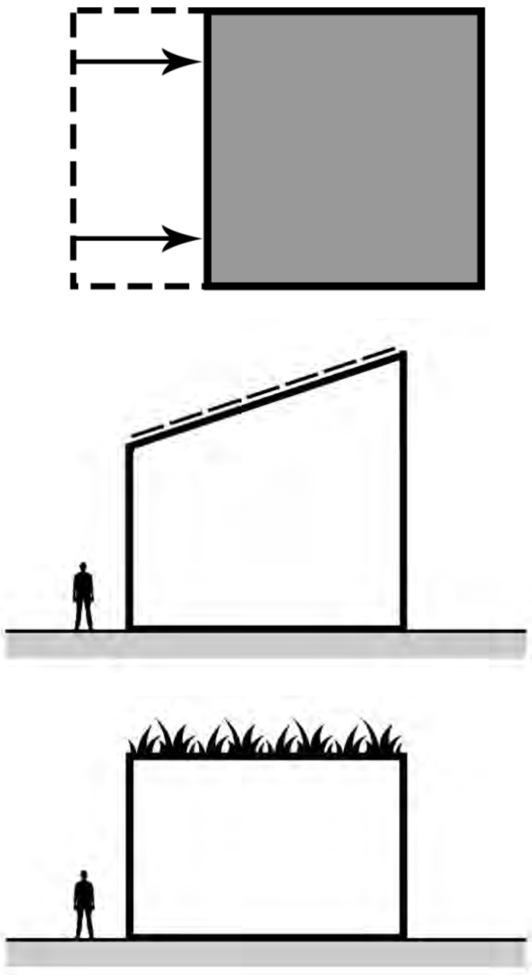


OBJECTIVES OF CASE STUDY

The concept building has been adapted for a range of scenarios, to see how embodied material emissions will be affected. The first scenario reduces the building footprint from 160m^2 to 117.8m^2, whereby one option keeps as much of the original internal layout as possible, and a second option optimises the internal layout based on passive design strategies. This second option requires changes to the external building envelope in terms of glazing ratios. The second scenario investigates implementing a sloped roof with building integrated photovoltaics (BIPV). Calculations for BIPV were based on the outer roof calculations used in the ZEB Living Lab pilot project. A second option for this scenario increases the heated floor space from 160m^2 to 190m^2, by incorporating a third floor mezzanine in the new roof space. The third scenario investigated the offset embodied emissions associated with installing a green roof.

SYSTEM BOUNDARIES AND SCOPE

The scope of the study and system boundaries used are the same as those outlined in the original study by Dokka et al. 2013.



Illustrations © Laurina Felius (Source: ZEB/NTNU)

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OPTIMISATION OF BUILDING FORM - RESULTS

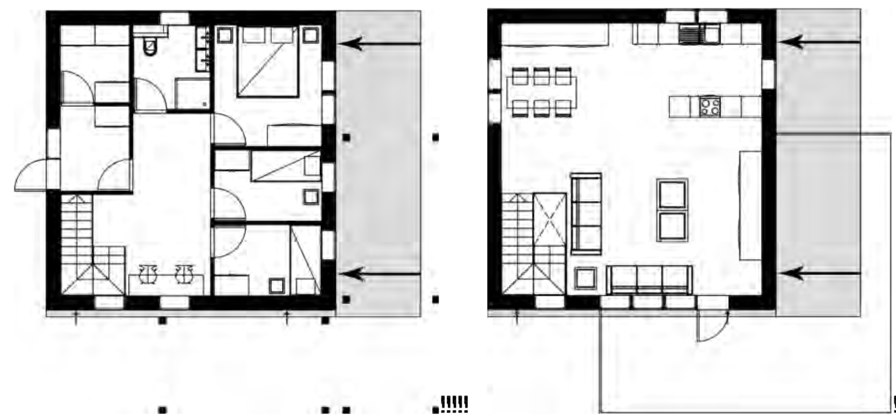
Annex 57

SCENARIO 1: OPTION 1

It was found that ‘Scenario 1: Option 1’ (whereby reduced internal layouts were kept as close to the original as possible), had embodied emissions of 7.18 $kgCO_{2eq}/m^2/year$, similar to that of the original ZEB single family house study at 7.2 $kgCO_{2eq}/m^2/year$. However, as the heated floor area has been reduced from 160m^2 to 117.8m^2, total emissions are in fact 25% less at 875 $kgCO_{2eq}/year$ compared to the original 1,15 $kgCO_{2eq}/year$. This highlights the sensitivity of area in a functional unit.

SCENARIO 1: OPTION 2

Scenario 1: Option 2 has optimised the internal layout based on passive design principles. As a result, the amount of glazing to the north has been reduced whilst to the south and east it has been maximised, in order to supply natural day lighting to the core living spaces. The results from this option show that further savings can be made in terms of embodied emissions, as total emissions were reduced to 7.08 $kgCO_{2eq}/m^2/year$ or 864 $kgCO_{2eq}/year$. It should be noted that this option has not taken into account the operational energy use savings made by implementing passive design strategies.



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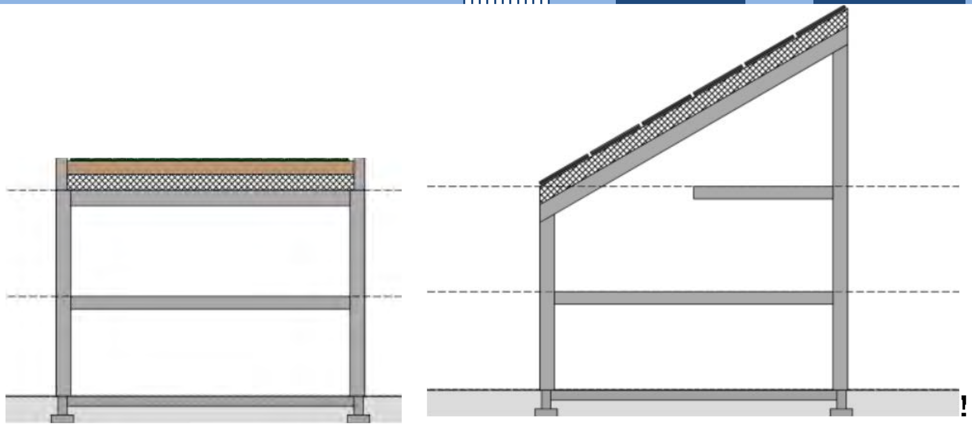
SCENARIO 2: OPTION 1

It was found that 'Scenario 2: Option 1' (whereby a sloped roof with building integrated photovoltaic panels were introduced) experienced a significant increase in embodied emissions. Embodied emissions totalled 8.86 $kgCO_{2eq}/m^2/year$. This increase in emissions is due to the increased amount of outer wall and outer roof building materials, as well as the high amount of embodied emissions from the aluminium PV mounting frame.



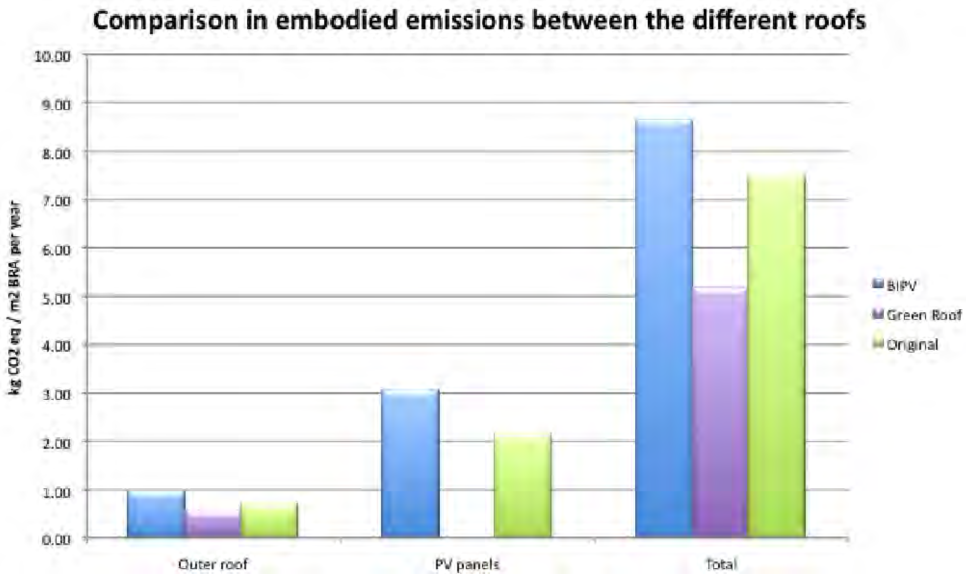
Illustrations © Laurina Felius (Source: ZEB/NTNU)

SCENARIO 2: OPTION 2

Scenario 2: Option 2 is based on Scenario 2: Option 1, however it increases heated floor area from 160m^2 to 190m^2 through the implementation of a third floor mezzanine. By increasing the internal floor area, total emissions can be reduced to 7.45 $kgCO_{2eq}/m^2/year$.

SCENARIO 3: OPTION 1

This scenario investigated the implementation of a green roof, instead of a more conventional roof. Previous studies have shown that a green roof can offset embodied emissions by 5.0 $kgCO_{2eq}/m^2/year$ and improve local environmental conditions. However such an option sacrifices on-site energy production from photovoltaics.



OBJECTIVES OF CASE STUDY

Two sensitivity analyses have been carried out on the original ZEB single family house concept study. The first sensitivity analysis, investigates the choice of data. In the original study, generic LCI data was gathered from EcoInvent. The sensitivity analysis on data, selects four core building materials essential to the construction of the ZEB single family house, and replaces the generic data with Norwegian EPD specific data. The second sensitivity analysis, investigates the choice of electricity mix. The overall ZEB balance, including operational energy use, embodied material emissions and energy production from photovoltaic panels is compared using a range of electricity mixes, namely: the ZEB ultra-green, the UCTE current, the ZEB current EU and and the NO current.

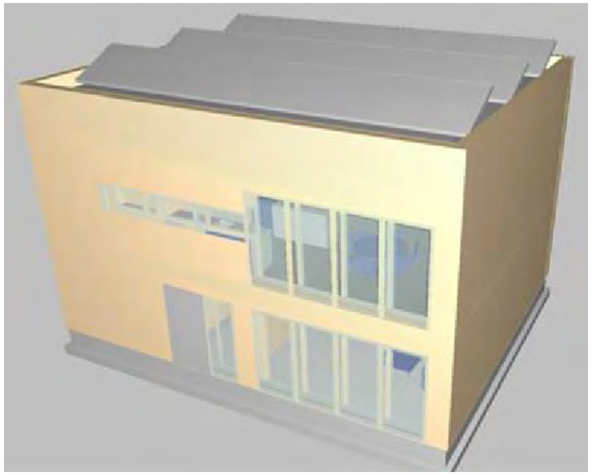


Illustration © Sofie Mellegård (Source: ZEB/SINTEF)

SYSTEM BOUNDARIES AND SCOPE

The scope of the study and system boundaries used are the same as those outlined in the original study by Dokka et al. Except in the case of the data sensitivity analysis, whereby data from Norwegian EPDs have also been used.

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HOULIHAN WIBERG, A. A-M., GEORGES, L., DOKKA, T.H., HAASE, M., TIME, B., LIEN, A. G., MELLEGÅRD, S., MALTHA, M. *A Net Zero Emission Concept Analysis of a Single-family House.* Energy and Buildings 74 (2014): 101-10.

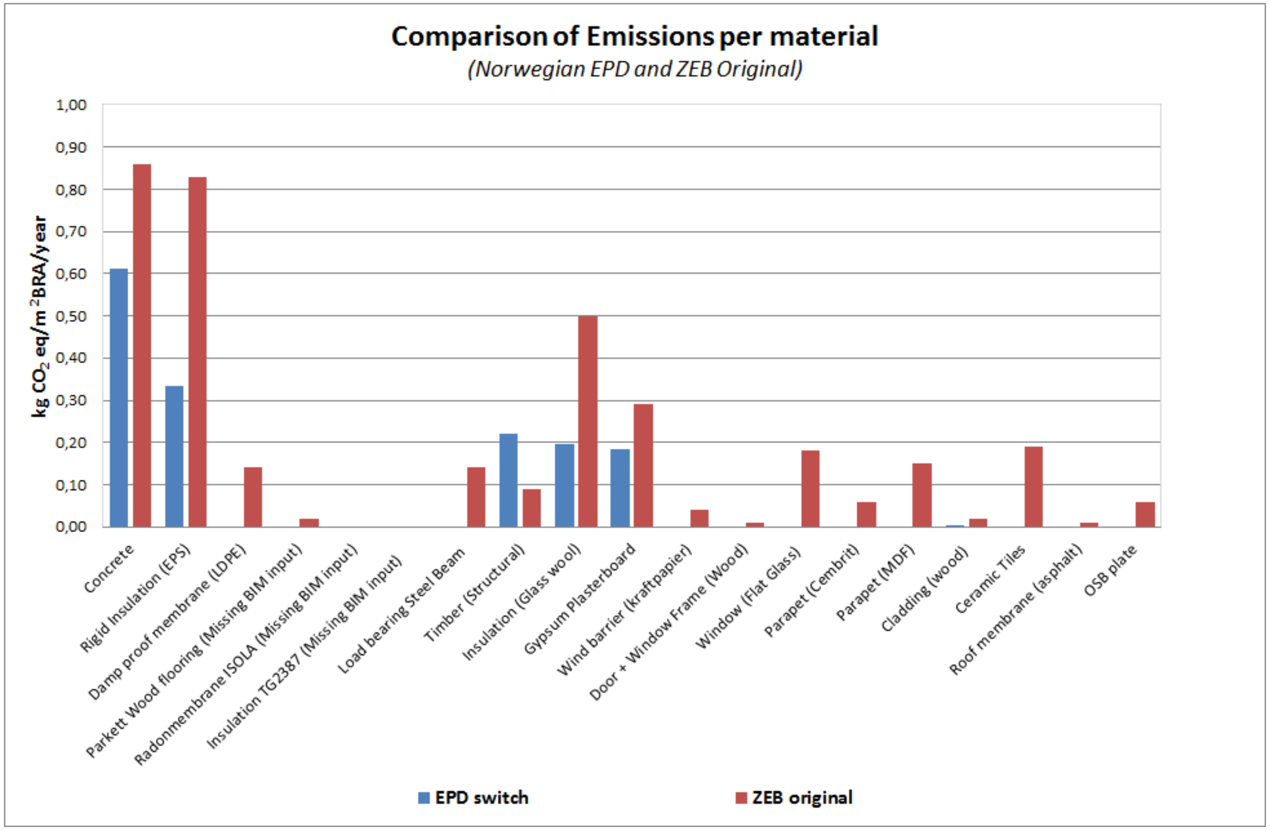
DOKKA, T.H., HOULIHAN WIBERG, A. A-M., MELLEGÅRD, S., GEORGES, L., TIME, B., HAASE, M., LIEN, A.G. (2013) *A Zero Emission Concept Analysis of a Single Family House.* The Research Centre on Zero Emission Buildings (ZEB). Technical Report 9. SINTEF ACADEMIC PRESS .ISBN 978-82-536-1324-6

HOULIHAN WIBERG, A. A-M., MAMO FUFA, S., RISHOLT, B., GEORGES, L. (2015) *A Zero Emission Concept Analysis of a Single Family House: Part 2: A Sensitivity Analysis.* The Research Centre on Zero Emission Buildings (ZEB). Technical Report 21. SINTEF ACADEMIC PRESS. ISBN 978-82-536-1449-6

GEORGES, L., et al. (2015) *Life cycle emissions analysis of two nZEB concepts.* Building Research and Information, **43**(1): p. 83-93.

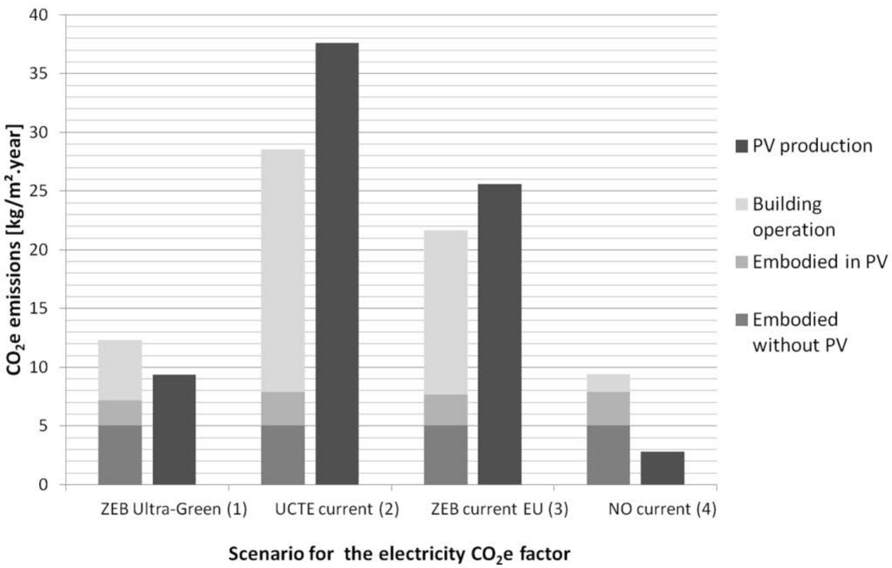
RESULTS

The embodied emissions results in red are for the original embodied emission calculations using generic data, whilst the results in blue show the embodied emissions when product specific data from Norwegian EPDs are used. It clearly shows that embodied emissions from concrete, EPS insulation, mineral wool insulation and gypsum plasterboard are significantly reduced when Norwegian EPD data is used. However, embodied emissions from the use of timber are slightly increased when Norwegian EPD data is used for material emission calculations.



RESULTS

The ZEB balances in the bar chart to the left, are developed from the original ZEB single family house concept study. However, the results are for a sensitivity analysis of the electricity mix used. The ZEB Ultra-Green electricity mix takes a 60 year average of emissions from electricity production, striving for a zero emission grid by 2050. Emissions are calculated as an 132 gCO_{2eq}/kWh average. The UCTE and ZEB current EU scenarios use higher emission factors, and are the only two scenarios that show that PV production can cover a ZEB-OM ambition level. The NO current electricity mix assumes lower embodied emissions than the ZEB Ultra-Green scenario, and shows that not even a ZEB-O balance can be reached.



Key issues related to Annex 57:
1. Strategies in building design
2. Significant factors
3. Calculation methodology

Case Study NO2
ZEB Office Concept - Norway

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a reference study period of 60 years. Embodied Greenhouse Gas (EG) emissions were calculated for both operational energy use and materials. The study showed that the emissions from building materials contributed 66% to total emissions. Energy production from photovoltaic panels on the roof and south façade cover 34 and 16% of total embodied emissions respectively.

Embodied(EG)emissions: 8.5 $kgCO_{2equiv.}/m^2_{HFA}/year$

The evaluation of different building parts, showed that embodied (EG) emissions from photovoltaic panels (25%), concrete (22%) and steel (15%) were the largest contributors to total embodied emissions.

[1] ZEB ambition levels aimed for (ZEB/SINTEF, 2013):

ZEB-O: The building's renewable energy production compensate for greenhouse gas emissions from operation of the building.

ZEB-OM: The building's renewable energy production compensate for greenhouse gas emissions from operation and production of its building materials.

OBJECTIVES OF CASE STUDY

The main focus of this study, is to complete realistic simulations and calculations of the energy use, embodied CO_{2eq}(EG) emissions and total CO_2 emissions for a typical office building in Norway. By doing this the main drivers behind CO_2 emissions will be revealed. In addition, the performance level necessary for components and solutions in a Zero Emission Building according to the current ZEB ambition levels[1] will be identified. The study evaluates:

- Embodied CO_{2eq} (EG) emissions and the impact from different building components and materials.
- Which materials and components in the ZEB office concept model contribute the most to embodied emissions?
- Whether nZEB-O and nZEB-OM can be achieved with current technologies?

BUILDING KEY FACTS

Intended use: Office

Size: 1980m² HFA

Location: Oslo, Norway

Building year: N/A

Architect: ZEB / SINTEF

Structure: load-bearing steel structure with concrete slabs

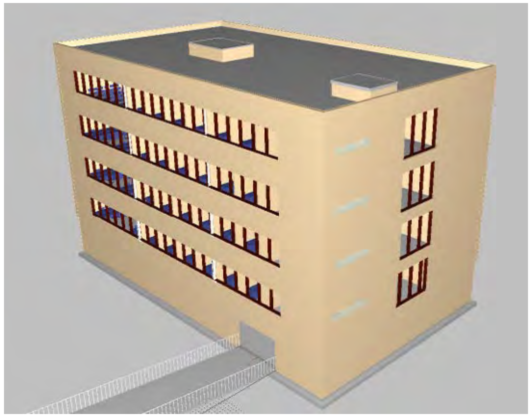


Illustration © Sofie Mellegård (Source: ZEB/SINTEF)

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NTNU – Trondheim Norwegian University of Science and Technology

SINTEF

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to ISO EN 15978:

A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Next Product System			
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D1: Reuse	D2: Recovery	D3: Recycling	D4: Exported energy / Potential
x	x	x						x		x									

LCA BACKGROUND

Reference study period: 60 years

Databases used: EcoInvent v 2.2, SimaPro 7.3.3

Standards/guidelines: ISO EN 15978: 2011

Method: IPCC GWP 2007 100 year scenario

The ZEB emission factor has been used for electricity during operational use (B6)

Production stage modeling: All phases of the production stages have been included in the calculations. This includes the raw material supply, transport to manufacturer and manufacturing. Some composite construction materials were not available in the EcoInvent database, so raw material inputs have been used. Chemicals such as glues, paints and primers have not been included.

Operation stage modeling: Operational energy use has been simulated through SIMIEN. Replacement of building materials has been included, and service lifetimes have been estimated according to Product Category Rules (PCR)s. There is one future scenario, whereby it has been assumed that the photovoltaic panels will be produced with 50% less embodied emissions in 30 years time.

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KRISTJANSDOTTIR, T., DOKKA, T. H., TIME, B., MELLEGÅRD, S., HAASE, M. & TØNNESEN, J. (2013) *A zero emission concept analysis of an office building.* ZEB Project Report 8, SINTEF Academic Press, Oslo, Norway.

DOKKA, T.H. (2011) *Proposal for CO_2 factor for electricity and outline of a full ZEB-definition*. The Research Centre on Zero Emission Buildings (ZEB), Internal Report.

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The Research Centre on Zero Emission Buildings

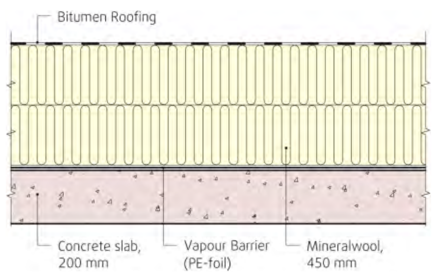
NTNU – Trondheim Norwegian University of Science and Technology

SINTEF

FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI

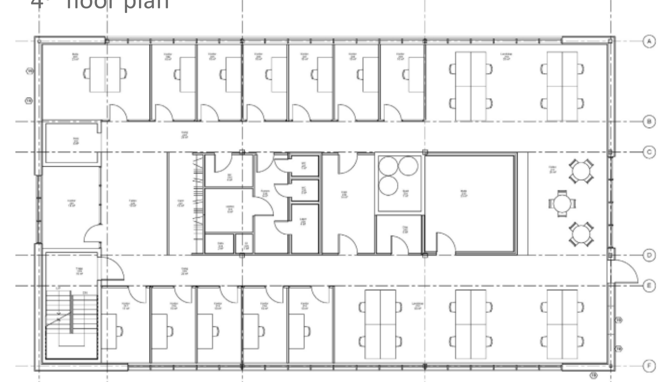
THE BUILDING

The concept building is a steel frame, 4 storey office with a concrete basement. The building has a high performance building envelope, achieved by using materials and solutions already on the market. The envelope consists of a well insulated timber frame wall construction with 350 mm mineral wool insulation. The floor construction consists of 350 mm EPS insulation facing an unheated basement. A compact roof construction with 450mm EPS insulation, supported on wooden loadbearing trussed beams, have been used in the design.



Illustrations © Sofie Mellegård (Source: ZEB/SINTEF)

4th floor plan



1st, 2nd and 3rd floor plan

Illustration © Sofie Mellegård (Source: ZEB/SINTEF)

Total Net Annual Energy Demand

57 kWh/m$^2_{GFA}$/year

Space heating and cooling (42%)

Domestic hot water (9%)

Fans and pumps (11%)

Lighting (16%)

Appliances (2%)

ENERGY SUPPLY

The energy supply solution for heating, cooling and electricity is an 'all electric' solution, based on:

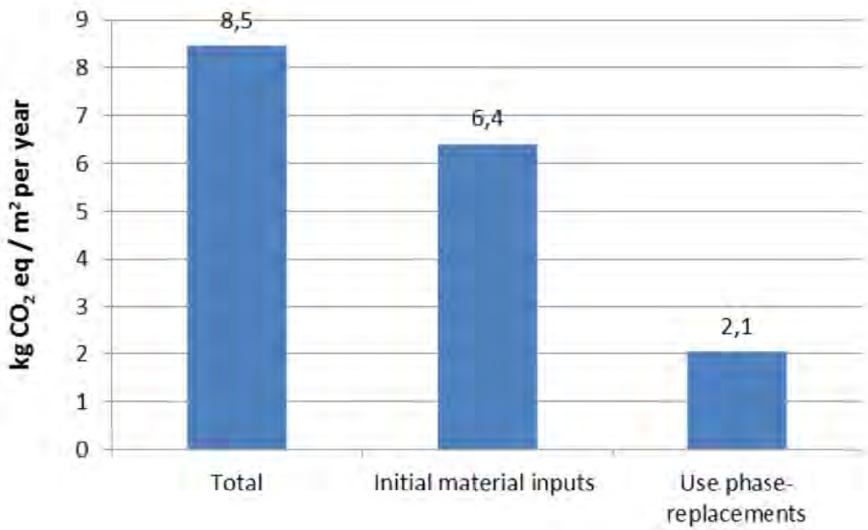
- A combined system of a geothermal heat pump and solar collectors covering the total heat demand, giving a high COP.
- The electricity demand is covered by high efficiency PV on the roof (and south façade).

EMBODIED CO_{2eq}(EG) EMISSIONS BY LIFECYCLE STAGE

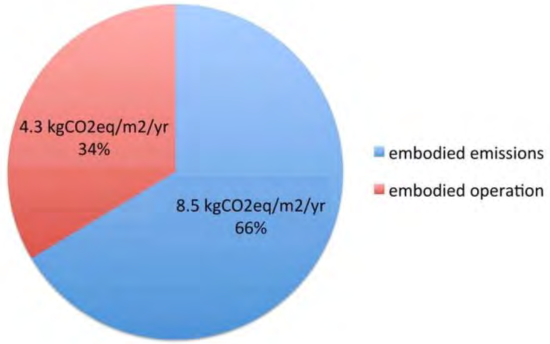
Embodied Greenhouse Gas:
12.8 $kgCO_{2\ equiv.}/m^2_{GFA}$/year

Material (EG) (A1 - A3): 6.4 $kgCO_{2\ equiv.}/m^2_{GFA}$/year
Use phase (EG) (B4): 2.1 $kgCO_{2\ equiv.}/m^2_{GFA}$/year
Operational (EG) (B6): 4.3 $kgCO_{2\ equiv.}/m^2_{GFA}$/year

Lifetime: 60 years

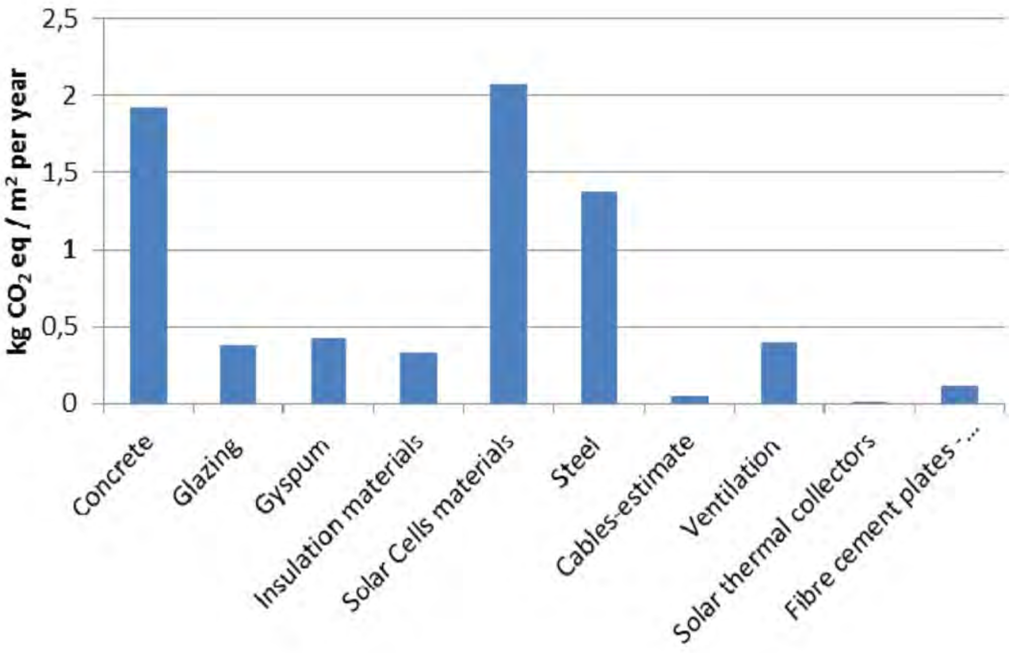


The initial material inputs corresponds to life cycle stages A1 – A3, whilst use phase replacements corresponds to life cycle stage B4. The bar chart shows emissions for these stages. Operational energy use emissions during the use stage are in addition to this. As shown in the pie chart, embodied emissions account for 66% whilst operational emissions account for 34%.



EMBODIED CO_{2eq}(EG) EMISSIONS BY MATERIAL: *A1-3 PRODUCTION STAGE*

When looking at embodied greenhouse gas, it is possible to see that photovoltaic panels under the category of solar cell materials is the largest contributor to CO_{2eq} (EG) emissions, contributing 25% to total emissions. The next largest contributor is found in concrete, which is responsible for 22% of total emissions. The third material to contribute the most to emissions is steel, contributing 15% to total embodied greenhouse gas emissions.



Materials with low embodied to CO_{2eq} (EG) emissions include the solar thermal collectors, the estimate used for cabling and fibre cement plates used on the facades. It should be noted that an estimate of 20% was used for the supporting systems used for the solar thermal collectors and photovoltaic panels.

The emissions for concrete are not based on low carbon concrete, so the embodied to CO_{2eq} (EG) emissions from this material component may be further optimised.

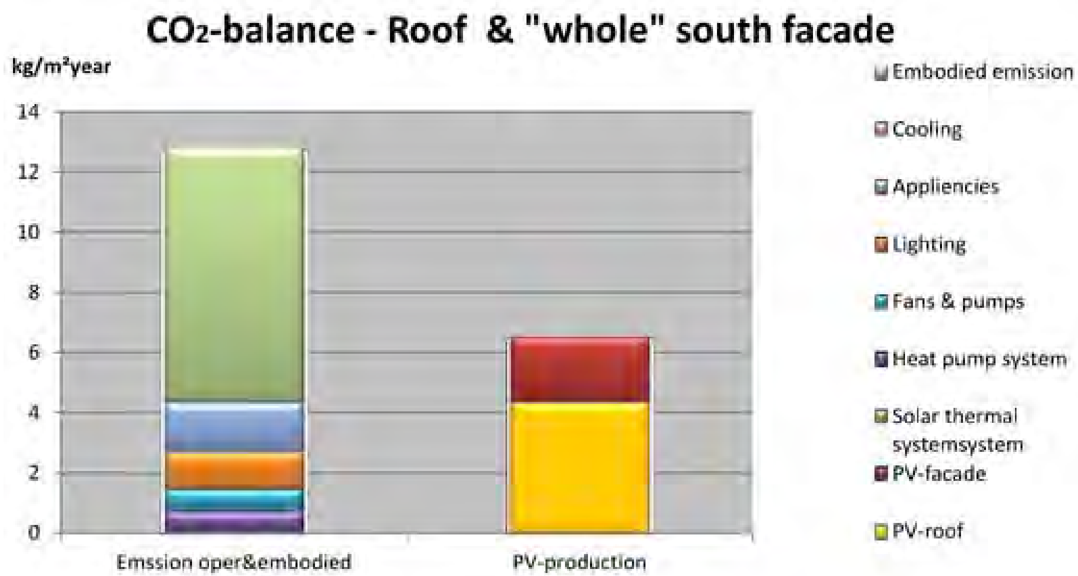
EMBODIED CO_2 (EG) EMISSIONS AS A ZEB BALANCE

Total embodied emissions for both material and operational phases are shown in the first column of the bar chart, with a breakdown of the different contributing elements. Such emissions are counter balanced during the 60 year lifetime of the office building, through the photovoltaic energy production on both the roof and south façade.

The south façade energy production is an optional building scenario, depending on the performance requirements of the office building. However, photovoltaic coverage from the south façade alone is not enough to meet the ZEB ambition levels set out at the beginning of this experiment.

In contrast, the roof photovoltaic coverage achieves a ZEB-O balance, covering the operational emission needs of the office building. However, more on-site energy production is required to achieve a ZEB-OM ambition level.

EMBODIED CO_2 (EG) EMISSIONS



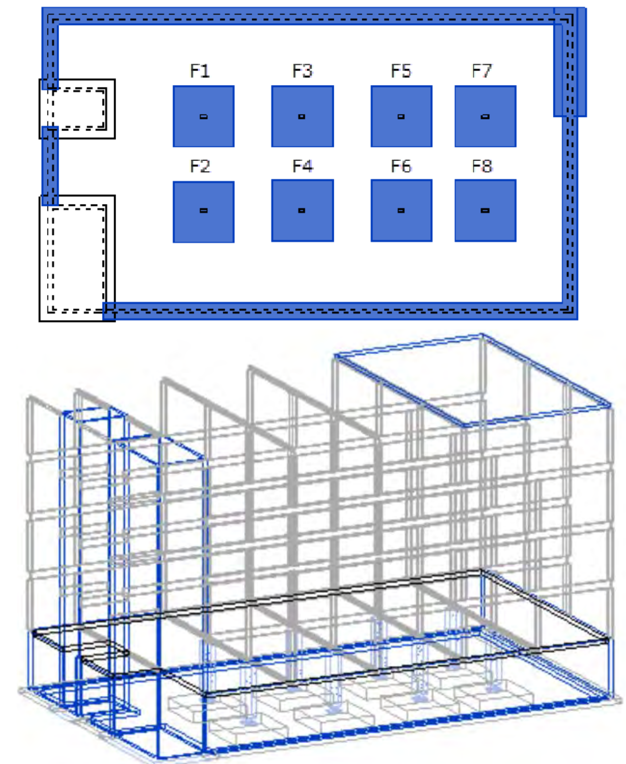
OPTIMISATION OF STRUCTURE

FROM CONCRETE & STEEL TO TIMBER

Through a series of studies, the ZEB office concept study has been optimised to consider a timber structure, instead of the original steel and concrete frame. Unfortunately, it was not possible to completely eliminate steel and concrete as construction materials. However, as can be seen in the images opposite (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.

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.

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



Illustrations © Tobias Hofmeister, Ingrid Thorkildsen and Hammersland P. (Source: ZEB/NTNU)

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HOFMEISTER, T. B., THORKILDSEN, I. (2014*) Environmental Comparison of the load-bearing structure in the ZEB office model concept with a wood based alternative.* [unpublished student paper] NTNU, Trondheim.

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HAMMERSLAND, P. V. (2013) *En nullutslipps konsept-analyse av et kontorbygg. Optimallisering av bæresystem i forhold til bundet CO2-utslipp*. Trondheim.

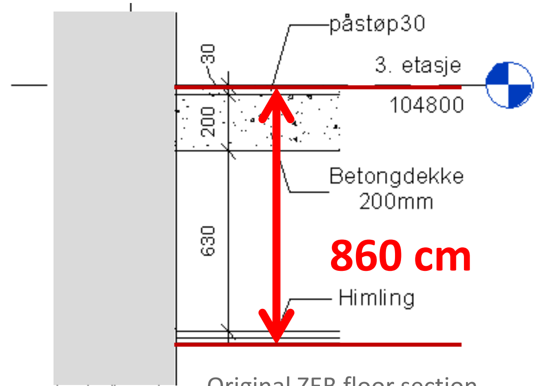
FLOOR MAKE-UP

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.

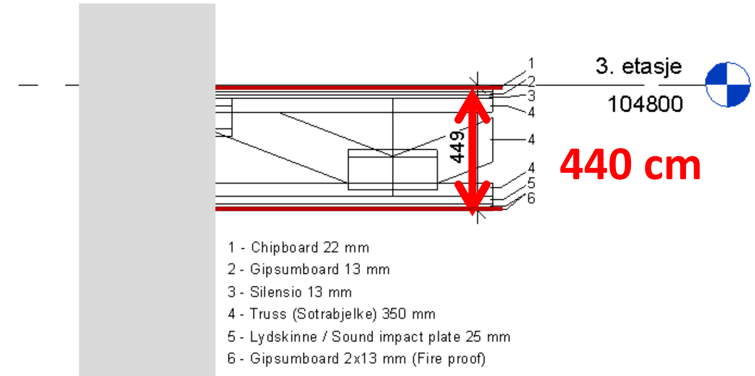
SYSTEM BOUNDARY

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:

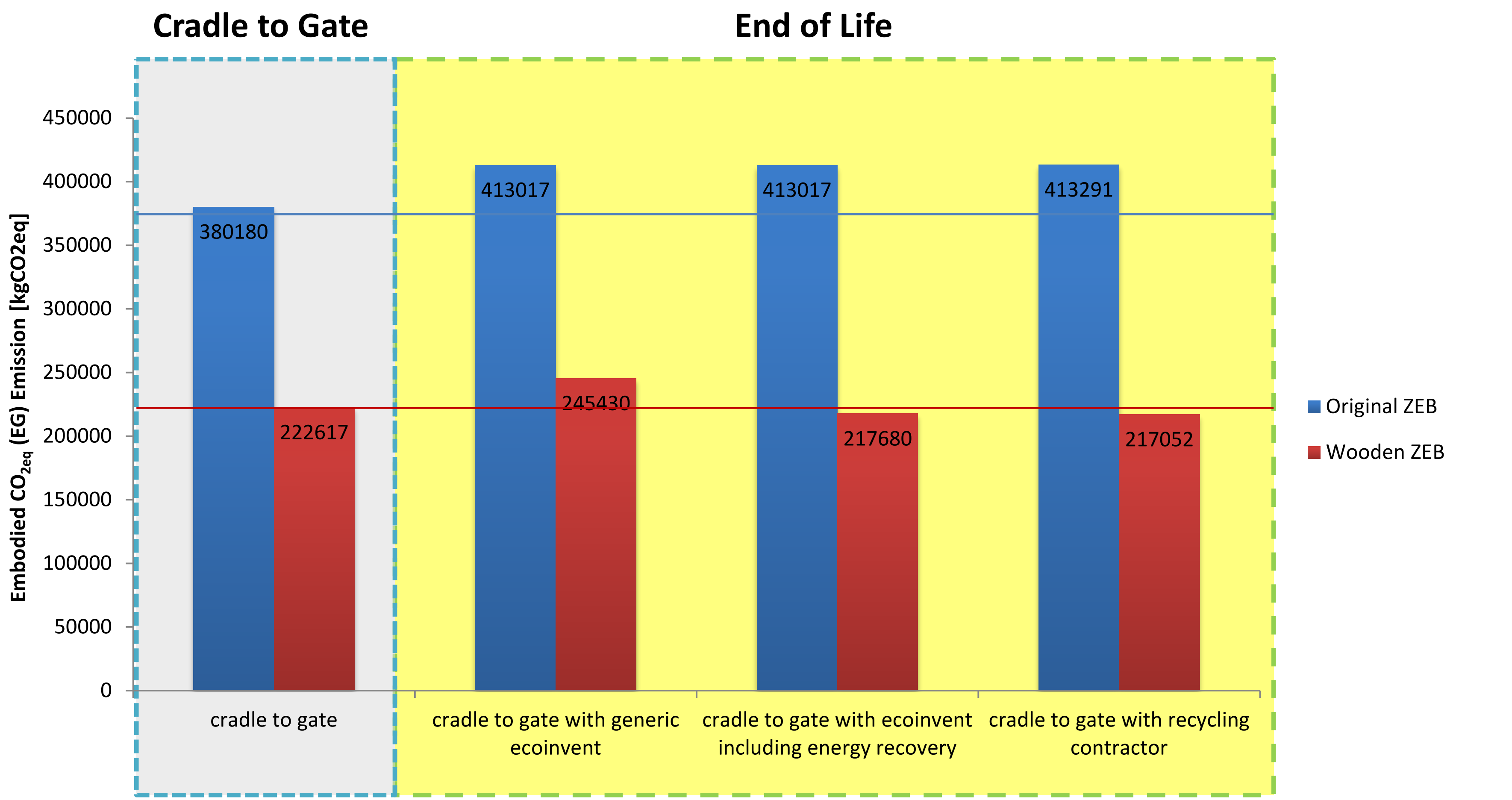
- **Generic EcoInvent:** This option follows the recommended End of Life treatment for building materials. It involves no energy recovery from waste materials treated with the process of municipal incineration.
- **EcoInvent with Energy Recovery:** This option considers energy recovery from municipal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



Original ZEB floor section



Timber ZEB floor section


Cradle to Gate
End of Life
Embodied CO_{2eq} (EG) Emission [kgCO2eq]
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
380180
222617
413017
245430
413017
217680
413291
217052
cradle to gate
cradle to gate with generic ecoinvent
cradle to gate with ecoinvent including energy recovery
cradle to gate with recycling contractor
Original ZEB
Wooden ZEB

Case Study NO4
ZEB Living Lab - Norway

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a reference study period of 60 years. Embodied CO_{2eq} (EG) emissions were calculated for construction materials.

Embodied CO_{2eq} (EG) Emissions: Production
Generic data: 13.3 $kgCO_{2equiv.}/m^2_{HFA}$/year
Specific data: 10.6 $kgCO_{2equiv.}/m^2_{HFA}$/year

Embodied CO_{2eq} (EG) Emissions: Transport to Site
Generic data: 5.33 $kgCO_{2equiv.}/m^2_{HFA}$/year
Specific data: 1.66 - 3.32 $kgCO_{2equiv.}/m^2_{HFA}$/year

The evaluation of different building parts, showed that emissions from the outer roof (30%), solar collectors (16%) and the outer walls (14%) were the largest contributors to total embodied emissions.

[1] ZEB ambition levels aimed for (ZEB/SINTEF, 2013):
ZEB-O: The building's renewable energy production compensate for greenhouse gas emissions from operation of the building.
ZEB-OM: The building's renewable energy production compensate for greenhouse gas emissions from operation and production of its building materials.

OBJECTIVES OF CASE STUDY

The Living Lab pilot project is a multipurpose experimental facility, with a ZEB ambition level of ZEB-O, meaning that material selection has not been optimised. The aim of the residential building, is to document actual energy use, for a range of inhabitants e.g. researchers, students, families etc. This study evaluates:

- Which materials and components in the Living Lab pilot project contribute the most to embodied emissions?
- Differences between generic and specific datasets?
- How 'transport to site' affects embodied emissions?
- The environmental burdens across 18 impact categories.

BUILDING KEY FACTS

Intended use: Residential
Size: 102m^2 HFA
Location: Trondheim, Norway
Building year: 2015
Architect: Bergersen arkitekter and Luca Finocchiaro
Structure: timber frame

Photograph ©Katrine Peck Sze Lim /ZEB

The Research Centre on Zero Emission Buildings

NTNU – Trondheim Norwegian University of Science and Technology

SINTEF

FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to ISO EN 15978:

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	x													

LCA BACKGROUND

Reference study period: 60 years

Databases used: EcoInvent v 2.2, SimaPro 7.3.3

Standards/guidelines: ISO EN 15978: 2011

Method: IPCC GWP 2007 100 year scenario

Production stage modeling: All phases of the production stages have been included in the calculations. This includes the raw material supply, transport to manufacturer and manufacturing. Some composite construction materials were not available in the EcoInvent database, so raw material inputs have been used. Chemicals such as glues, paints and primers have not been included.

Construction process stage modeling: Transport of construction materials to the building site have been included as an additional option. Transport distances and mode of transportation were ascertained from the manufacturer or from product specific literature.

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FINOCCHIARO, L., GOIA, F., GRYNNING, S. & GUSTAVSEN, A. (2014) *The ZEB Living Lab: A Multi-Purpose Experimental Facility*. *Ghent Expert Meeting.* Ghent Univeristy.

Inman, M.R., Houlihan Wiberg, A.A-M. (2016). Life Cycle GHG Emissions of Material Use in the Living Laboratory. I: *CESB16 – Central Europe towards Sustainable Building 2016*. Grada Publishing 2016 ISBN 978-80-271-0248-8. p. 1381-1388

Inman, M.R., Houlihan Wiberg, A.A-M. (2015). Life Cycle GHG Emissions of Material Use in the Living Laboratory. SINTEF akademisk forlag 2015 (ISBN 978-82-536-1481-6) 54 p. ZEB Project report(24)

SIMAPRO (2012) *Simapro 7.3.3*. PRé Consultants, Amersfoort, The Netherlands.

STANDARD NORGE (2009) *NS 3451: 2009 Table of Building Elements*. Oslo, Norway.

THE BUILDING

The Living Lab's foundations consist of three reinforced concrete strip footings with 50mm extruded polystyrene (XPS) ground insulation. There is a raised timber floor decking with 400mm of mineral wool insulation. The external walls are timber framed and have 400mm mineral wool insulation with a treated pine cladding. Two solar thermal collectors are integrated into the south façade. The internal walls consist of timber stud partitions, with mineral wool insulation and a plywood finish. The roof is also of timber frame construction. It has 400mm of mineral wool insulation, a treated pine cladding and 48 building integrated photovoltaic panels (BIPV). The roof also contains two roof lights. There is 90m^2 of phase change material (PCM) in the roof, vacuum insulation panels (VIP) over the sliding doors, and a range of probes and sensors to monitor the building's performance.

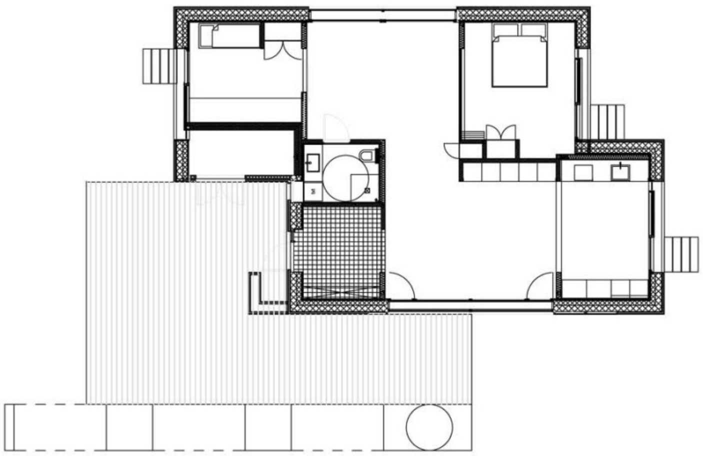


Illustration © Luca Finochiarro (Source: Bergersen Arkitekter AS)

ENERGY SUPPLY

The energy supply solution for heating, cooling and electricity is an 'all electric' solution, based on:

- A triple-coil hot water combination boiler
- A 3kW brine to water heat pump, with COP 2.8
- Variable air volume hybrid ventilation system with 85% heat recovery
- 2 no. solar collectors
- 48 no. high efficiency photovoltaic panels
- Hydronic under floor heating system and 2 no. panel radiators

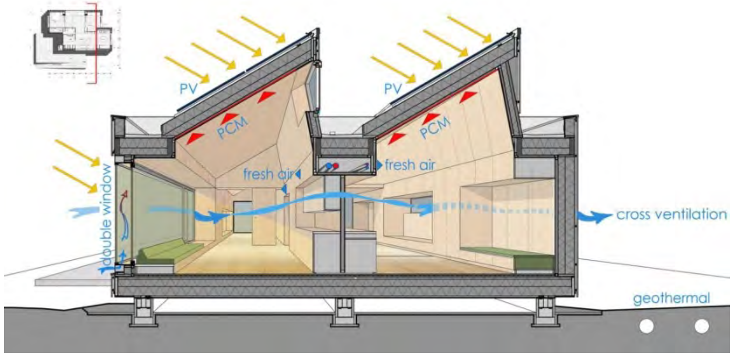


Illustration © Luca Finochiarro (Source: Bergersen Arkitekter AS)

EMBODIED CO_{2eq} (EG) EMISSIONS BY LIFECYCLE STAGE

Embodied CO_{2eq} (EG) Emissions: Production

Generic data: 13.3 $kgCO_{2equiv.}/m^2_{HFA}$/year

Specific data: 10.6 $kgCO_{2equiv.}/m^2_{HFA}$/year

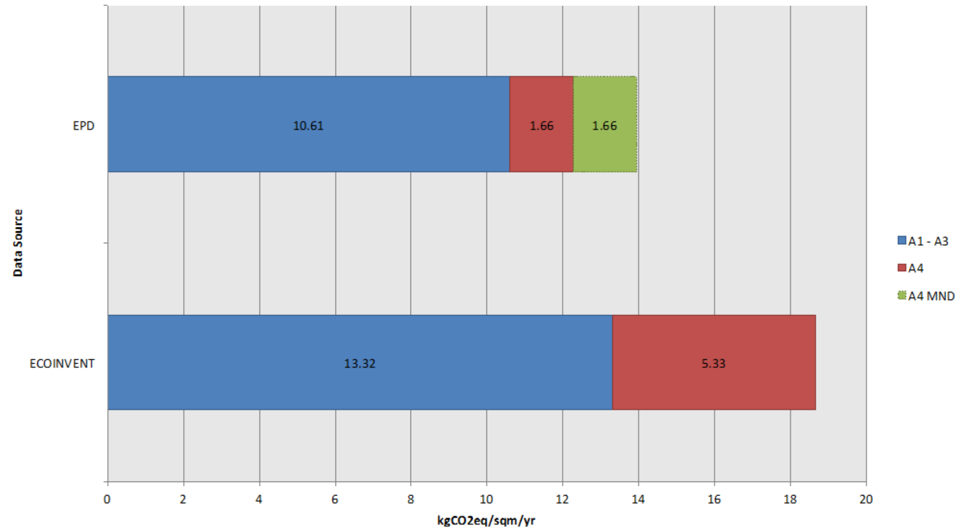
Embodied CO_{2eq} (EG) Emissions: Transport to Site

Generic data: 5.33 $kgCO_{2equiv.}/m^2_{HFA}$/year

Specific data: 1.66 - 3.32 $kgCO_{2equiv.}/m^2_{HFA}$/year

Lifetime: 60 years

The bar chart shows embodied emissions by life cycle stage. The majority of emissions occur during the production stage, however transport to site can contribute from 14 to 29% of total emissions. It also shows that using generic European datasets, instead of product specific EPDs, increases embodied emissions by 20%. The table opposite shows the top ten generic processes that contribute to climate change in the Living Lab pilot project. It shows that nearly 14% of all embodied CO_2 emissions originate from the process ‘operation, lorry 16-32t, EURO5 / RER / tkm’.

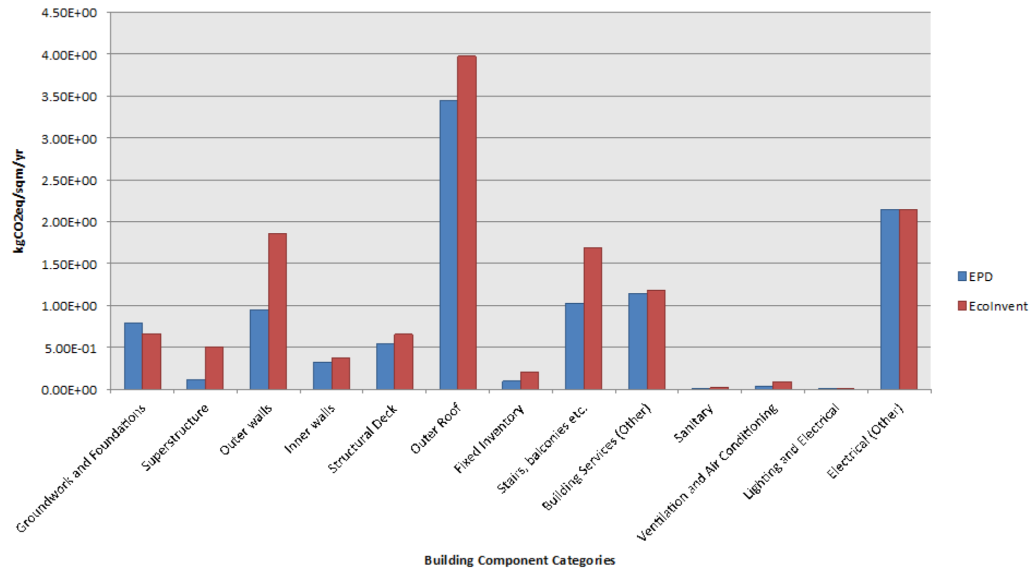


Climate change, Hierarchist, GWP100	Absolute	Relative
operation, lorry 16-32t, EURO5/ RER/ vkm	1.58E+04	13.81%
aluminium, primary, liquid, at plant/ RER/ kg	4.92E+03	4.31%
hard coal, burned in power plant/ DE/ MJ	4.16E+03	3.64%
lignite, burned in power plant/ DE/ MJ	4.02E+03	3.52%
clinker, at plant/ CH/ kg	3.99E+03	3.50%
hard coal, burned in industrial furnace 1-10MW/ RER/ MJ	3.78E+03	3.32%
diesel, burned in building machine/ GLO/ MJ	3.70E+03	3.24%
natural gas, burned in industrial furnace >100kW/ RER/ MJ	3.51E+03	3.08%
polypropylene, granulate, at plant/ RER/ kg	3.13E+03	2.74%
electricity, at cogen 1MWe lean burn, allocation exergy/ RER/ kWh	2.84E+03	2.49%

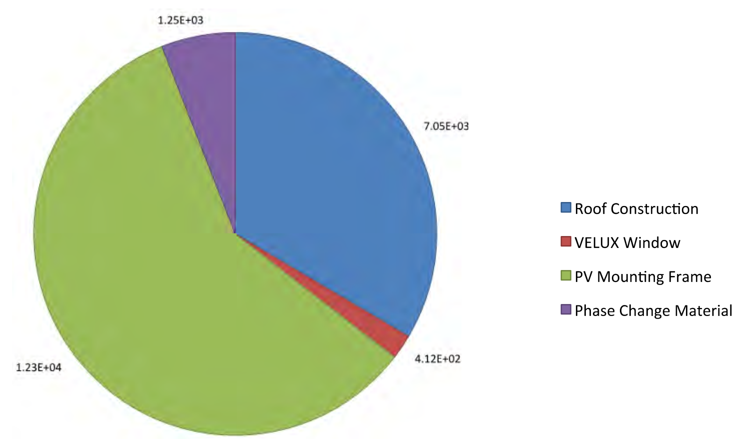
EMBODIED CO_{2eq} (EG) EMISSIONS:

A1 - A3 PRODUCTION STAGE

When looking at embodied greenhouse gas, it is possible to see that the outer roof is the largest contributor to GWP, contributing 30% to total emissions. The next largest contributor is found in the photovoltaic panels, under the category of electrical (other), which is responsible for 16% of total emissions. The third component category to contribute the most to climate change is the outer walls, contributing 14% to total embodied greenhouse gas emissions.



The pie chart shows a breakdown of embodied emissions for the outer roof building component category. It clearly shows that the majority of emissions originate from the PV mounting frame, consisting mainly of aluminium. As only system boundary modules A1 - A3 were included in these calculations, the emission savings from recycling aluminium in module D were not implemented, which has therefore resulted in a higher emission for the early life cycle stages of the photovoltaic mounting frame.



EMBODIED CO_{2eq} (EG) EMISSIONS ACROSS 18 IMPACT CATEGORIES

The table opposite shows total emissions for the Living Lab pilot project, for 18 impact categories. The five highest results are shown in red, whilst the five lowest environmental burdens are shown in green. Interestingly, the largest impacts are experienced under water depletion potential (WDP), and agricultural land occupation potential (ALOP). Climate change impacts rank third.

ALOP impacts originate from either softwood or hardwood processes 'standing, under bark, in forest / RER / m³'. Such a result is explained by the use of timber throughout construction. Timber is used for the superstructure, as internal and external surface cladding, as well as flooring.

WDP impacts originate from hydropower. Norway's electricity mix is characterised by a high level of hydropower.

Environmental Stressor	Scope	Perspective	Unit	Total Emissions	Emissions (per m2/yr)
Agricultural land occupation	Midpoint	Hierarchist	m2a	3.81E+05	6.22E+01
Climate change	Midpoint	Hierarchist	kg CO2 eq	8.15E+04	1.33E+01
Fossil depletion	Midpoint	Hierarchist	kg oil eq	2.77E+04	4.52E+00
Freshwater ecotoxicity	Midpoint	Hierarchist	kg 1,4-DB eq	2.02E+03	3.30E-01
Freshwater eutrophication	Midpoint	Hierarchist	kg P eq	4.99E+01	8.15E-03
Human toxicity	Midpoint	Hierarchist	kg 1,4-DB eq	7.05E+04	1.15E+01
Ionising radiation	Midpoint	Hierarchist	kg U235 eq	2.49E+04	4.07E+00
Marine ecotoxicity	Midpoint	Hierarchist	kg 1,4-DB eq	2.10E+03	3.43E-01
Marine eutrophication	Midpoint	Hierarchist	kg N eq	2.38E+01	3.89E-03
Metal depletion	Midpoint	Hierarchist	kg Fe eq	4.24E+04	6.93E+00
Natural land transformation	Midpoint	Hierarchist	m2	4.65E+01	7.60E-03
Ozone depletion	Midpoint	Hierarchist	kg CFC-11 eq	1.83E-02	3.00E-06
Particulate matter formation	Midpoint	Hierarchist	kg PM10 eq	1.82E+02	2.98E-02
Photochemical oxidant formation	Midpoint	Hierarchist	kg NMVOC	3.69E+02	6.03E-02
Terrestrial acidification	Midpoint	Hierarchist	kg SO2 eq	3.72E+02	6.08E-02
Terrestrial ecotoxicity	Midpoint	Hierarchist	kg 1,4-DB eq	9.17E+01	1.50E-02
Urban land occupation	Midpoint	Hierarchist	m2a	4.76E+03	7.77E-01
Water depletion	Midpoint	Hierarchist	m3	1.16E+06	1.89E+02

Agricultural land occupation, Hierarchist, ALOP100	Absolute	Relative
softwood, standing, under bark, in forest/ RER/ m3	2.63E+05	69.08%
hardwood, standing, under bark, in forest/ RER/ m3	1.17E+05	30.59%

Water depletion, Hierarchist, WDP100	Absolute	Relative
electricity, hydropower, at run-of-river power plant/ RER/ kWh	1.08E+06	92.83%
electricity, hydropower, at run-of-river power plant/ CH/ kWh	6.54E+04	5.64%
electricity, hydropower, at reservoir power plant, non alpine regions/	6.47E+03	0.56%

Key issues related to Annex 57:
1. Strategies in building design
3. Calculation methodology
6. Decision making process

Case Study NO8
Powerhouse Kjørbo - Norway

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a reference study period of 60 years. Embodied emissions were calculated for operational energy use (minus technical equipment) and materials. Existing material components with a service lifetime longer than 30 years were included in embodied emission calculations, namely concrete and steel. The study showed that emissions from building materials contributed 36% to total emissions. Energy production from photovoltaic panels covers over 100% of total embodied emissions, therefore producing a plus energy building.

Operational energy use: 58.1 kWh/m^2_{HFA}/year
Energy generation: 121.8 kWh/m^2_{HFA}/year
Embodied emissions (EG): 6.6 kg$CO_{2equiv.}$/m^2_{HFA}/year
Note: Appliances (plug loads) are not included in the operational energy use.

A positive energy building is defined as a *'building that during its lifecycle produces more renewable energy than it consumes for production of building materials, construction, operation and demolition of the building. The project should be built at a competitive price.'*

OBJECTIVES OF CASE STUDY

The main focus of this study, is to demonstrate that it is possible to build energy positive buildings in the cold climate of Norway. The building achieved BREEAM-NOR Outstanding. The renovated office building uses on-site energy production and meets passive house standard NS3701 as a minimum requirement. This study evaluates:

- The minimisation of embodied emissions, through reusing existing materials and carefully selecting new materials.
- Reducing existing operational energy use, and introducing on-site energy production to cover energy needs.
- Embodied emission methodology for existing buildings and their material components.

BUILDING KEY FACTS

Intended use: Office
Size: 5180m^2 HFA
Location: Sandvika, Norway
Building year: 1979 / 2014
Architect: Snøhetta
Structure: existing concrete and steel structure

Photograph © Remy Eik (Source: Snøhetta)

The Research Centre on Zero Emission Buildings
NTNU – Trondheim Norwegian University of Science and Technology
SINTEF
FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI

Building life cycle stages included in the study, according to ISO EN 15978:

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		x				x		x						

Production stage modeling: All phases of the production stages have been included in the calculations. This includes the raw material supply, transport to manufacturer and manufacturing.

Construction stage modeling: Emissions from installing materials into the building have been included, however transport to site is not included.

Operation stage modeling: Operational energy use has been simulated through SIMIEN. Replacement of building materials has been included, and service lifetimes have been estimated according to Product Category Rules (PCR)s. There is one future scenario, whereby it has been assumed that the photovoltaic panels will be produced with 50% less embodied emissions in 30 years time.

LCA BACKGROUND

Reference study period: 60 years

Databases used: EcoInvent v 2.2, SimaPro 7.3.3

Standards/guidelines: ISO EN 15978: 2011

Method: IPCC GWP 2007 100 year scenario

The ZEB emission factor has been used for electricity during operational use (B6)

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THE BUILDING

The office buildings were originally built in 1979, using a concrete and steel structure with curtain wall glazing. The complex consists of 9 blocks in total, however only two blocks (owned by Entra Eiendom) were renovated in 2014. The building envelope is optimised to passive house standards, through the addition of insulation and a new charred wood cladding. The roof had to be strengthened to support the addition of photovoltaic panels. Due to the fact that the energy need for ventilation normally comprises a large share of the energy budget in office buildings, there has particularly been a high focus on reducing the energy need for ventilation for Powerhouse Kjørbo.

Photograph © Chris Aadland (Source: Snøhetta)

ENERGY SUPPLY

The energy supply solution for heating, cooling and electricity is an ‘all electric’ solution, based on:

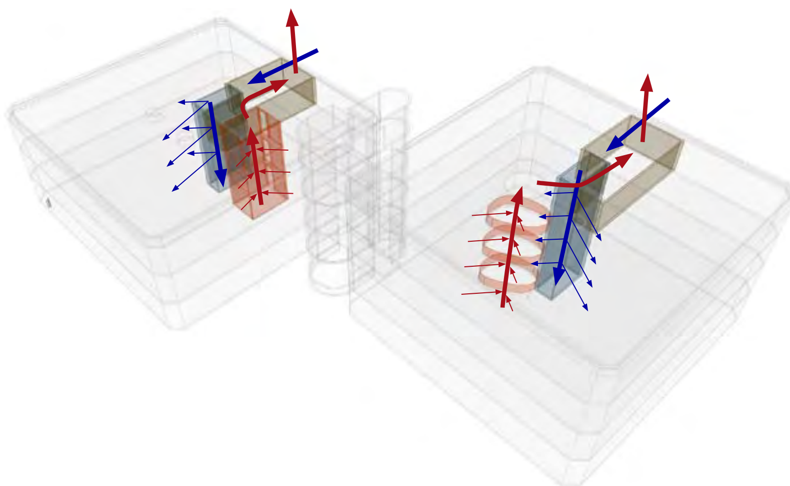
- 2 heat pumps with 10 energy wells that provide space heating and domestic hot water
- Approx. 1560m^2 photovoltaic panels placed on the roofs of the two office blocks
- Recovering waste heat from the server room

Photograph © Chris Aadland (Source: Snøhetta)

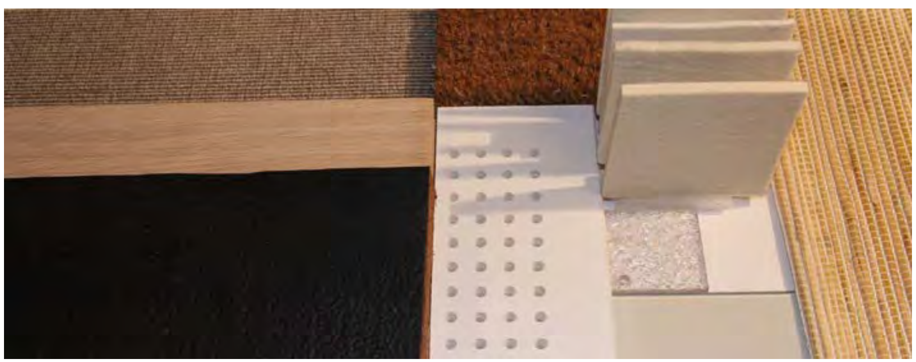
MATERIAL COMPONENTS

Materials have been reused or recycled wherever possible, for example the original façade glazing has been up-cycled into internal office partitions. In order to contribute to a good indoor climate, materials with low toxicity have been selected. Dynamic shading has also been installed to better regulate indoor climate.

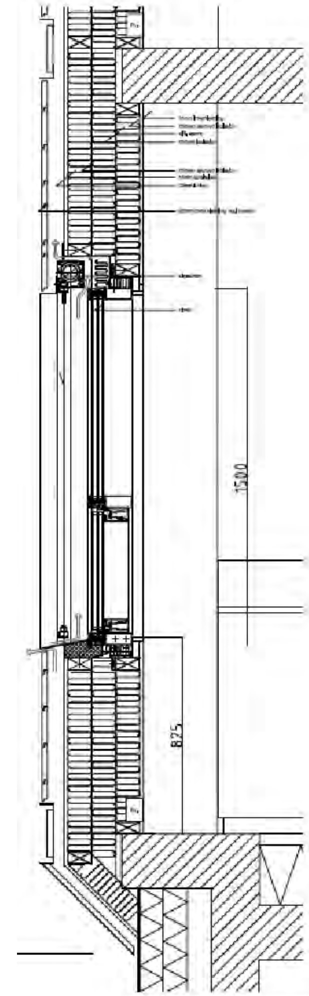
Integrated, holistic solutions have also been implemented to reduce environmental burdens. For example, the central stair core acts as a ventilation shaft, a light well and provides vertical circulation.



Illustrations © Snøhetta/MIR



Illustrations © Snøhetta/MIR



Illustrations © Snøhetta/MIR

Detaljutsnitt av ny klimavegg

EMBODIED ENERGY IN A POSITIVE ENERGY BALANCE

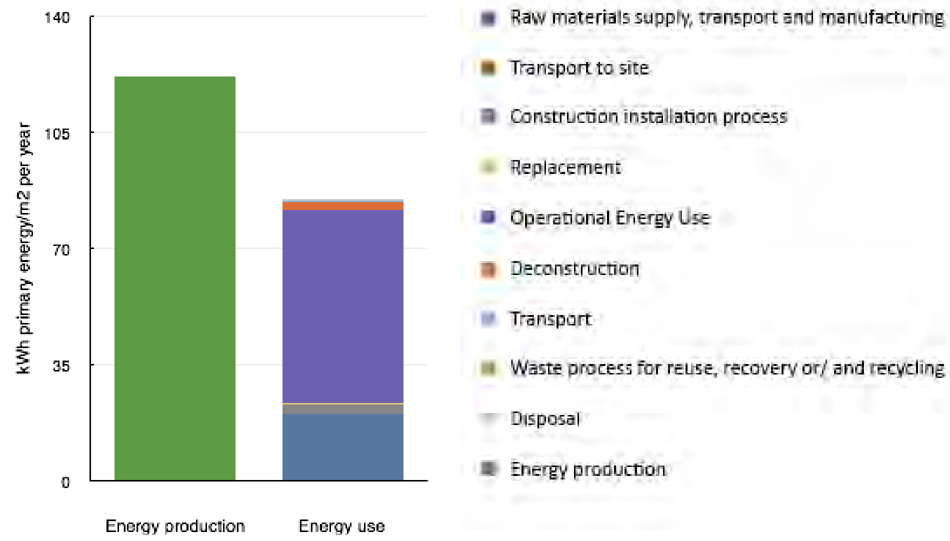
Operational energy use: 58.1 kWh/m$^2_{HFA}$/year

Energy generation: 121.8 kWh/m$^2_{HFA}$/year

Embodied CO_{2eq}(EG) emissions: 6.6 kg$CO_{2equiv.}$/m$^2_{HFA}$/year

Note: Appliances (plug loads) are not included in the operational energy use.

Lifetime: 60 years



The overall balance for primary energy and GHG emissions

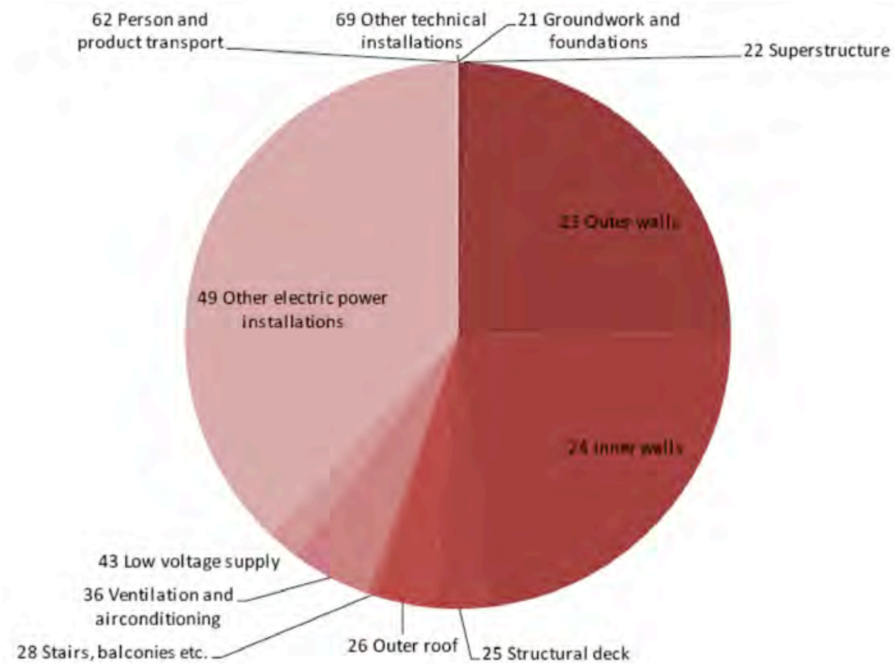
Life cycle stages		Primary energy balance	Balance of EG emissions
		kWh primary energy/m2 year	kg CO2 eq/m2 year
A1-A3	Raw materials supply, Transport and Manufacturing	20,11	3,77
A4	Transport to site	0,11	0,02
A5	Construction installation process	2,67	0,23
B4	Replacement	10,34	1,82
B6	Operational Energy Use - Energy demand	58,10	3,89
B6	Operational Energy Use - Energy production	-121,80	-7,03
C1	Deconstruction	2,67	0,23
C2	Transport	0,27	0,06
C3	Waste process for reuse, recovery or/ and recycling	0,11	0,02
C4	Disposal	0,47	0,43
Sum		-26,96	3,44

The graph above shows the energy use versus the energy production for the renovated office building. The overall balance can be found in the table and the negative sum means that there is surplus of produced energy. The results show that materials, transport, construction, deconstruction and end-of-life treatment make up 39% of the total lifecycle primary energy demand and 63% of the lifecycle CO_{2eq}(EG) emissions of which the production of materials and components make up about 85% in both cases.

EMBODIED EMMISSIONS: MATERIAL COMPONENTS

When looking at embodied CO_{2eq}(EG) emissions, it is possible to see that the 'other electric power installations', including the PV panels, is the largest contributor. The next largest contributor is found in outer walls, followed by the inner walls. This is due to the material use (concrete and steel) in the walls.

During the design process, decisions were made based on the environmental performance of different construction techniques. For example, internal partitions made of plasterboard and wooden studs were chosen, as they contain a smaller amount of embodied energy compared to inner walls consisting of steel studs or timber panelling.



Embodied CO_{2eq} (EG) emissions in materials and components distributed according to NS 3451:2009

Huntonitt/wooden studs/
glava

Key issues related to Annex 57:
1. Strategies in building design
6. Decision making process

Case Study NO9
Multikomfort Larvik

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a reference study period of 60 years. Embodied CO_{2eq} (EG) emissions were calculated for construction materials.

Embodied CO_{2eq}(EG) Emissions :
Material use: 5.96 $kgCO_{2equiv.}/m^2_{HFA}$/year

Operational energy use:
4.49 $kgCO_{2equiv.}/m^2_{HFA}$/year

Energy generation: 12.48 $kgCO_{2equiv.}/m^2_{HFA}$/year

The evaluation of different building parts, showed that emissions from photovoltaic panels (30%), low carbon concrete (11%) and windows (9%) were the largest contributors to total embodied emissions.

[1] ZEB ambition levels aimed for (ZEB/SINTEF, 2013):
ZEB-O: The building's renewable energy production compensate for greenhouse gas emissions from operation of the building.
ZEB-OM: The building's renewable energy production compensate for greenhouse gas emissions from operation and production of its building materials.

OBJECTIVES OF CASE STUDY

The Multikomfort house is an experimental plus-energy house, with a ZEB ambition level of ZEB-OM. The aim of the Multikomfort house project, is to demonstrate that a residential building can produce more energy than it requires from operational energy use and embodied material emissions, during the whole lifetime of the building. In this case, the surplus energy is used for charging an electric vehicle on-site. This study evaluates:

- Which materials and components in the Multikomfort house project contribute the most to embodied emissions?
- How much additional energy can be produced on-site?
- Embodied emissions, operational energy use and on-site energy production from photovoltaic panels in a ZEB energy balance.

BUILDING KEY FACTS

Intended use: Residential
Size: 203m² GFA
Location: Larvik, Norway
Building year: 2014
Architect: Snøhetta
Owner: Brødrene Dahl and Optimera
Structure: Glulam timber

Photograph © Paal André Schwital (Source: Snøhetta / EVE)

ZEB The Research Centre on Zero Emission Buildings
NTNU – Trondheim Norwegian University of Science and Technology
SINTEF
FME Forsknings-senter for miljøvennlig energi

SYSTEM BOUNDARIES AND SCOPE

Annex 57

Building life cycle stages included in the study, according to ISO EN 15978:

A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Next Product System			
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D1: Reuse	D2: Recovery	D3: Recycling	D4: Exported energy / Potential
x	x	x						[illegible]		[illegible]									

LCA BACKGROUND

Reference study period: 60 years

Databases used: EcoInvent v 2.2, SimaPro 7.3.3, EPDs

Standards/guidelines: ISO EN 15978: 2011

Method: IPCC GWP 2007 100 year scenario

Production stage modeling: All phases of the production stages have been included in the calculations. This includes the raw material supply, transport to manufacturer and manufacturing. Some composite construction materials were not available in the EcoInvent database, so raw material inputs have been used.

Operational stage modelling: The energy consumption in the building's operation stage has been modelled by the tool SIMIEN (Programbyggerne.no). The PV system was modelled by PVSyst while the heat pump and thermal solar systems were modelled by PolySun. Site-specific weather data from Meteonorm was used as input in the simulations.

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STANDARD NORGE (2009) *NS 3451: 2009 Table of Building Elements*. Oslo, Norway.

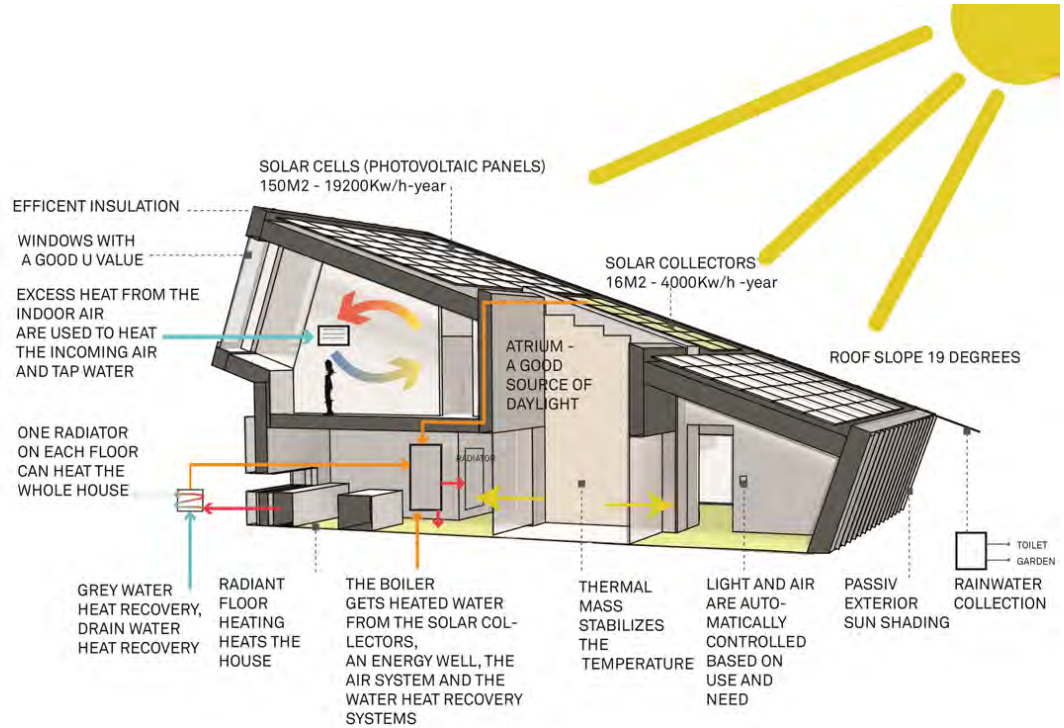
THE BUILDING

The Multikomfort house is characterised by a glue laminated timber structure, with a high performing thermal building envelope and building integrated photovoltaic panels and solar thermal collectors. A range of building materials have been used, including a brick thermal mass at the core of the building, reinforced concrete for the foundations, and an external timber cladding. Where possible, recycled materials have also been used. Excess energy is used to heat an outdoor swimming pool and power an electric vehicle on-sit.

ENERGY SUPPLY

The energy supply solution for heating, cooling and electricity is an 'all electric' solution, based on:

- 150m^2 photovoltaic panels
- 16m^2 solar thermal collectors
- Thermal mass for stable temperatures
- Grey water heat recovery
- Ground source heat pump



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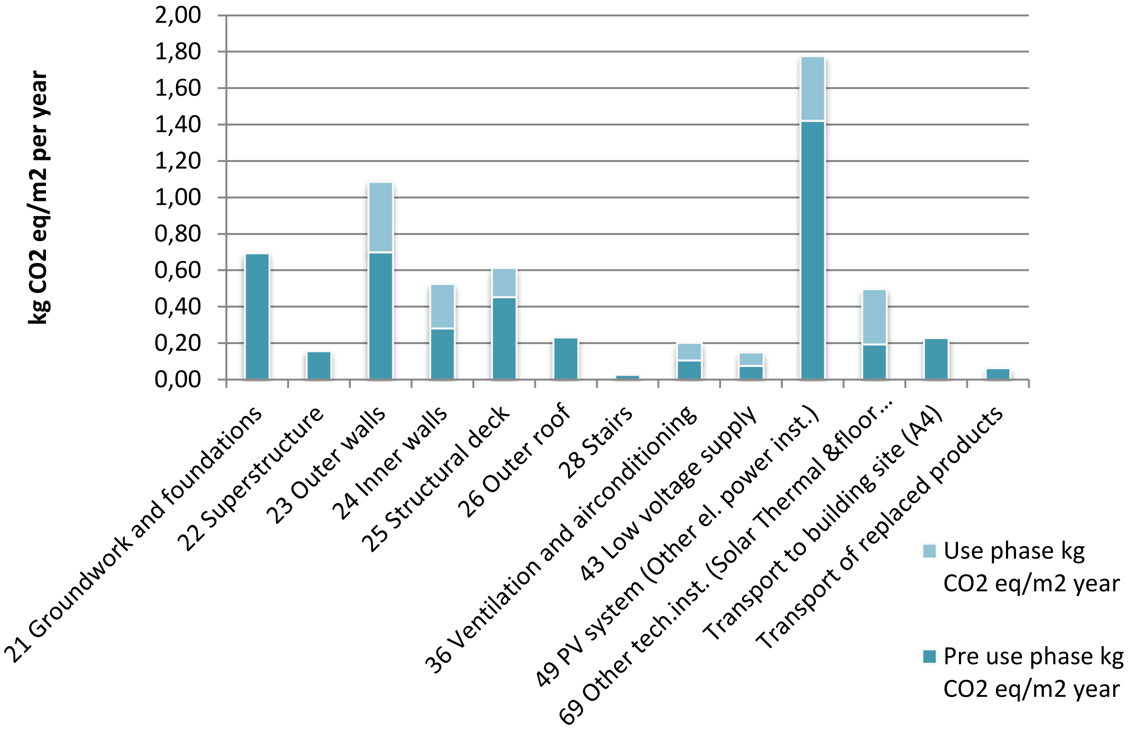
EMBODIED greenhouse gas BY COMPONENT



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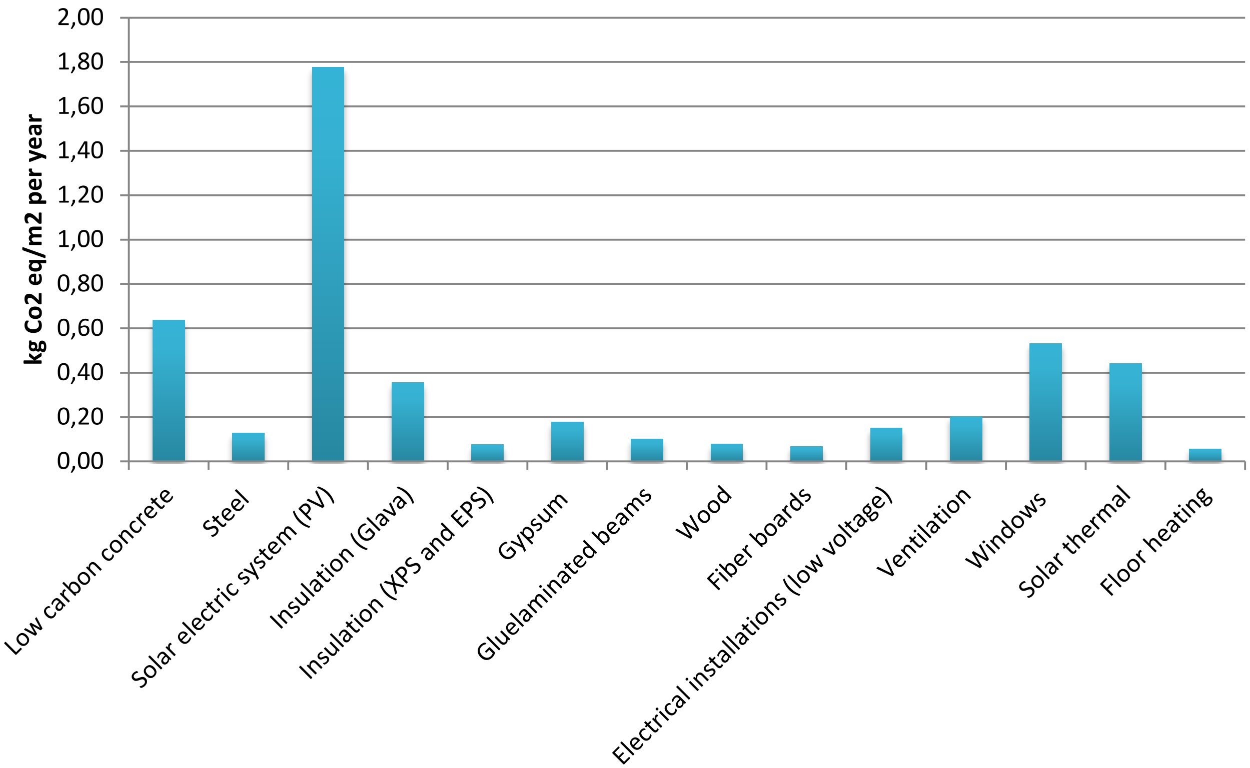
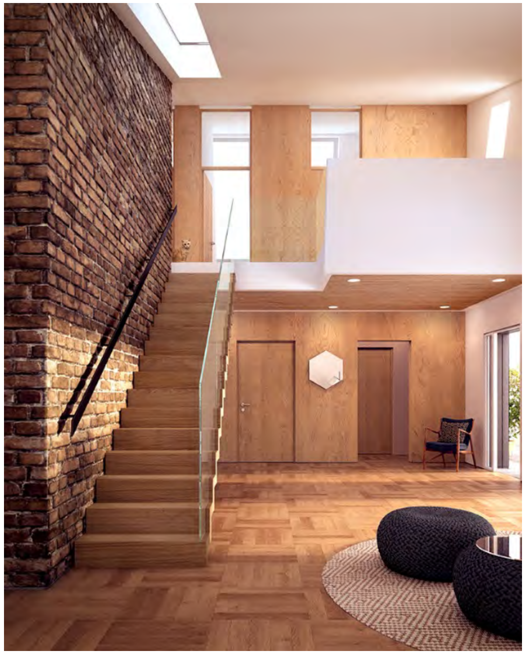
The bar chart shows embodied emissions by building component, as defined by NS 3451: 2009 Table of Building Elements. The bar chart shows that the majority of emissions originate during the production of photovoltaic panels, followed by the 'outer wall' and 'groundwork and foundations' components.

EMBODIED CO_{2eq}(EG) EMISSIONS BY MATERIAL



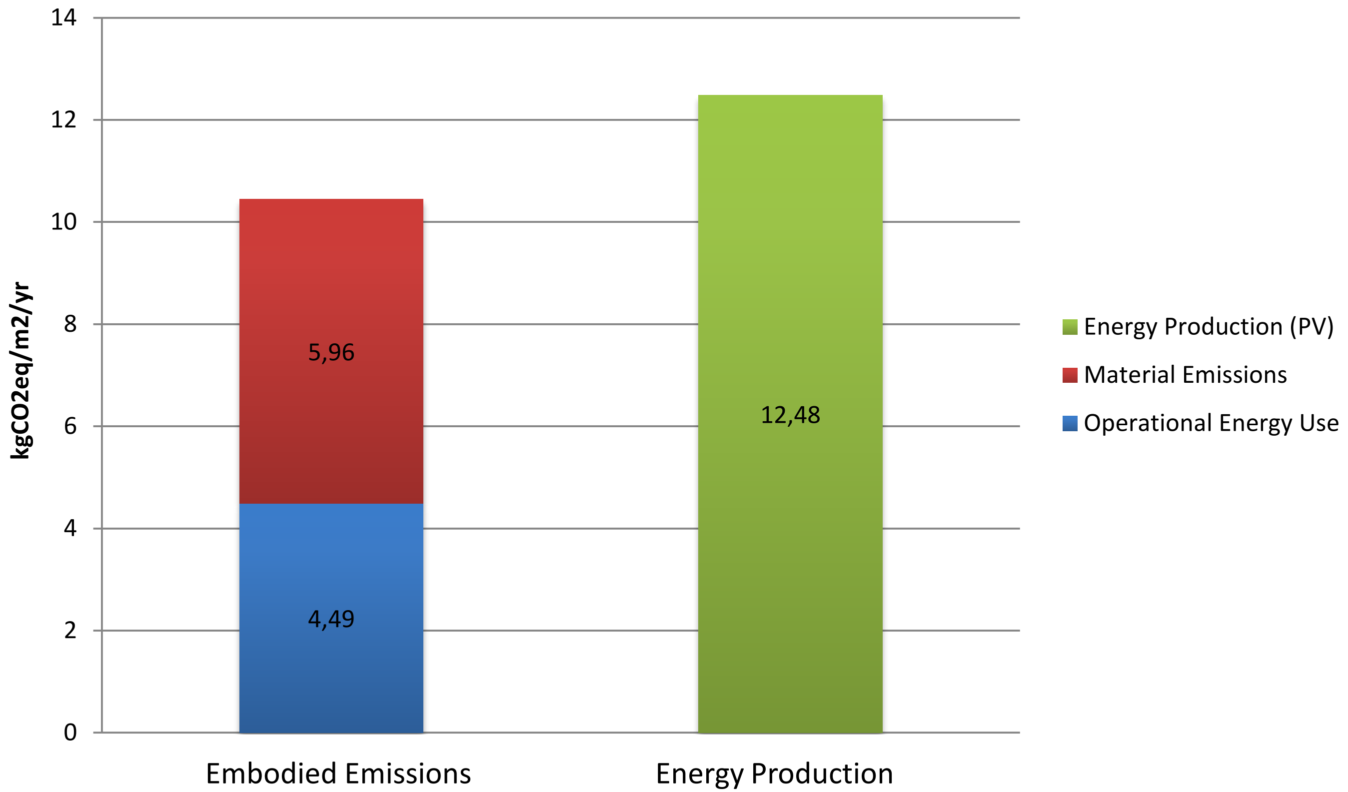


Photograph © Paal André Schwital
(Source: Snøhetta / EVE)

When looking at the bar chart results in terms of building materials, it is possible to see that the photovoltaic panels (30%), low carbon concrete (11%) and windows (9%) contain the highest amount of embodied emissions.

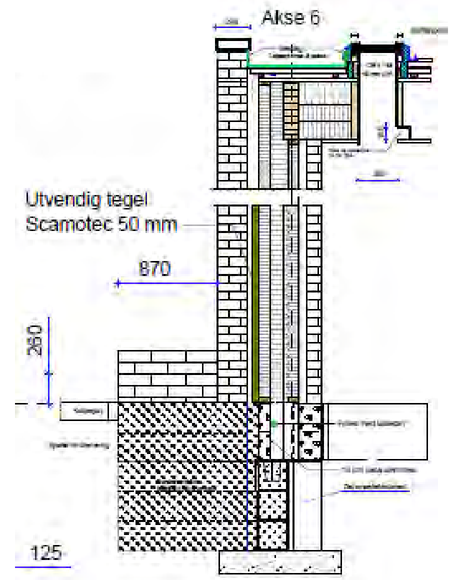
ZEB ENERGY BALANCE

The table opposite shows total emissions for the Multikomfort house in terms of a ZEB energy balance. The first column shows embodied emissions and operational energy use that is embodied in the whole building, during its 60 year lifetime. The second column shows energy production from photovoltaic panels on-site. The emissions from the electricity use and energy generation in the operational stage were calculated with an EU-27 power grid mix. It can be seen that there is a surplus of energy production, that can be used for heating the outdoor pool or charging an electric vehicle.



OBJECTIVES OF CASE STUDY

A sensitivity analysis of the Multikomfort house has been carried out, in terms of the choice of building material used in the outer walls. One scenario evaluates the use of low carbon concrete for the outer walls, whilst the other scenario evaluates reusing reclaimed bricks from a nearby old barn. There is also a base case scenario, that looks at embodied emissions relating to a traditional brick wall construction. This area of the building was focused upon, as it was shown that the outer walls and windows contribute significantly to total embodied material emissions.



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SYSTEM BOUNDARY AND SCOPE

This sensitivity analysis uses a Cradle to Gate system boundary. The functional unit is defined as $kgCO_{2eq}/m^2_{GFA}/yr$. The building life time is set at 60 years. Datasets from EcoInvent and product specific data from EPDs have been used.

REFERENCES

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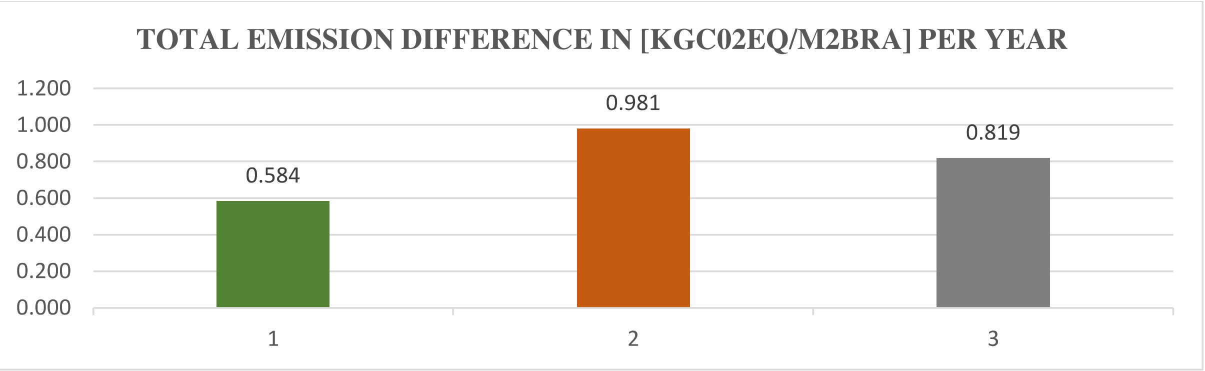
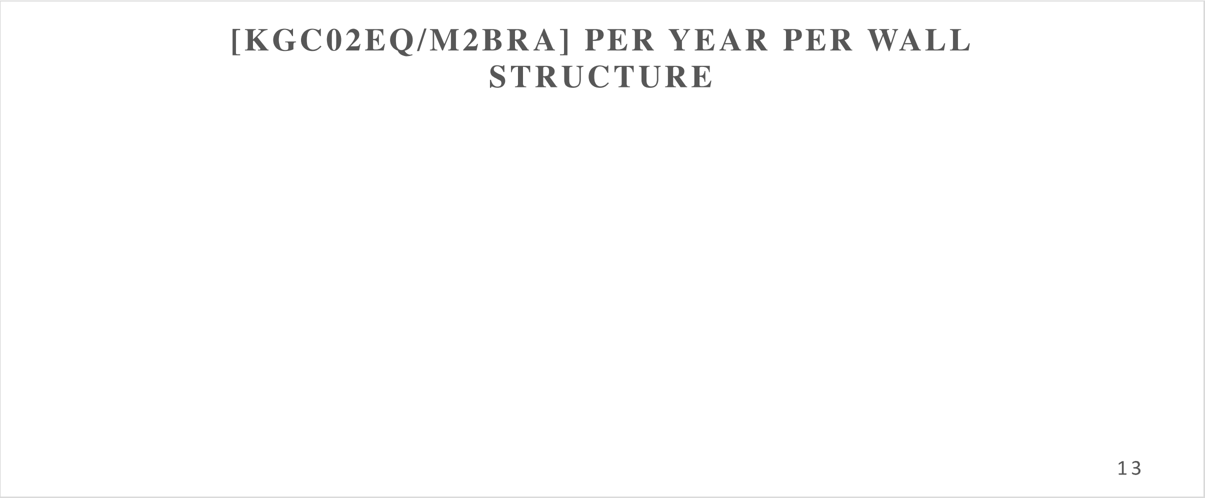
RESULTS

The first bar chart on the left, shows the embodied emissions for the three different scenarios. It shows that using reclaimed bricks has the lowest amount of embodied emissions, followed by using low carbon concrete. The base case scenario of using traditional bricks produces the most amount of embodied CO_2 emissions.

The second bar chart shows the embodied emissions for each of the 13 walls prescribed in the Multikomfort house. It clearly shows that the outer walls with the highest amount of embodied emissions originate from the traditional brick wall, whilst lower embodied emissions are experienced in the reclaimed brick wall and low carbon concrete wall.



	Reused Bricks	Traditional bricks	Low Carbon Concrete
Difference:		40%	29%



Sweden

Key issues related to Annex 57:
5.2 National level calculations
5.3 Life cycle stages
5.4. Life cycle analysis method

Case study SE1
Building sector - Sweden

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The building and real estate management sector accounts for around 28% of the total energy use and 20% of the total GWP of Sweden in 2005.

In 2007 around 35% of the energy use in the sector could be connected to construction and management activities (EE) and the rest with heating of buildings. For GWP, nearly 60% was associated with construction and management (EG) and the rest with heating of buildings.

Production of non-metallic mineral products (e.g bricks, concrete), transports and production of metals contribute significantly to the greenhouse gas emissions related to construction and management.

The study concludes that strategies to reduce climate change should not only prioritize heating of buildings but also include increased recycling, well-informed selection of building materials and choice of building methods that extend building life.

OBJECTIVES OF CASE STUDY

Assess the EE and EG of the entire Swedish building and construction sectors over a time series and compare it to the impact related to heating of buildings

CASE STUDY KEY FACTS

Location: Sweden

Study period: 1993-2007

KTH Architecture and the Built Environment

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	x	x		x	x	X	x	X		x				

LCA BACKGROUND

Reference study period: Impacts calculated per year in a time series 1993-2007
Calculation of Energy: includes energy losses
Calculation of GWP: Covers emissions of CO2, N2O and CH4 with characterization factors as implemented in Simapro 7.0
Databases used: Environmental accounts of Statistics Sweden (made up of the monetary input-output tables in the National Accounts to which emissions coefficients have been added)

Standards/guidelines: LCA based approach which uses IOA for the inventory step and LCA methodology for impact assessment.

REFERENCES

Toller, S, Carlsson, A, Wadeskog, A, Miliutenko, S, Finnveden, G. (2013). Indicators for environmental monitoring of the Swedish building and real estate management sector. Buiilding Research & Informations, vol. 41, no 2, pp. 146-155.

Toller, S, Wadeskog, A, Finnveden, G, Malmqvist, T, Carlsson, A. (2011). Energy use and environmental impacts of the Swedish building and real estate management sector. Journal of Industrial Ecology, vol. 15, no. 3, pp. 394-404.

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials used in the Swedish building and construction sector for one year are included (both manufactured in Sweden and imported). Environmental impacts of imported materials have been modeled using Swedish datasets, e.g concerning Swedish electricity mix. Construction stage includes modeling of environmental impacts associated with fuels used for working machines.

Operation stage modeling: Heating of buildings is modeled as all district heating produced in one year + Swedish electricity mix production for each year assuming that on average 20% of the heating each year is produced by electricity. User and property electricity during the use stage of buildings are omitted in the study.

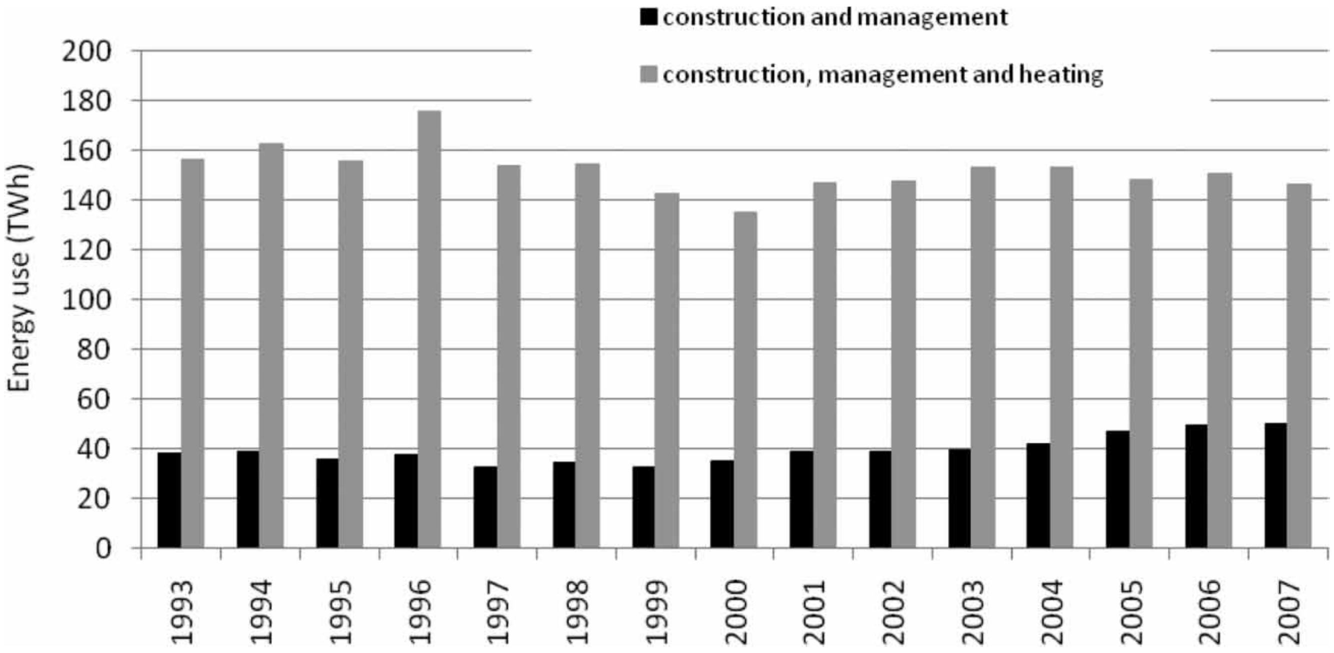
The replacements of building materials and components in the operation stage are not separately modeled but instead included in the impact modeling described above under “Production and construction stage modeling” and in the results referred to Management.

End of life stage and next product system modeling: Not included in the calculations apart from fuels used for deconstruction and demolition. This impact is not separated but included in the impact modeling described above under “Production and construction stage modeling”.

THE SECTOR

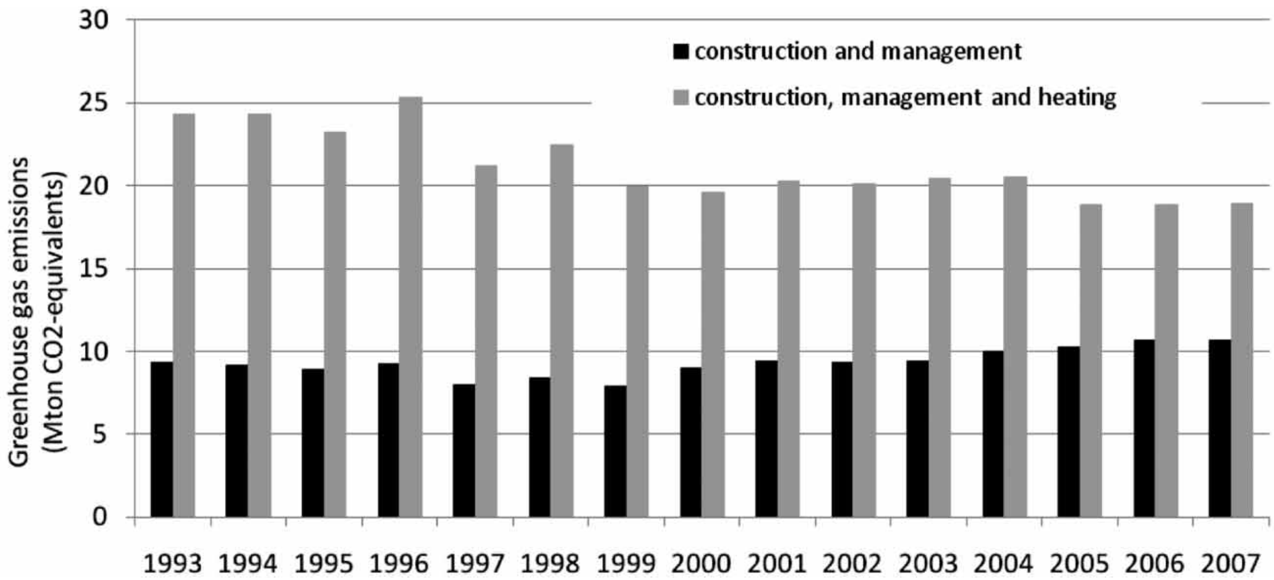
The study uses national accounts data from two separate industry branches: Construction activities and Facility management. The latter is quite well covering management and maintenance of buildings. The branch Construction activities includes both construction of buildings and of transport infrastructure (roads, railways, etc) which implies a methodological difficulty. In this study the part belonging to transport infrastructure has been deducted from the results, based on results of other LCAs of roads and railways. However, the share from the transport infrastructure was relatively small and the energy use, for example, constituted less than 10% of the energy use in the Swedish building and real estate management sector.

ENERGY USE OF THE SWEDISH BUILDING AND REAL ESTATE MANAGEMENT SECTOR



Energy use by the Swedish building and real estate management sector was 135–176 TWh/year in the period 1993–2007. Heating is included in these figures and it constituted the major part of the energy use. Considering only construction and management, energy use was between 32 and 51 TWh/ year and was equally distributed between construction and management.

EMISSIONS OF GREENHOUSE GASES OF THE SWEDISH BUILDING AND REAL ESTATE MANAGEMENT SECTOR



Emissions of GHG were between 19 and 25 Mton/ year, and there was a trend for decreasing emissions towards the end of the monitoring period. However, only for construction and management there was a slight increase over the period. Thus, while heating gave rise to the largest proportion of GHG emissions in the beginning of the period, construction and management became more important towards the end. The emissions not caused by heating were derived mainly (60–70% throughout the period) from construction. The most likely explanation for this trend is the transition from fossil fuels to renewable fuels for heat production in Sweden during this period.

Production of non-metallic mineral products (e.g bricks, concrete), transports and production of metals contribute significantly to the greenhouse gas emissions related to construction and management.

These results point out that important strategies to reduce the greenhouse gas emissions of the sector include increased recycling, well-informed selection of building materials and choice of building methods that extend building life.

Key issues related to Annex 57:
2.1 Life Cycle Stages
2.2 Significance of building elements and materials
6.1 Design process

Case study SE2a
Terrinen - Sweden

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period of years. The study showed that the building materials contributed with **47%** of Global Warming Potential (GWP).

EG: 3,3 kg CO_2 equiv. /$m^2_{\text{Net conditioned area}}$/year

Evaluation of different building parts showed the significance of the shell and core. The floor structure contributed with 55 % and External walls incl. windows and doors with 22% of the embodied GHGs. Evaluation of the different building materials showed that for EG, concrete contributed with 77% and steel with nearly 6%.

The rather low figure for EG can be a result of the simplifications of the calculations. Only main building elements are considered and no replacements of materials was undertaken during the life cycle.

KTH VETENSKAP OCH KONST
KTH Architecture and the Built Environment

OBJECTIVES OF CASE STUDY

To evaluate the Global Warming Potential (GWP) related to the life cycle of a new residential building in Sweden. The study evaluates:

- The significance of different life cycle stages and processes
- The materials contribution to the impacts compared to the total impacts
- The impacts related to different building parts
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Housing, multi-family

Size: 13944 m2 (NET conditioned area), 118 apts for housing and 41 apts for health care

Location: Sollentuna, Sweden

Architect: Joliark

Building year: Completed 2013


Source: Joliark

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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								X						

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: -
Calculation of GWP: GWP at 100 years: kg CO_2-Equivalents/m2,yr; (IPCC for 2007)
Databases used: Ecoinvent v2.0 (2007), Own Swedish data incl. in BECE-tool
Energy supply: Swedish electric mix 34 g CO_2e/kWh, District heating Sollentuna 50 gCO_2e/kWh
Energy demand: Heating: 50 kWh/m2,yr, Power: 40 kWh/m2,yr
Standards/guidelines: the BECE tool developed by KTH (excel)

REFERENCES

Mauritz Glaumann at KTH, Linda Turner at Skanska, Sollentunahem

About the calculation tool:

Wallhagen, M., Glaumann, M. and Malmqvist, T. (2011). Basic building life cycle calculations to decrease contribution to climate change - case study on an office building in Sweden. *Building and Environment, vol 46, issue 10, pp. 1863-1871*

Malmqvist, T, Glaumann, M, Scarpellini, S, Zabalza, I, Aranda, A, Llera, E, Díaz, S. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. (2011) *Energy, vol 36, issue 4, pp. 1900-1907.*

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials in main building elements (building envelope, slabs and internal walls) are included.

Operation stage modeling: The energy consumption in the building's operation stage is modeled with datasets representing Swedish power grid mix and average heating of the municipality´s current district heating mix . The energy demand estimated through a degree-day model. The dimensions of the building and the layers of the building envelop are inserted. Areas, U-values and amounts of materials are then calculated automatically. Default values for use of electricity are used (kWh/m2,yr).

The replacements of building materials and components in the operation stage are modeled by multiplying the amount with the building reference study period/service life for each building material.

End of life stage and next product system modeling: Not included in the calculations.

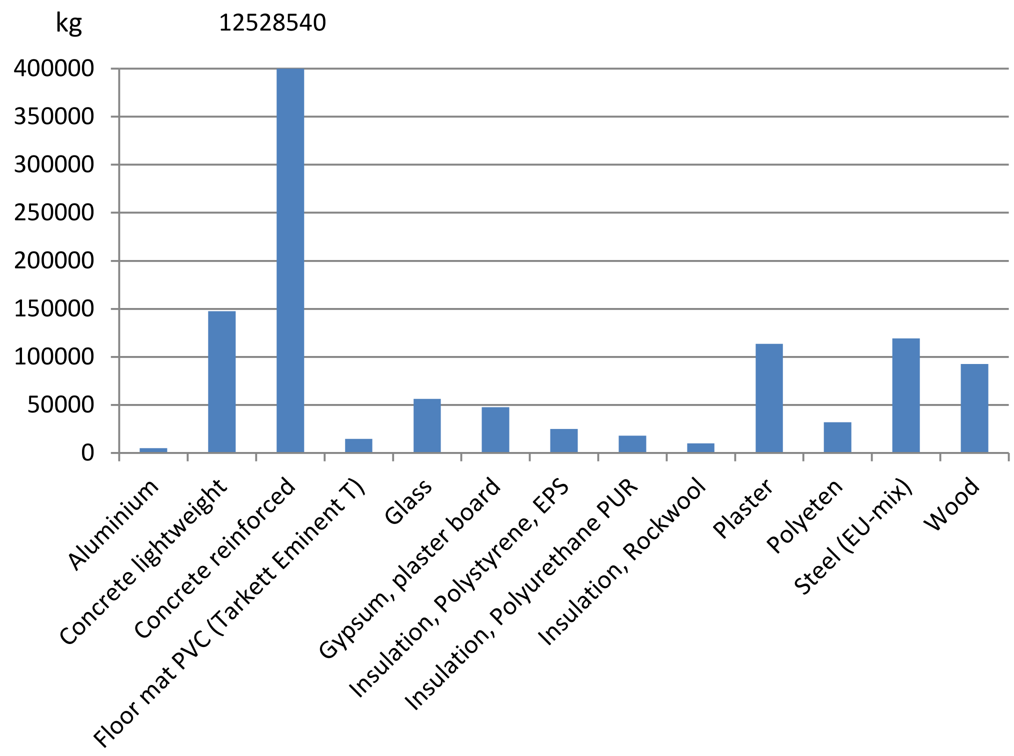
THE BUILDING

2 multi-family buildings with in total 159 apartments in 3-5 floors with concrete construction and plastered facades.

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated to approximately 13209 tons or 950 kg/m$^2_{NFA}$(not including gravel).

This calculation does not take different service life times into account and only the main building elements of the building. The reason for this simplification is to facilitate basic calculations in early design stages to take out a ”compass course” for how to achieve both a low operaitional energy use and low GWP over the life cycle.



Global Warming Potential

7,2 kg CO_2 equiv. /$m^2_{Net\ Conditioned\ Area}$/year

- construction materials: 47%
- operational energy: 53%

Embodied Global Warming Potential:

3,3 kg CO_2 equiv. /$m^2_{Net\ Conditioned\ Area}$/year

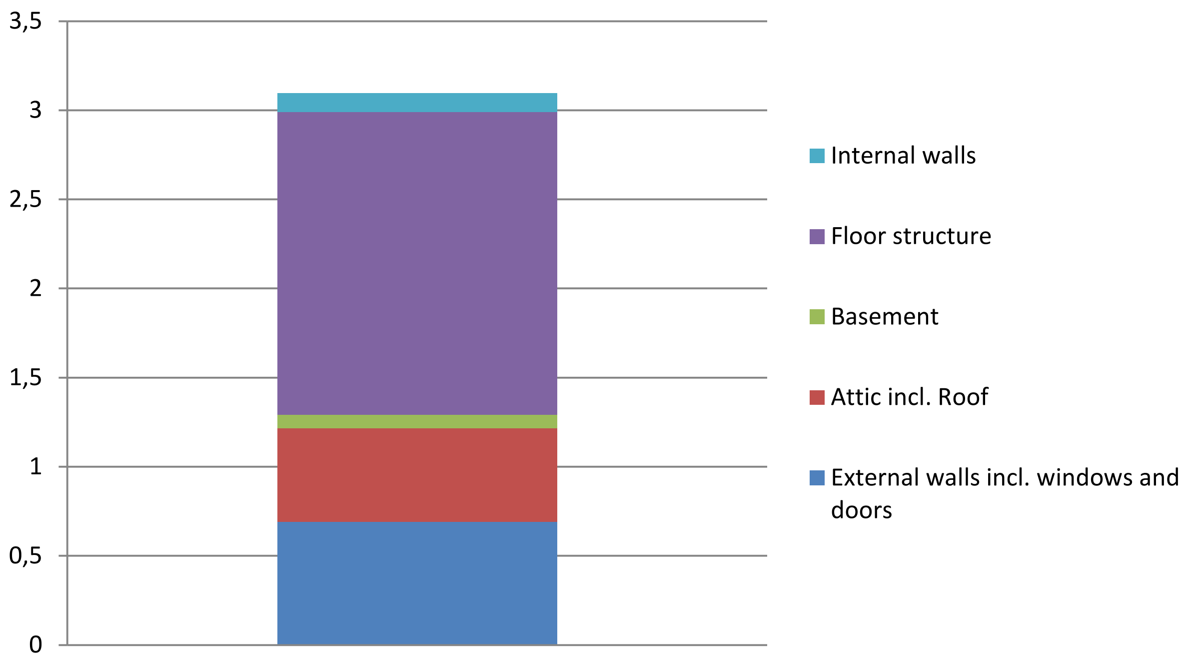


Figure 1: Contribution from the construction materials divided into 5 different building elements (kg CO2e/Net Conditioned Area/year). The impacts related to replacements of materials in the operation phase are not expressed here.

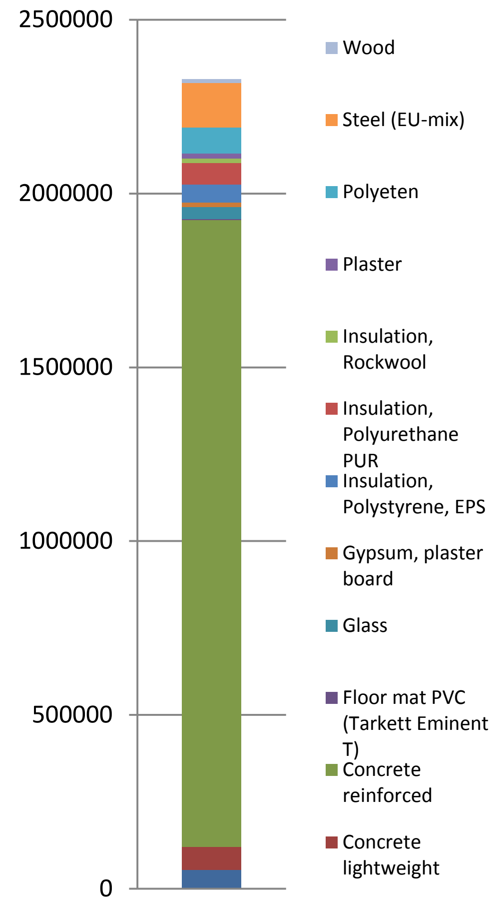


Figure 2: Contribution from the construction materials divided into different types of building materials (kg CO2e).

COMPARISON COMPLETED BUILDING TO ORIGINAL DESIGN

	As completed	Early design	Early optimised design**	
GWP*	5002	6398	2792	tons CO_2 equiv.
GWP*	7,9	10,6	4,7	kg CO_2 equiv. /m^2_{HFA}/year
EG	3,3	2,9	0,7	kg CO_2 equiv. /m^2_{HFA}/year
Energy demand	90	101	165	kWh/m^2_{HFA}/ year

•GWP over the 50 year study period including emissions related to operational energy use and embodied CO2e
**This proposal includes a wooden construction regarding shell and core of the building.

Conclusions

The final EG exceeds the estimated EG of the early design proposals. However when studying the GWP over the building life cycle, the GWP is still lower than the original design proposal despite the concrete construction which was finally chosen.

The study thus highlights the importance of not working with EG in isolation when optimising building design towards higher environmental performance.

Key issues related to Annex 57:
1.1 Selection of materials
2.1 Life Cycle Stages
6.1 Design process

Case study SE2b

Terrinen early design - Sweden

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

With help of an optimisation and calculation tool in early design stage, key improvements of the original building design were identified to reach targets concerning operational energy use and GWP over the life cycle.

Key improvements:
- Exchange the concrete to a wooden construction
- Ventilation heat recovery
- 350m2 solar collectors
- Waste water heat exchange
- 150 mm extra insulation external walls
- CO2 free building electricity
- Reduced window area

From 165 to 101 kWh/m^2_{HFA}/year
From 10,6 to 4,7 kg CO_2 equiv. /m^2_{HFA}/year

EG Concrete construction: 2,6 kg CO_2 equiv. /m^2_{HFA}/year
EG Wooden construction: 0,6 kg CO_2 equiv. /m^2_{HFA}/year

The low figure for EG can be assumed to be a result of the simplifications for use in early design stages – only main building elements are considered and no replacements of materials was undertaken during the life cycle.

OBJECTIVES OF CASE STUDY

Test potential design strategies to reduce the operational energy use and GWP over the life cycle further from the *early design proposal*

BUILDING KEY FACTS

Intended use: Housing, multi-family

Size: 12 110m²/39 465m³ (NET conditioned area)

Location: Sollentuna, Sweden

Architect: Joliark

Building year: Completed 2013

Source: Joliark

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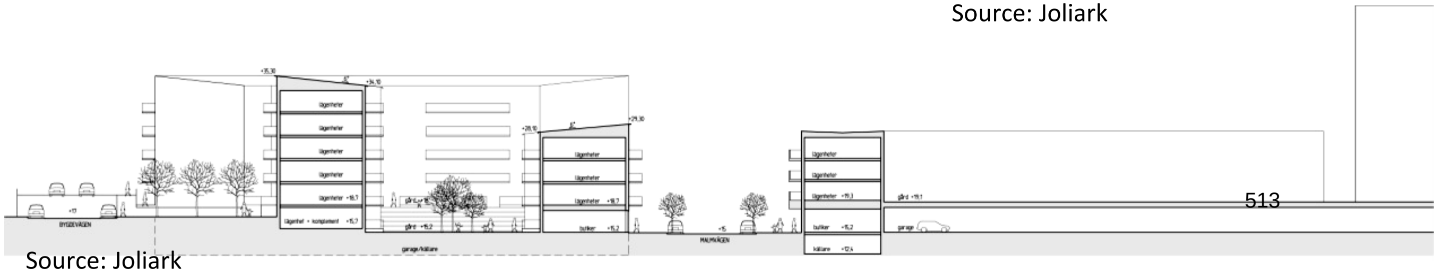


Source: Joliark

Building life cycle stages included in the study, according to EN15978

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								X						

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: -
Calculation of GWP: GWP at 100 years: kg CO_2-Equivalents/m2,yr; (IPCC for 2007)
Databases used: Ecoinvent v2.0 (2007), Own Swedish data incl. in BECE-tool
Energy supply: Swedish electric mix 34 g CO_2e/kWh, District heating Sollentuna 50 gCO_2e/kWh
Standards/guidelines: the BECE tool developed by KTH (excel)

REFERENCES

Case study: www.enslic.eu/case studies/KTH Case study 3

About the tool:

Wallhagen, M., Glaumann, M. and Malmqvist, T. (2011). Basic building life cycle calculations to decrease contribution to climate change - case study on an office building in Sweden. *Building and Environment, vol 46, issue 10, pp. 1863-1871*

Malmqvist, T, Glaumann, M, Scarpellini, S, Zabalza, I, Aranda, A, Llera, E, Díaz, S. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. (2011) *Energy, vol 36, issue 4, pp. 1900-1907.*

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials in main building elements (building envelope, slabs and internal walls) are included.

Operation stage modeling: The energy consumption in the building's operation stage is modeled with datasets representing Swedish power grid mix and average heating of the municipality´s current district heating mix . The energy demand estimated through a degree-day model. The dimensions of the building and the layers of the building envelop are inserted. Areas, U-values and amounts of materials are then calculated automatically. Default values for use of electricity are used (kWh/m2,yr).

The replacements of building materials and components in the operation stage are modeled by multiplying the amount with the building reference study period/service life for each building material.

End of life stage and next product system modeling: Not included in the calculations.

THE BUILDING

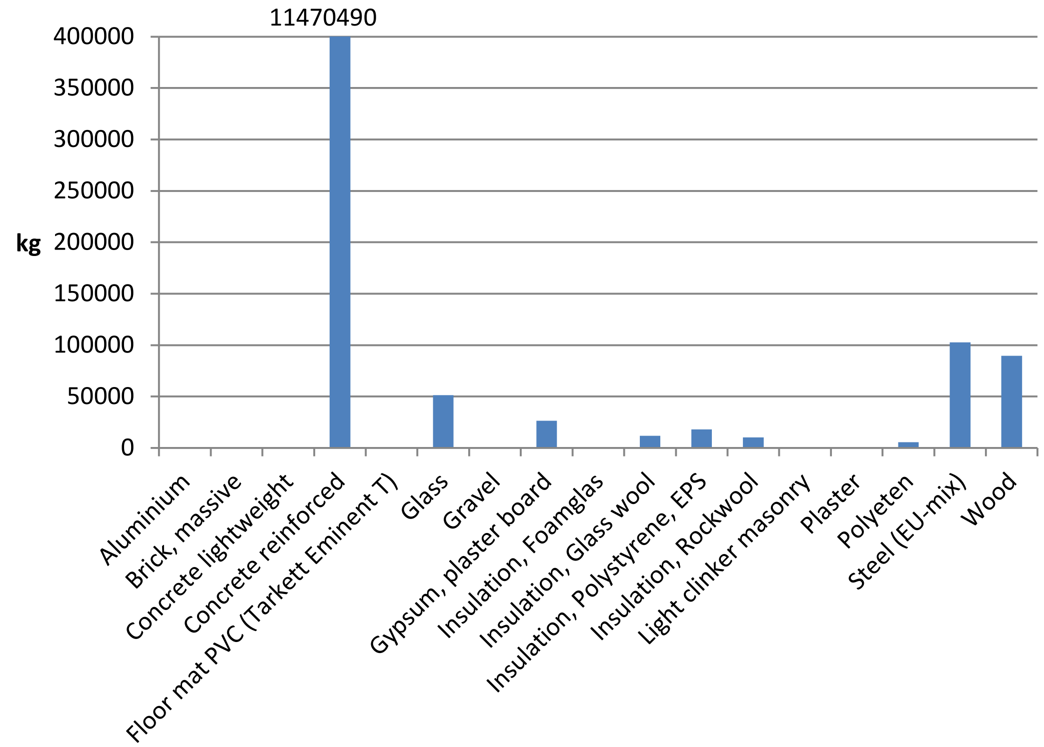
2 multi-family buildings with 130 apartments in 3-5 floors. The original early design of the building includes a concrete construction and plastered facades.

MATERIAL USE AND QUANTITIES

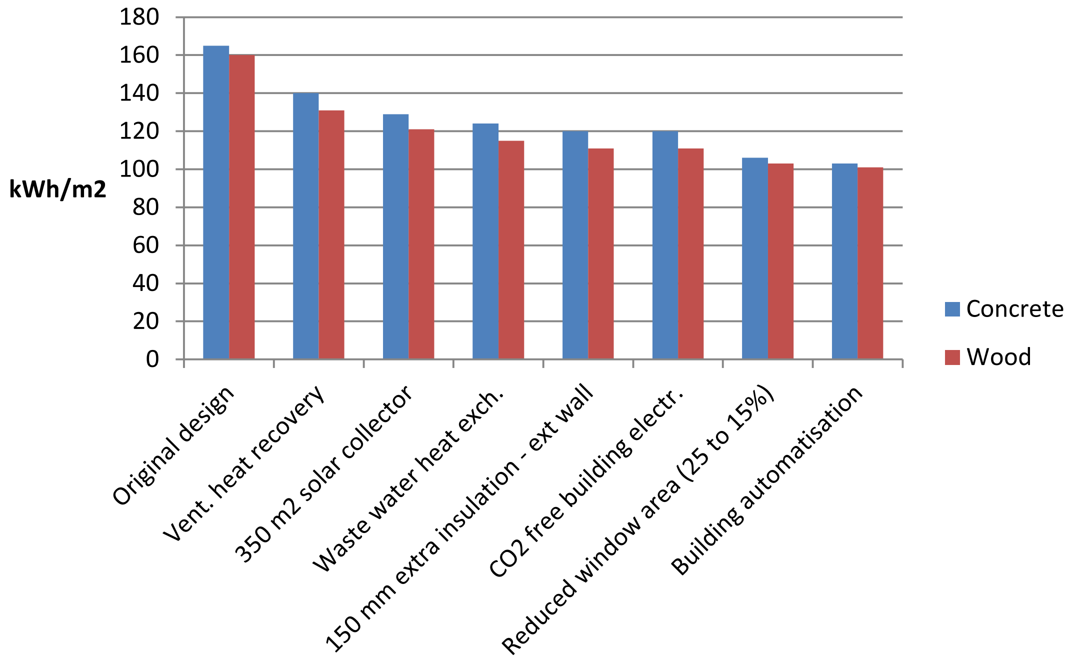
The total consumption of building materials is estimated to approximately 11800 tons or 970 kg/m^2_{NFA}(not including gravel).

This calculation does not take different service life times into account and only the main building elements of the building. The reason for this simplification is to facilitate basic calculations in early design stages to take out a ”compass course” for how to achieve both a low operaitional energy use and low GWP over the life cycle.

These amounts represent the original design of the building based on a concrete construction. After considering improvement of the building with reference to a energy and GHG budget, some changes incur.



OPTIMISING THE INITIAL CONSTRUCTION – ENERGY TARGET



First the initial early design was modeled and operational energy use and GWP was calculated. After that an optimisation process was initiated, trying out different potential improvement measures with the goal to gain understanding about key improvement measures if to reach as low operational energy use and as low GWP as possible in the final design.

The figure above shows the final suggestion of improvement measures after the optimisation process and the approximate possible reduction of energy demand that could be targeted.

Total Operational Energy demand:

Concrete construction

Original design: 165 kWh/m$^2_{HFA}$/year incl. building and user electricity: 39 kWh/m$^2_{HFA}$/year

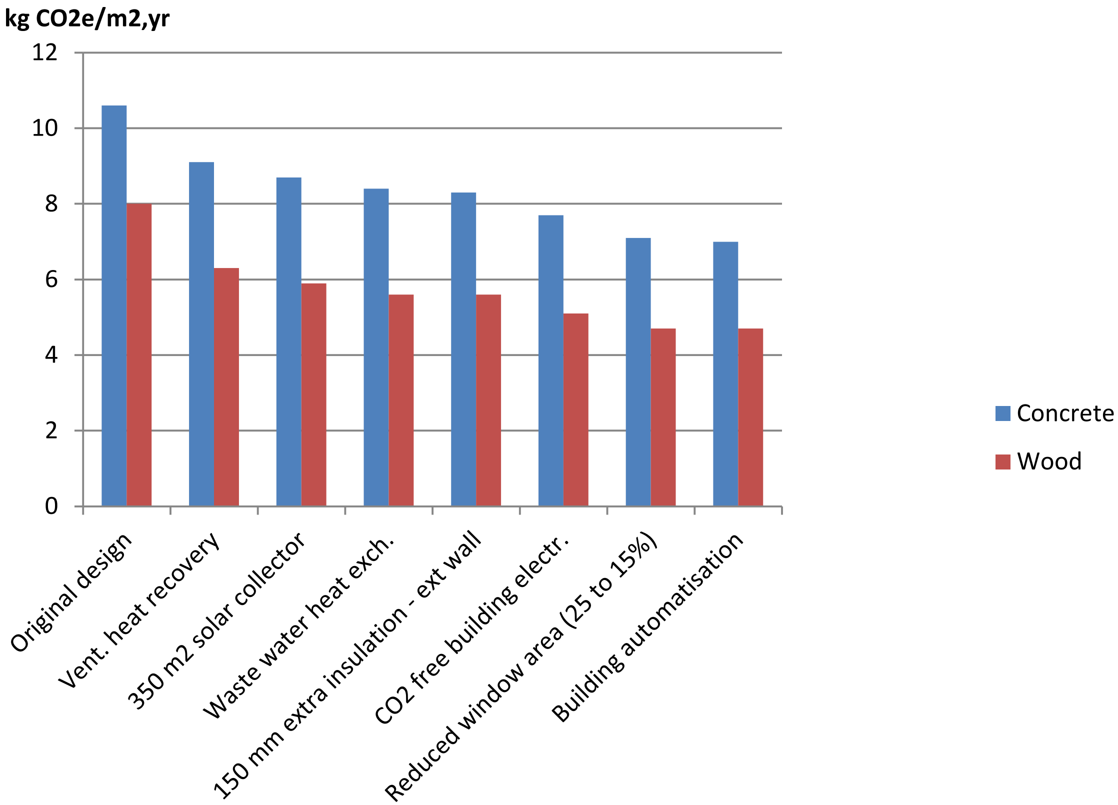
After improvements: 103 kWh/m$^2_{HFA}$/year incl building and user electricity: 46 kWh/m$^2_{HFA}$/year

Wooden construction

Original design: 160 kWh/m$^2_{HFA}$/year incl. building and user electricity: 39 kWh/m$^2_{HFA}$/year

After improvements: 101 kWh/m$^2_{HFA}$/year incl. building and user electricity: 46 kWh/m$^2_{HFA}$/year

OPTIMISING THE INITIAL CONSTRUCTION – CO2e TARGET



The figure above shows the final suggestion of improvement measures after the optimisation process and the approximate possible reduction of CO2e emissions that could be targeted.

Global Warming Potential:

Concrete construction

Original design:
10,6 kg CO_2 equiv. /m^2_{HFA}/year
- embodied: 28%
- operational energy: 72%

After improvements:
7,0 kg CO_2 equiv. /m^2_{HFA}/year
- embodied: 43%
- operational energy: 57%

EG: **2,9** kg CO_2 equiv. /m^2_{HFA}/year

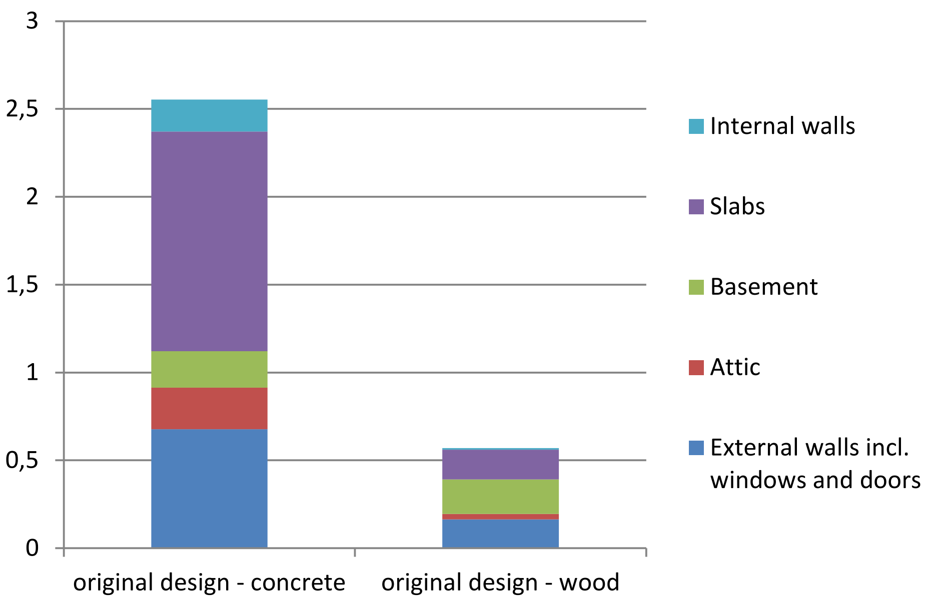
Wooden construction

Original design:
8,0 kg CO_2 equiv. /m^2_{HFA}/year
- embodied: 9 %
- operational energy: 91%

After improvements:
4,7 kg CO_2 equiv. /m^2_{HFA}/year
- embodied: 16%
- operational energy: 84%

EG: **0,7** kg CO_2 equiv. /m^2_{HFA}/year

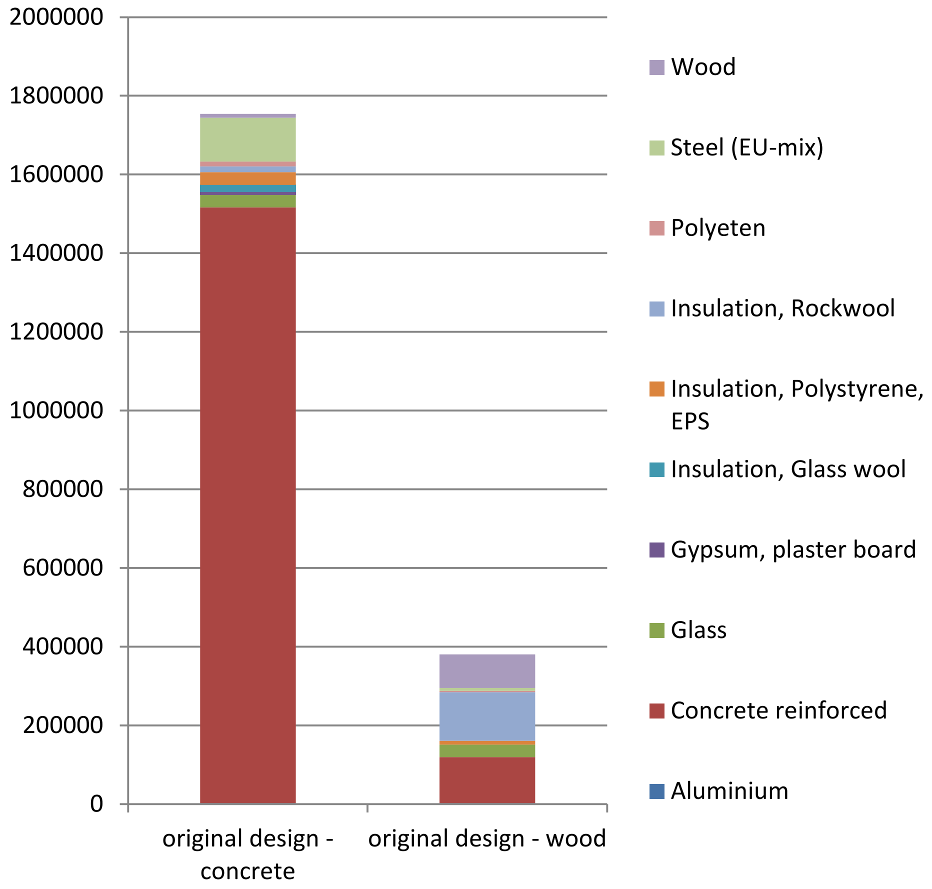
EMBODIED CO2e (kg CO2e/m2*y)



Impact of simplified calculation method
The values for embodied CO2e in this study can be assumed to be a result of the simplifications implemented in the optimisation and calculation tool . The tool aims to identify in early design stage key design and technical features to focus in the design process in order to reach a low operational energy use and low GWP over the life cycle for the building.

This implies that values like the ones presented in the figure to the left are lower than if a more global calculation is done for the final design. In this calculation only main building elements elements are considered and no replacements of materials was undertaken during the life cycle.

EMBODIED CO2e (kg CO2e)



Key issues related to Annex 57:
1.1 Selection of materials
1.4 Design choices

Case study SE3

Large ZEB single family home Sweden

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

A large single family house built to net zero energy (operation) demand was used as a case to evaluate the effect of different design alternatives to mitigate lifetime GWP.

	Lifetime GWP, kg CO2-e/m2, year		
	EG	operational energy	Total
Original building	4.4	0	4.4
Timber/cellulose external walls instead of concrete/rockwool	3.2	0	3.2
300 mm Rockwool in attic instead of 500 mm	4.15	0.15	4.3

These results demonstrate that in the case of zero energy buildings, material choice affects the total lifetime GWP significantly. As with many other cases concrete in the original design is responsible for the majority of the total lifetime material GWP, and by replacing the walls with timber, GWP can be reduced by approx. 25 %. It should however be noted that EGfor solar panels and photovoltaics was not part of this calculation.

The study also showed that with some changes to the design to allow more residents per unit area, the GWP per resident can be halved from 200 kg CO2-e/dwelling to 100 kg CO2-e/dwelling.

OBJECTIVES OF CASE STUDY

The aim of this study was to examine the lifetime GWP du to a single family home with zero external operational energy demand. The BECE simplified tool used for analysis was also used to assess the contribution that certain design measures could make to further reduction of GWP, specifically:

- Replacing concrete/rockwool external load-bearing walls with timber/cellulose fibre external load-bearing walls
- Reducing rockwool thickness in attic to 300 mm from 500 mm.

The study also investigated the possibility of changing design parameters to accommodate more living space and more residents

BUILDING KEY FACTS

Intended use: Single Family House
Size: 173 m^2 (HFA)
Location: Uppsala, Sweden
Architect: *Ross Arkitektur & design AB*
Year: 2010

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KTH Architecture and the Built Environment

Source: Ross Arkitektur & design AB

Building life cycle stages included in the study, according to EN15978

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								X						

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Total Bought energy demand for operational energy use: Space heating, hot water, user electricity and building electricity
Calculation of GWP: IPCC (4AR) characterisation, 100 years
Databases used: EcoEffect project data, BEAT (Danish tool for building LCA) and EcoInvent
Energy supply: Nordic electricity mix: 100.0 g CO_2-e/kWh
Standards/guidelines: Applied the ENSLIC guidelines (see reference below) for assessing design choices in the early stages of construction

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials in main building elements (external and internal walls, foundation, floor slabs, attic and roof, windows and external doors) are included. Mechanical and electricial installations (including on site energy production facilities e.g. solar panels, heat pump) and surface coverings are not included.

Operation stage modeling: Building's initial operational energy use calculated with BECE simplified degree-day model. Use stage energy includes all bought energy: Building and user electricity, and space heating and hot water. GWP for bought energy carriers based on typical Swedish data. No other impacts due to the operational stage are considered. Note building operational energy entirely from on-site solar and wind.

End of life stage and next product system modeling: Not included in the calculations.

REFERENCES

About the case:

Juliana Nakao, Tove Malmqvist and Mauritz Glaumann, 2011. Basic analysis to minimize contribution to climate change at building design - a Swedish case study, Integrated approach towards sustainable constructions, Department of Civil and Structural Engineering, University of Malta.

Nakao, J. 2010. *A comparison of a low energy building and a standard house from the life cycle assessment perspective.* SoM EX 2010-32. Stockholm: KTH Department of Urban Planning and Environment, Division of Environmental Strategies Research.

About the BECE tool:

Malmqvist, T, Glaumann, M, Scarpellini, S, Zabalza, I, Aranda, A, Llera, E, Díaz, S. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. (2011) *Energy, vol 36, issue 4, pp. 1900-1907.*

BUILDING DESCRIPTION - INVENTORY

Annex 57

These amounts represent the original design of the building based on a concrete construction. Design improvement measures imply some changes to this initial inventory

THE BUILDING

The initial building is a large single family house for four residents, built to net-zero energy standards. Load-bearing external walls on concrete foundation, aerated concrete internal walls, concrete internal slabs, aluminium roof. Building energy demands are met with solar PV, a small wind turbine, solar thermal panels and an air-source heat pump.

Design alternatives considered include i. replacing external walls with wooden load-bearing external walls with cellulose fibre insulation and ii. Reducing thickness of rockwool in attic from 500 mm to 300 mm.

MATERIAL USE AND QUANTITIES

The total material demand is estimated to be 140 tons. The breakdown of calculated material demand for the building is shown in the table on the right hand side below. For convenience the table also shows the GWP due to materials.

This calculation does not take different service life times into account and only the main building elements of the building. The reason for this simplification is to facilitate basic calculations in early design stages to take out a "compass course" for how to achieve both a low operaitional energy use and low GHG emissions over the life cycle.

	kg material	EG, kg CO2e	EG, kg CO2e/m2, year	EG proportion
Aluminium	513	5712	0.66	15%
Concrete lightweight	16905	7607	0.88	20%
Aerated concrete	102260	13498	1.56	35%
Glass	1783	1079	0.12	3%
Gypsum, plaster board	4862	1459	0.17	4%
Insulation, Polystyrene, EPS	1919	3460	0.40	9%
Insulation, Rockwool	2320	3387	0.39	9%
Plaster	4749	518	0.06	1%
Polythene	366	782	0.09	2%
Wood	4987	558	0.06	1%
TOTALS	140664	38060	4.4	100%

	THICKNESS (mm)	U-VALUE (W/m^{2}K)
External wall (EPS, Reinforced concrete, Polyethene, Wood, Gypsum, Plaster)	514	0,15
Roof (Gypsum, Wood, Rockwool, Wood, Air gap, Aluminum)	643	0,09
Basement (Concrete, Plastic film, EPS)	500	0,09
Floor Structure (Gypsum, Wood, Concrete)	306	Not relevant
Internal wall type 1 (Concrete lightweight, Plaster)	150	
Internal wall type 2 (Concrete lightweight, Plaster)	120	Not relevant
Window (Wood, Glass, Air gap)	Not relevant	0,8
Door (Wood, Glass, Air gap)	Not relevant	1,2

ENERGY BALANCE FOR BUILDING

The table below shows the energy balance for the building in the original design specification and how energy demands are met by onsite renewable energy technologies

	kWh/m², year
Electricity demand	58
Heat demand	68
Total energy demand	126
Onsite electricity production	
Photovoltaics	-66
Small wind turbine	-2.6
Total onsite electricity production	-68.6
Air source heat pump	-45.6
Solar panels	-12.7
Total onsite heat production	-58.3
Total onsite energy production	-126.5

GWP DUE TO INTITAL DESIGN AND AFTER IMPROVEMENT MEASURES

The table below shows the calculated lifetime GWP for the original building and two different design improvements (that are assumed to be implemented separately).

	Lifetime GWP, kg CO2-e/m2, year		
	EG	operational energy	Total
Original building	4.4	0	4.4
Timber/cellulose external walls instead of concrete/rockwool	3.2	0	3.2
300 mm Rockwool in attic instead of 500 mm	4.15	0.15	4.3

In a further analysis, the lifetime GWP is assessed *per resident* instead of *per unit area* after decreasing the envelope area and increasing the heated floor area. The original building contained 4 people, compared with the new design that could house 7 people. This changed the total GWP from 200 kg CO2-e/year to 100 kg CO2-e/year.

The table below shows a breakdown of the lifetime GWP of the original design of the building in terms of the constituent building elements

	kg/m^2	%	$kg\ CO_2$-equiv./m^2.yr	%
External walls including windows and doors	475	58%	1,7	38%
Attic	37	5%	1,2	26%
Basement	44	8%	0,5	12%
Slabs	160	20%	0,4	10%
Internal walls	80	10%	0,6	14%
Total	797	100%	4,4	100%

Global Warming Potential:

Original design:

4.4 kg CO_2 equiv. /m^2_{HFA}/year

- embodied (A1-3): 100%
- operational energy use (B6): 0%

Change in external wall:

3.2 kg CO_2 equiv. /m^2_{HFA}/year

- embodied (A1-3): 100%
- operational energy (B6): 0%

Reduction of insulation thickness

4.15 kg CO_2 equiv. /m^2_{HFA}/year

- embodied (A1-3): 97%
- operational energy (B6): 3%

Key issues related to Annex 57:
1.1 Selection of materials
1.4 Design choices, building form, space efficiency
2.1 which stages in the life cycle of the building are most important?
3.1 Length of the reference study time
6.1 LCA integrated into the design process

Case study SE4

Multi-family buildings greater Stockholm

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The assessment showed that in all cases of electricity supply mix and RSP considered (see "objective of case study", right) the timber alternatives for load-bearing construction material were demonstrably favorable (on the basis of lifetime GWP) to the concrete. Therefore the choice of material was shown to be a significant factor for life-cycle impact. However, the sensitivity analysis showed a great variation in: a. calculated GWPs for a given load-bearing material (maximum values 100 % greater than minimum values for a given material), b. "advantage" for timber as compared to concrete (100 to 35 % lower lifetime GWP) and c. the share between product stage and operational energy GWP (from 16 % product/84 % operational energy to 59 %/41 %).

It was further showed that the square building form consistently had about 5 % lower lifetime GWP than the rectangular building form. This follows closely the difference in the ratio of total envelope area/total heated floor area for the forms.

The case is an example of the application of life-cycle thinking in the early stages of a development process.

OBJECTIVES OF CASE STUDY

The aim of this study was to evaluate the effect that two different building forms:

- Square cross-section and
- Rectangular cross-section

And three different load-bearing construction material choices:

- Laminated wood
- Timber stud-wall and
- Concrete

Have on the life-cycle global warming potential (GWP) for new multifamily buildings in Greater Stockholm assessed per unit heated floor area and year. Design specifications were determined by the fact that it is intended that the buildings achieve the Nordic passive house standard and Miljöbyggnad Gold (highest rating for Swedish environmental rating tool). The case is based on work carried out for a developer in the planning phase of the project. To understand the effect of significant and uncertain parameters assessment was performed for two different reference study periods (RSP):

- 50 years and
- 100 years

And for different assumed electricity mixes, of which those that are presented here include:

- Swedish hydropower (reflecting the choice of "green electricity") and
- Nordic mix (better reflecting the current actual status of supply in the Nordic countries)

Heating in both cases is supplied by district heating according to the supply mix for the local network.

BUILDING KEY FACTS

Intended use: Multi-family residential
Size: 383 m^2 HFA, 2 x 3 room apartment (square); and 452m^2 HFA (rectangle), 1 x 6 room apartment
Location: Greater Stockholm, Sweden
Building year: Breaking ground 2015

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study (according to EN15978)

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								X						

LCA BACKGROUND

Reference study period: 50 and 100 years
Calculation of GWP: IPCC (4AR) characterisation, 100 years
Databases used: EcoEffect project data, SBi database and EcoInvent
Energy supply: Varied in sensitivity analysis: Thermal energy from district heating (municipal supply) and user and property electricity (Nordic mix, Swedish hydropower)
Standards/guidelines: N/a

REFERENCES

BROWN, N. W. O. 2013. Basic Energy and Global Warming Potential Calculations at an Early Stage in the Development of Residential Properties. *Sustainability in Energy and Buildings, SEB'12.* Stockholm, Sweden: Springer.

MALMQVIST, T., GLAUMANN, M., SCARPELLINI, S., ZABALZA, I., ARANDA, A., LLERA, E. & DIAZ, S. 2011. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. *Energy,* 36**,** 1900-1907.

EcoEffect data:

ASSEFA, G., GLAUMANN, M., MALMQVIST, T., KINDEMBE, B., HULT, M., MYHR, U. & ERIKSSON, O. 2007. Environmental assessment of building properties - Where natural and social sciences meet: The case of EcoEffect. *Building and Environment,* 42**,** 1458-1464.

The case applies the ENSLIC/BECE simplified method for LCA in the early stages of a construction project (Malmqvist et al. 2011).

Production and construction stage modeling: Inventory of material demand was calculated based on initial architectural sketches (see next slide) and specifications, and detailed cross-sectional drawings of each significant building element (i.e. external wall, internal walls, foundation etc. obtained from contractors for each load-bearing material alternative considered). The inventory specifically excluded surface coverings, HVAC installations and internal doors. Documentation according to ISO standards was requested from contractors referring to material lifetime and GWP. None could be provided and therefore reference data from the BECE/ENSLIC tool was used (see info. On the same slide).

Operation stage modeling: During operation only impacts from operational energy demand are considered. Operational energy demand was calculated based on a simple method developed specifically for passive houses, see Brown (2013). Active space heat demand was calculated based on monthly climate data, building dimensions, material specifications, and assumed internal gains. Relevant literature values were used for property and user electricity, domestic hot water and occupant heat gains. As shown in the table to the left, material replacement and other actions during the use stage were excluded from the assessment. As documented on the previous slide, two different mixes for use stage electricity were assumed in sensitivity analyses.

End of life stage and next product system modeling: End-of-life modelling was excluded from the assessment.

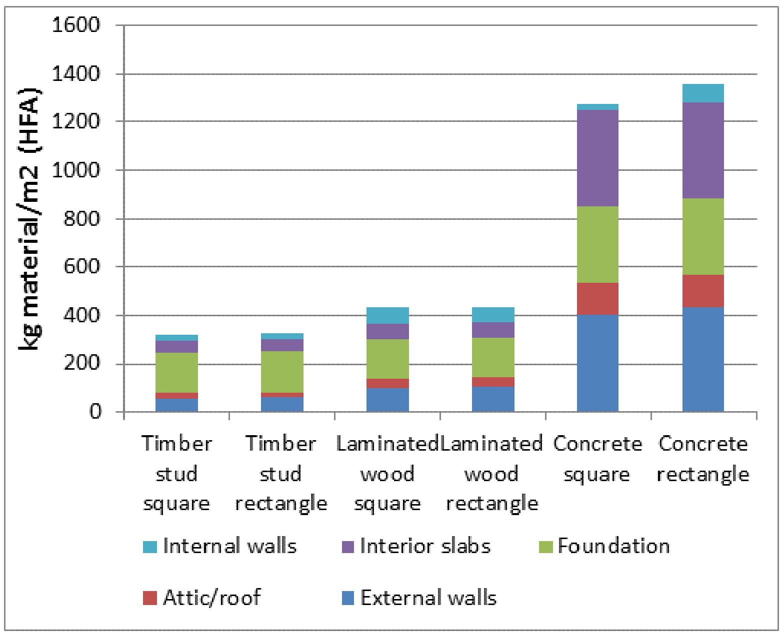
BUILDING DESCRIPTION - INVENTORY

Annex 57

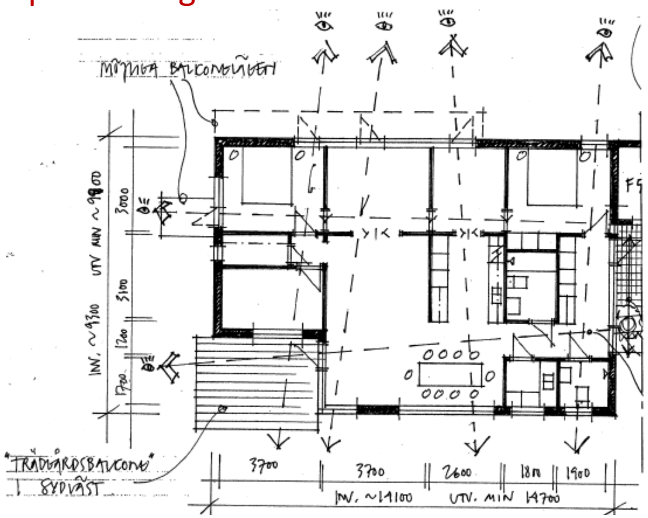
STRUCTURAL ALTERNATIVES

	Laminated wood	Stud-wall timber	Concrete
Load-bearing walls	Solid laminated wood	timber stud-walls	Reinforced concrete
Dwelling separating walls	Gypsym, mineral wool, timber stud-walls	Gypsym, mineral wool, timber stud-walls	Reinforced concrete
Other separating walls	Laminted wood, gypsum	Timber stud walls, gypsum	Steel stud walls, gypsum
Insulation (external wall and attic)	Mineral wool	Mineral wool	PIR-foam
Slabs/attic	Laminated wood, mineral wool, gypsum	Timber stud, mineral wool, gypsum	Reinforced concrete, mineral wool
Foundation	Reinforced concrete slab, XPS insulation		
Roof	Wooden saddle roof, aluminium sheeting		
Windows	Al-clad, wooden 3 glass, Low-E coated, argon filled		
Doors	Wooden with XPS insulation		
Facade	Wood panel		

Material demand



Square Design



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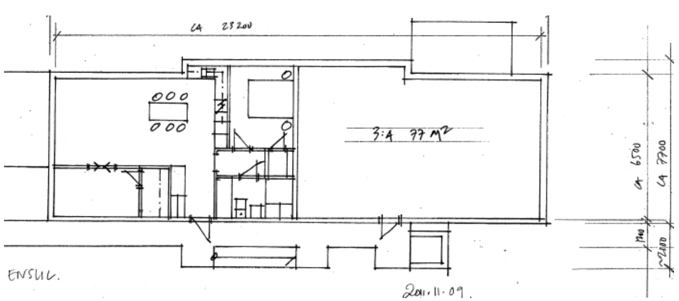
Rectangular Design



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SUMMARY OF CASES CONSIDERED

	GWP (100) in kg CO2-e/m2 HFA, year			
Reference study period	50		100	
Assumed electricity source (see note below)	Nordic mix	Swedish hydro	Nordic mix	Swedish hydro
Concrete rectangle, material (EG)	4.8 (52 %)	4.8 (74 %)	2.4 (36 %)	2.4 (59 %)
Concrete rectangle, op. energy	4.35 (48 %)	1.7 (26 %)	4.35 (64 %)	1.7 (41 %)
Total	9.15	6.5	6.75	4.1
Timber rectangle, material	1.6 (28 %)	1.6 (50 %)	0.8 (16 %)	0.8 (33 %)
Timber rectangle, op. energy	4.2 (72 %)	1.6 (50 %)	4.2 (84 %)	1.6 (67 %)
Total	5.8	3.2	5	2.4

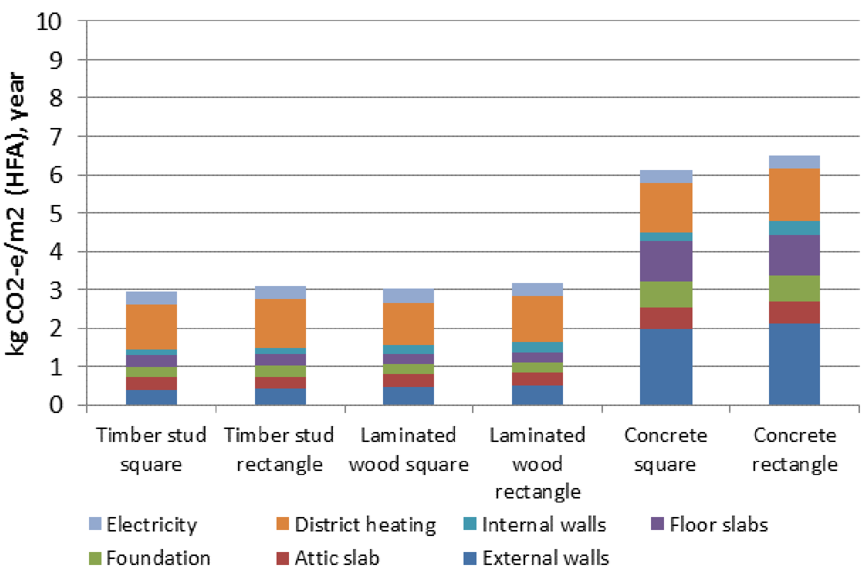


Fig. 1: District heat: 31.0 g CO_2-e/kWh (local network), Use electricity 9.9 g CO_2-e/kWh ("green electricity" - Swedish hydropower) 50 year RSP

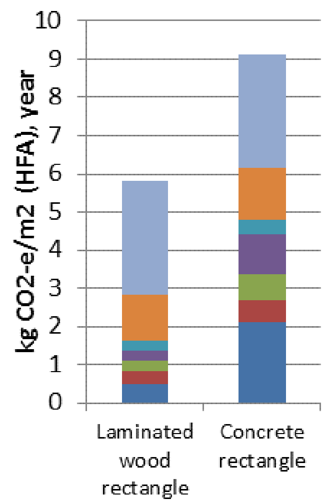


Fig. 2: District heat: 31.0 g CO_2-e/kWh (local network), operational electricity 85 g CO_2-e/kWh (Nordic grid average) 50 year RSP

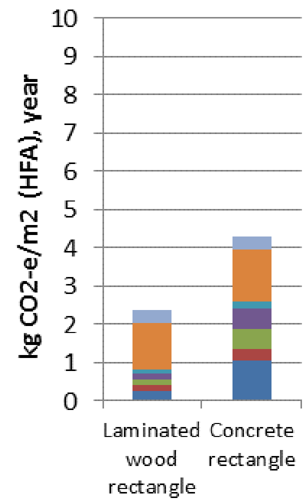


Fig. 3: District heat: 31.0 g CO_2-e/kWh (local network), operational electricity 85 g CO_2-e/kWh (Nordic grid average) 100 year RSP

CONCLUDING DISCUSSION

The study contributed to knowledge-gathering in the planning phase of a development project. The procedure was based around the method applied in the BECE/ENSLIC simplified tool. Although specific data according to ISO standards was requested from contractors as per the GWP (and lifetime) of supplied materials this could not be provided. This is probably not surprising but had the practical result that reference data was used for these input data. The value of the life-cycle procedure as it was applied in the development project was therefore as a tool for understanding the environmental consequences of design and material choices in a well-ordered manner. In particular it highlights how uncertain parameters may greatly affect the numerical results of the LC-procedure and therefore of decisions. Therefore although applied directly in a decision making context it could not formally demonstrate an optimal solution, rather it was important from the point of view of more general learning and communication amongst decision makers per the consequences of their decision. A future application of the tool in a development project could build upon this experience. For example, a future application could more clearly express in the scoping stage:

- The role of the tool for systematised learning about life-cycle environmental consequences of decisions
- The value of the numerical results in determining the focus of environmental management in subsequent stages of the development process
- Those uncertainties and variabilities to be accounted for in the study

Key issues related to Annex 57:
1.1 Selection of materials
1.4 Design choices

Case study SE5

Uppfinnaren Office - Sweden

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

A newly-built re-inforced concrete office building was used as a case to evaluate options at the early design stage for reducing GWP due to the product stage and operational energy use. A total of 12 design improvment measures were applied achieving the following GHG emissions reductions:

	GWP, KgCO2 equiv./ m^2 (HFA),yr		
	Op. Energy Use	EG	Total
Reference building	2.7	3.2	5.9
Plus measures for reduction op. energy use	2.2	3.3	5.6
Plus assuming CO_2 free electricity	0.8	3.3	4.1
Plus internal floor in solid laminated wood	0.8	2.3	3.1

The case shows that for buildings with low operational energy demand supplied by low-GWP energy carriers (District heating and Swedish electricity mix), lifetime GWP can be most effectively mitigated with reducing EG. In this case the replacement of re-inforced concrete internal floors with timber alternatives.

OBJECTIVES OF CASE STUDY

The aim of this study was to examine how energy use and climate change contributions can be reduced by decisions taken in early building design phases. This was achieved by exploring different improvement measures on an existing building with the basic ENSLIC tool. Special attention was paid to the impact from building materials in relation to the impact from operational energy.

BUILDING KEY FACTS

Intended use: Office

Size: 3537 m^2 (HFA)

Location: Gävle, Sweden

Architect: Arkitektgruppen i Gävle AB

Year: 2009

KTH Architecture and the Built Environment

Source: Arkitektgruppen i Gävle

Building life cycle stages included in the study, according to EN15978

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								X						

LCA BACKGROUND

Reference study period: 50 years
Calculation of Energy: Total Bought energy demand for operational energy use: Space heating, hot water, user electricity and building electricity
Calculation of GWP: IPCC (4AR) characterisation, 100 years
Databases used: EcoEffect project data, BEAT (Danish tool for building LCA) and EcoInvent
Energy supply: Varied based on different design measures considered:
Swedish electricity mix: 33.4 g CO_2-e/kWh, Nordic electricity mix: 100.0 g CO_2-e/kWh,
District heating (Gävle): 21.6 g CO_2-e/kWh, District heating Stockholm: 33.8 g CO_2-e/kWh,
Coal 503.5 g CO_2-e/kWh, PV cell: 61.2 g CO_2-e/kWh
Standards/guidelines: Applied the ENSLIC guidelines (see reference below) for assessing design choices in the early stages of construction

REFERENCES

About the case:

Wallhagen, M., Glaumann, M. and Malmqvist, T. (2011). Basic building life cycle calculations to decrease contribution to climate change - case study on an office building in Sweden. *Building and Environment, vol 46, issue 10, pp. 1863-1871*

About the BECE tool:

Malmqvist, T, Glaumann, M, Scarpellini, S, Zabalza, I, Aranda, A, Llera, E, Díaz, S. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. (2011) *Energy, vol 36, issue 4, pp. 1900-1907.*

Production and construction stage modeling: Impacts related to raw material extraction and manufacturing of building materials in main building elements (external and internal walls, foundation, floor slabs, attic and roof, windows and external doors) are included. Mechanical and electricial installations and surface coverings are not included.

Operation stage modeling: Building's initial operational energy use calculated with modelling software Enorm 1000, V. 1.10. Changes in operational energy use due to improvement measures calculated using BECE simplified degree-day model. Use stage energy includes all bought energy: Building and user electricity, and space heating and hot water. GWP for bought energy carriers based on typical Swedish data. No other impacts due to the operational stage are considered.

End of life stage and next product system modeling: Not included in the calculations.

THE BUILDING

An office building with 4 storeys. The original design (pre-improvement measures) comprises load bearing structure in steel and reinforced concrete and CLT roof beams. External walls are curtain walls with lightweight steel beams, mineral wool insulation. Façade is mostly rendered with some wooden paneling. Concrete foundation with polystyrene insulation .

These amounts represent the original design of the building based on a concrete construction. Design improvement measures imply some changes to this initial inventory

MATERIAL USE AND QUANTITIES

The total consumption of building materials is estimated according to the tool to be 3248 tons, 0.919 tons/m^2 HFA. The breakdown of calculated material demand for the building is shown in the table below. For convenience the table also shows the GWP due to materials.

This calculation does not take different service life times into account and only the main building elements of the building. The reason for this simplification is to facilitate basic calculations in early design stages to take out a ”compass course” for how to achieve both a low operational energy use and low GWP over the life cycle.

MATERIALS	Bought amount kg	Spec. matr. Use kg/m^2	Weight fraction %	GWP, kg eqv CO_2	GWP kg eqv CO_2/m^2	Contribution to total GWP, %
Concrete reinforced	3004250	850	92,5%	396560	112	69,6%
Aluminium	2750	1	0,1%	30670	9	5,4%
Glass	44130	12	1,4%	26700	8	4,7%
Gypsum, plaster board	87270	25	2,7%	26180	7	4,6%
Insulation, cellulose fibre	13860	4	0,4%	3900	1	0,7%
Insulation, Polystyrene, EPS	1240	0	0,0%	2240	1	0,4%
Insulation, Rockwool	10560	3	0,3%	15410	4	2,7%
Polyeten	300	0	0,0%	640	0	0,1%
Steel (EU-mix)	60270	17	1,9%	65210	18	11,4%
Wood	23820	7	0,7%	2670	1	0,5%
Total	3248450	919	100%	570180	161	100%

OPERATIONAL ENERGY USE DUE TO INITIAL DESIGN AND AFTER IMPROVEMENT MEASURES

BUILDING AND CHANGES	BOUGHT ENERGY	
	Total	Electricity
	kWh/m^2, yr	kWh/m^2, yr
REFERENCE BUILDING	100	46
1. 150mm extra insulation in walls (BE)	99	46
2. 300mm extra insulation roof (BE)	98	46
3. 150mm extra insultion in basement/slab (BE)	93	46
4. Window U-value 0,9 (BE)	87	46
5. Window area / Facade area %	86	46
6. Waste water heat exchange (ESE)	86	46
7. Low energy lighting and white wares 20% better (ESE)	84	44
8. Building automatisation	83	43
9. $50m^2$ solar cells (ES)	81	42
10. CO_2 free electricity building (ES)	81	42
11. CO_2 free electricity users (ES)	81	42
12. Slabs, solid laminated wood (BUILDING AF ALL CHANGES)	81	42
BUILDING AFTER ALL CHANGES	81	42

Total Operational Energy demand:

Original design: 100 $kWh/m^2_{HFA}/year$ incl. building and user electricity: 46 $kWh/m^2_{HFA}/year$

After improvements: 81 $kWh/m^2_{HFA}/year$ incl building and user electricity: 42 $kWh/m^2_{HFA}/year$

First the initial early design was modeled and operational energy use and GWP was calculated. After that an optimisation process was initiated, trying out different potential improvement measures with the goal to gain understanding about key improvement measures if to reach as low operational energy use and as low GWP as possible in the final design.

The table above shows the final suggestion of improvement measures after the optimisation process and the approximate possible reduction of energy demand that could be targeted.

GWP DUE TO INTITAL DESIGN AND AFTER IMPROVEMENT MEASURES

	Operational Energy Use GWP (B6) Kg equiv. CO_2/m^2,yr	Product stage GWP (A1-3) Kg equiv. CO_2/m^2,yr	Total GWP Kg equiv. CO_2/m^2,yr	Difference, Kg equiv. CO_2/m^2,yr
REFERENCE BUILDING	2.7	3.2	5.9	
1. 150mm extra insulation in walls (BE)	2.7	3.2	5.9	0
2. 300mm extra insulation roof (BE)	2.7	3.3	5.9	0
3. 150mm extra insultion in basement/slab (BE)	2.6	3.3	5.9	-0.1
4. Window U-value 0,9 (BE)	2.4	3.3	5.7	-0.1
5. Window area / Facade area %	2.4	3.3	5.7	0
6. Waste water heat exchange (ESE)	2.4	3.3	5.7	0
7. Low energy lighting and white wares 20% better (ESE)	2.3	3.3	5.6	0
8. Building automatisation	2.3	3.3	5.6	0
9. 50m² solar cells (ES)	2.2	3.3	5.6	-0.1
10. CO_2 free electricity building (ES)	1.9	3.3	5.2	-0.3
11. CO_2 free electricity users (ES)	0.8	3.3	4.1	-1.1
12. Slabs, solid laminated wood (BUILDING AF ALL CHANGES)	0.8	2.3	3.1	-1
BUILDING AFTER ALL CHANGES	0.8	2.3	3.1	-2.8

The table above shows the calculated GWP due to initial building design and after application of successive design improvement measures. Swedish electricity mix and Gävle district heating mix are assumed.

Global Warming Potential:

Original design:

5.9 kg CO_2 equiv. /m^2_{HFA}/year

- embodied (A1-3): 46%
- operational energy use (B6): 54%

After improvements:

3.1 kg CO_2 equiv. /m^2_{HFA}/year

- embodied (A1-3): 43%
- operational energy (B6): 57%

CHANGED ENERGY SOURCES	Operational Energy Use GWP (B6) Kg equiv. CO_2/m^2,yr	Product stage GWP (A1-3) Kg equiv. CO_2/m^2,yr	Total GWP Kg equiv. CO_2/m^2,yr	Difference, Kg equiv. CO_2/m^2,yr
Swedish electricity-mix and district heating Stockholm	3,4	3,2	6,6	0,7
Nordic electricity mix and district heating Stockholm	6,4	3,2	9,6	3,7
Electricity and heating from coal	50,6	3,2	53,8	47,9

Key issues related to Annex 57:
2.1 which stages in the life cycle of the building are most important?
3.3 Completeness of building data

Case study SE6

Office fit-out - Sweden

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Life-cycle assessments of office buildings do generally not include recurring impacts associated with office fit-outs. Consequently, there is a lack of knowledge on its relative importance compared to other life-cycle phases of buildings.

This study analysed material resource use, CED and GWP of an office fit-out project in Sweden. The amount of waste generated in the fit-out was 70 kg/m^2 and the amount of installed materials was 64 kg/m^2. The GWP amounted to 74 kg CO_2-eq./m^2. retrofitted area. The total CED was 1.7 GJ/m^2.

Considering that office fit-outs may be undertaken several times during the life-time of an office building, GWP and CED of fit-outs could contribute more to life-cycle impacts than new construction, and other activities undertaken in the use phase of office buildings. To limit resource use, and thereby reducing GWP and CED, of fit-outs could thus constitute a great possibility to reduce the environmental impacts of office buildings.

OBJECTIVES OF CASE STUDY

To investigate the type and quantity of waste generated and material resources used in an office fit-out project, and to quantify the cumulative energy demand (CED) and global warming potential (GWP) associated with the fit-out.

The study was performed for an office fit-out project, typical for large property owners and attractive office premises, in an office building in central Stockholm, Sweden.

BUILDING KEY FACTS

Intended use: Office building

Size of building: 27 844 m^2 A_{temp} (temperature controlled space)

Size of office under study: 2 234 m^2 A_{temp}

Location: Stockholm, Sweden

Owner: Vasakronan

Building year: 1940, the office fit-out project was performed in 2014

Source: Vasakronan

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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						

Production and construction stage modeling: Not included.

Operation stage modeling:
The operation stage included transportation of demolished materials to waste treatment, waste management of demolished materials, production of new components, transportation of these to the office building, and operational energy use.

All calculations were based on the actual amount of waste generated and materials used in the fit-out project, and the actual energy use in the office building.

The following building categories were taken into account in the assessment: construction materials for walls, floors, and ceilings; paint; floor coverings; tiles; pipes; ventilation; electric installations; control equipment; doors; kitchen equipment; and furniture. GWP and CED from raw material extraction and manufacturing of building materials were included.

The waste fractions were landfilled, recycled, or reused according to Swedish regulations. No benefits and loads outside of the system boundary were taken into account.

The operational energy use included electricity, and district heating and cooling.

End of life stage and next product system modeling: Not included.

LCA BACKGROUND

Reference study period: 1 office fit-out project, 1 year of operational energy use
Calculation of Energy: CED (non-renewable + renewable, feedstock energy included)
Calculation of GWP: GWP (100 years)
Databases used: Specific EPDs, Ökobau 2013, Ecoinvent 3.1, KBOB 2012
Energy supply: Electricity from 100 % renewable energy; average district heating and cooling for the area (mainly renewable energy)
Standards/guidelines: n/a

REFERENCES

Liljenström, C, Malmqvist, T. (2016). Resource use and greenhouse gas emissions of office fit-outs – a case study. *Conference Proceedings of Central Europe towards sustainable building, Prague, June 22-24.*

THE OFFICE

The study object consists of an office with a total area of 2 234 m^2 A_{temp} (temperature controlled space). It is located in an office building in central Stockholm, Sweden. The office fit-out project was performed in 2014 when a new tenant was moving in to the premises.

The fit-out project included demolition and reconstruction of the interior walls, construction of an internal staircase, renovation of bathrooms and kitchens, change of floor and ceiling finishes, doors, ventilation, lighting, and control and electronic equipment.

The fit-out project is representative for offices which undergo major adaptations between tenants in cases where the interior decorations are no longer fashionable, and that are located in office buildings situated in attractive regions in city centres and are owned by large property companies.

WASTE GENERATION AND RESOURCE USE

The total amount of waste generated was 69 kg/m^2. The majority of this was concrete, mainly blue concrete from the demolished walls. Due to limitations in data received from the sub-contractors, it was not possible to further divide these fractions into share of single materials.

The total amount of materials used in the fit-out was 63 kg/m^2. Materials used for construction of walls, floors, and ceilings contributed most to the overall resource use. Plasterboards, plywood and steel frames used in wall construction accounted for 55 % of the total weight of installed materials.

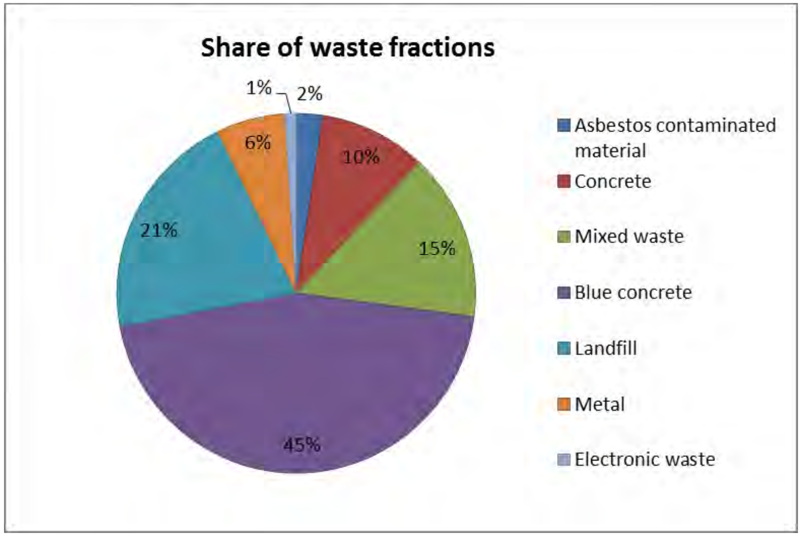


Figure 1: Contribution of waste fractions to the total amount of generated waste.

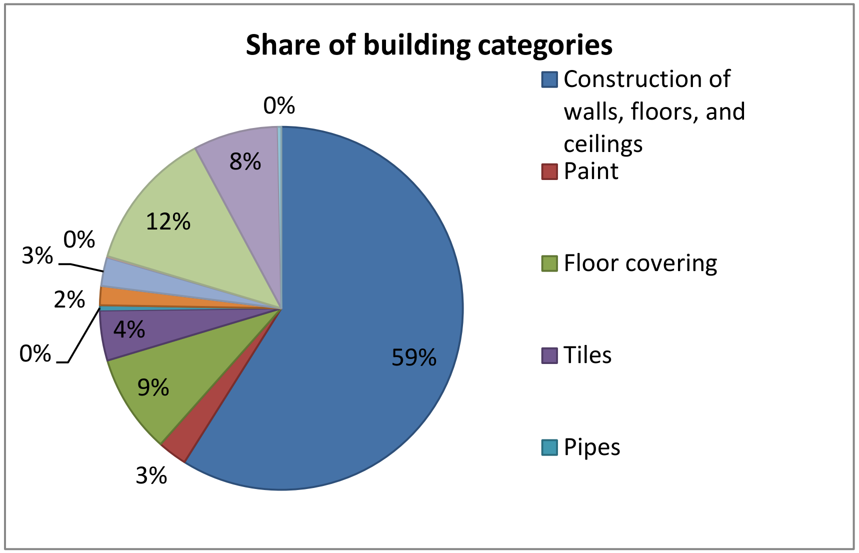


Figure 2: Contribution of building categories to the total weight of installed materials.

GREENHOUSE GAS EMISSIONS AND PRIMARY ENERGY USE

The total EG of the fit-out project was 75 kg CO_2-eq./m^2 and the total CED was 1.7 GJ/m^2 retrofitted area. If a similar fit-out project is assumed to take place in the entire building, the EG would amount 62 kg CO_2-eq./m^2 total heated floor area in building, and EE to 1.4 1.7 GJ/m^2.

GWP and CED are mainly caused by material production, in particular production of furniture, and construction material for walls, floors, and ceilings. The categories control and pipes contributed little to the emissions and energy use, but contained materials for which impacts could not be assessed. Similarly, kitchen equipment is a category which was excluded from the calculations due to lack of emission factors.

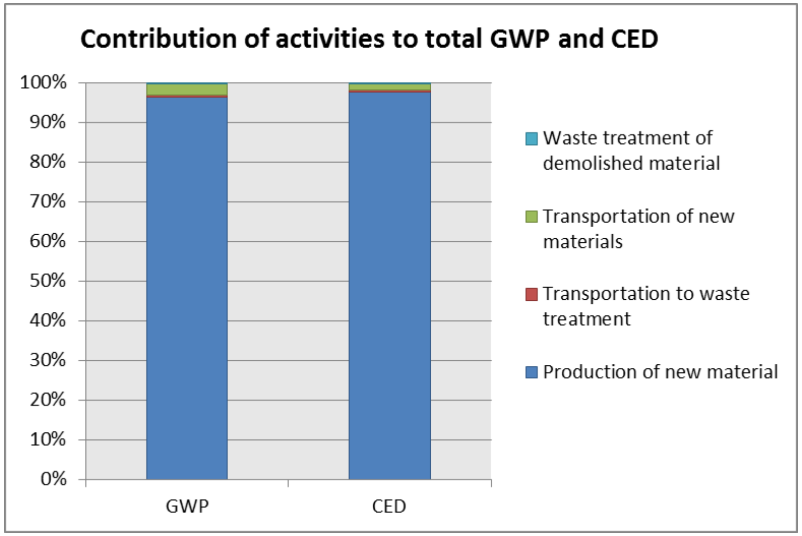


Figure 3: Contribution of material production, transportation, and waste management to total GWP and CED.

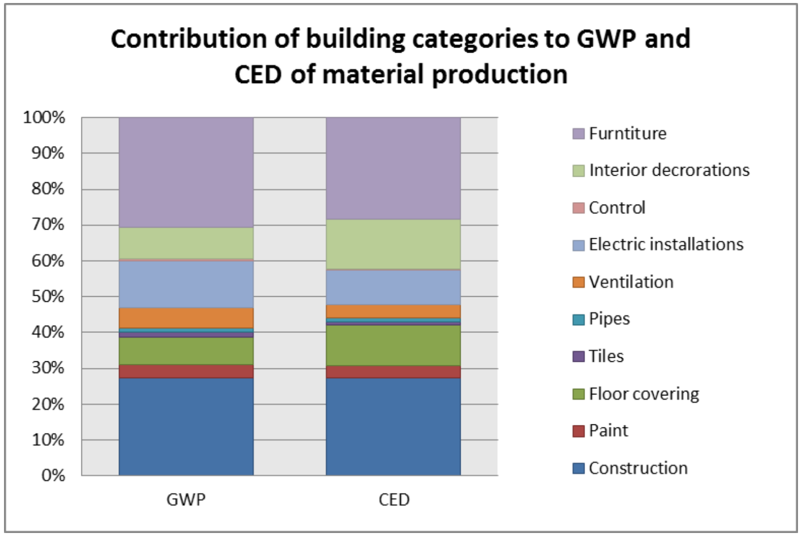


Figure 4: Contribution of building categories to GWP and CED of material production.

Key issues related to Annex 57:
1.1 Selection of materials
2.2 significance of elements in the building
3.1 Length of the reference study time

Case study SE7
New multifamily building- Sweden

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated with a Reference Study Period (RSP) of 50 and 100 years respectively and with three scenarios for the operational energy use. For the medium impact energy scenario, the study showed that the embodied part contributed with **27%** of Cumulative Energy Demand Total (CEDtot)and **60%** of Global Warming Potential (GWP) with RSP of **50 years**, and 15**%** of Cumulative Energy Demand Total and **47%** of GWP when RSP extended to **100 years**. With other energy scenarios these proportions change much. Note though, that EG includes modules A1-5+B2,B4+C1-4 whereas EE only includes modules A1-5.

REFERENCE STUDY PERIOD

	50	100	years
EE	80	40	$MJ/m^2_{Atemp}/year$
EG	8,9	5,3	kg CO_2 equiv. $/m^2_{Atemp}/year$

For EG, concrete contributed with more than 50%. A 15% reduction in EG was potentially possible by changing external walls to wood.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) to evaluate the use of Primary Energy and Global Warming Potential (GWP) related to the life cycle of a typical new, low-energy, multifamily residential building in concrete structure in Sweden. The study evaluates:

- The significance of different life cycle stages and processes
- The materials' contribution to the impacts compared to the total impacts
- The Embodied Energy (EE) and Embodied greenhouse gas emissions (EG)
- The impacts related to different building materials

Additionally the study evaluates:
- The length of the reference study period on the results of the study
- Three scenarios for operational energy use and its impact on the result
- Impact of including garage under building
- Impact of changing external walls into wooden ones
- Impact of reducing energy performance down to current Swedish building regulation

BUILDING KEY FACTS

Intended use: Residential, multifamily
Size: Atemp (≈heated floor area) = 11 003 m2. (Dwelling area 8 173 m2)
Location: Hökarängen, Stockholm, Sweden
Architect:
Developer: Skanska
Owner: Svenska Bostäder
Building year: Completed in 2010

SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	X	X			X		X	X		X	X	X	X	

LCA BACKGROUND

Reference study period: 50 and 100 years
Calculation of Energy: Cumulative energy demand (non-renewable + renewable)
Calculation of GWP: GWP (100 years)
Databases used: IVL Miljödata, Specific EPDs, Ecoinvent/KBOB 2012/Bath Ice
Energy supply: District heating Sw. average 2010-2012, Nordic electricity mix 2011-2012
Standards/guidelines: EN 15978 standard

REFERENCES

Liljenström, C, Malmqvist, T, Erlandsson, M., Freden, J., Adolfsson, I., Larsson, G., Brogren, M. (2015). Byggandets klimatpåverkan. Livscykelberäkning av klimatpåverkan och energianvändning för ett nyproducerat energieffektivt flerbostadshus i betong. Stockholm: Sveriges byggindustrier.

Production and construction stage modeling: All impacts from the raw material extraction and the manufacturing of all building materials , based on the economic calculations, are included. All transports of material to building site are included based on transport distances and assumptions regarding fuels and fuel use per ton*km. Module A5 is based on actual use of electricity, district heating and fuels for machines on-site including fuel use for rented machinery. On-site dressing works are however not included due to limited data.

Operation stage modeling: The energy use in the building's operation stage is modeled for three scenarios with the base scenario being average Swedish district heating (2010-2012) and Nordic power grid mix. (2009-2011). Observe that used data is including CO2 emissions associated with electricity production based on waste incineration. Operational energy use data is average measured use for three years of operation.

The replacements of building materials and components in the operation stage covers only production of materials for external maintenance of the building shell and internal maintenance of installations (electricity, ventilation equipment and sanitary goods). Module B3 is omitted due to the difficulty to assume reparation activities and module B5 is only included in the 100 reference study period. Components iwith a life time exceeding the building life time (for ex of 45 years) is represented by a double-load in the environmental accounting because it is installed 2 times in the building's 50 year life span according to EN 15978,

End of life stage and next product system modeling: All modules C1-4 are included in the The EoL modeling. C1 is based on assumptions mainly. Transport distance of 15km has been used for all wasted materials and waste treatment for different building elements and materials follow the sector recommendations in Sweden.

THE BUILDING(S)

The study object consists of four buildings with 97 apts and a total dwelling area of 8 173 m2. The last tenants moved in 2010. The buildings are constructed in concrete with pre-fabricated shell elements (VST-boards) which are filled with concrete on-site. Thus, the construction becomes very air-tight. The building is a low energy building (55 kWh/m2 Atemp, year for heating, hot water and building electricity).

Concerning concrete amounts, the buildings are representative for current, new construction of multi-family buildings in concrete in Sweden including e.g 300 mm concrete in slabs, 180-200 mm concrete in bearing inner walls and 160-200 mm in foundation slab.



Source: Skanska

RESULTS OF STUDY PERIOD = 50 YEARS

Total Primary Energy consumption:

78 MJ/m$^2_{Atemp}$/year

- embodied energy: 27%
- operational energy: 73%

Global Warming Potential

5,9 kg CO_2 equiv. /m$^2_{Atemp}$/year

- embodied GHGs: 54%
- operational energy GHGs: 46%

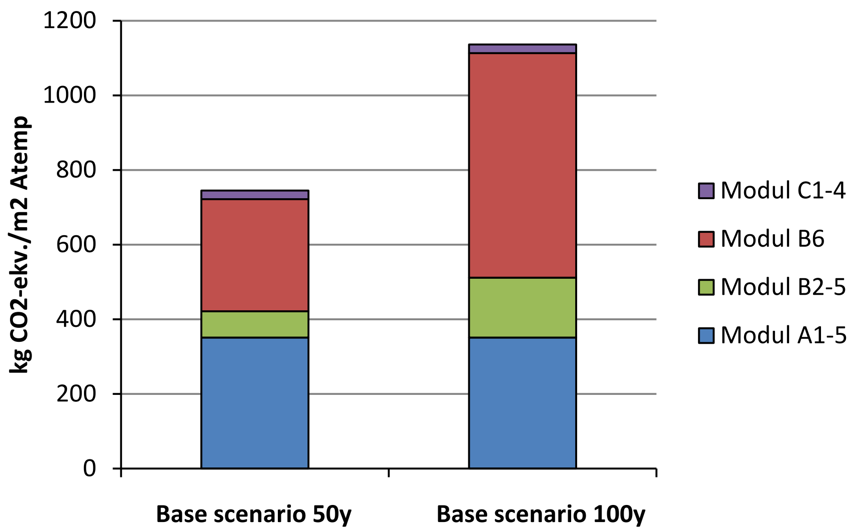


Figure: Total CO2e emissions for base energy scenario, 50 and 100 years ref. study period respectively.

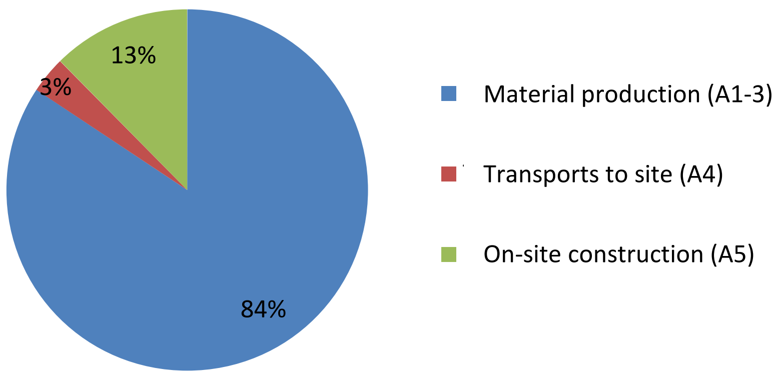


Figure: EG – divided on modules A1-3, A4 and A5.

EMBODIED GREENHOUSE GAS EMISSIONS (EG)

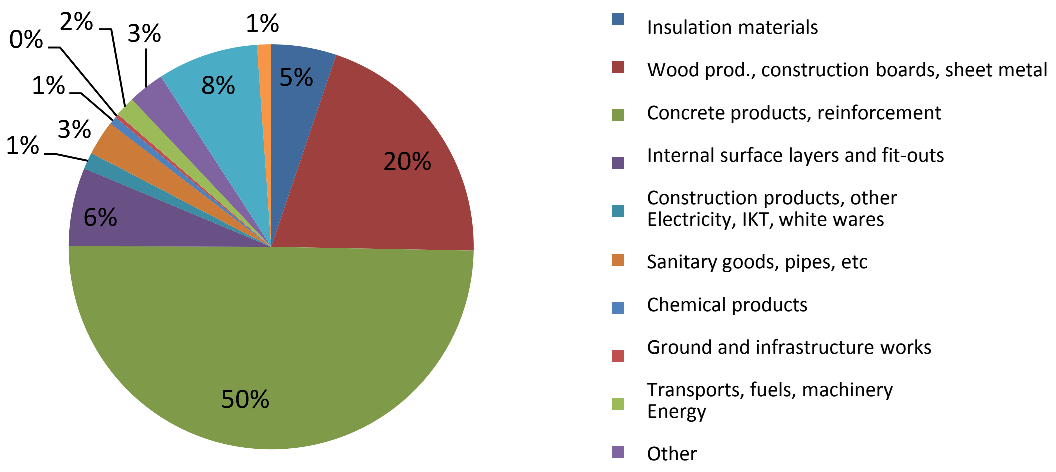


Figure: Contributing building components – to module A1-5

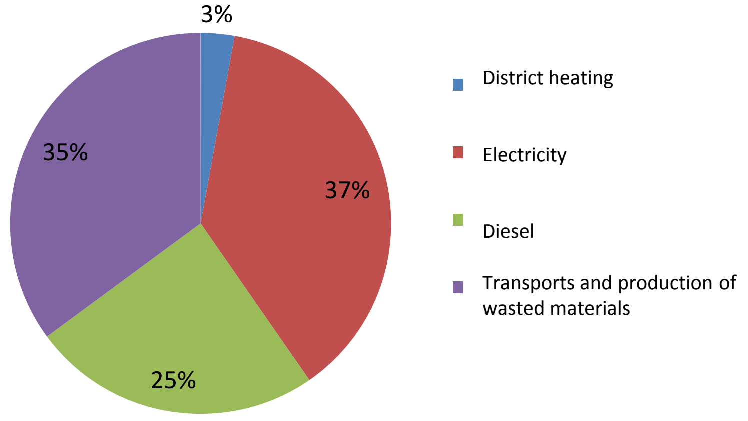


Figure: Contributing processes to EG – if only considering module A5.

ADDITIONAL ANALYSES

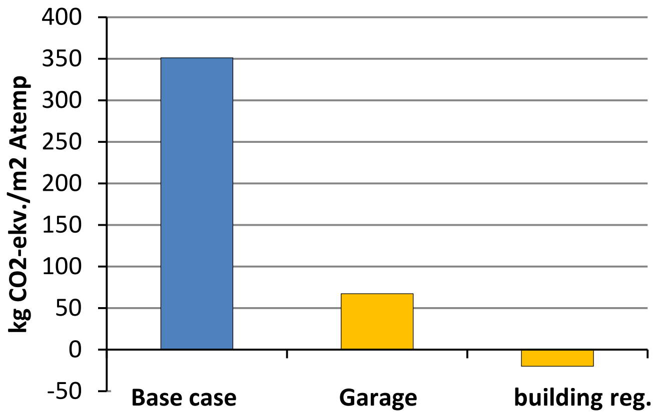


Figure: Module A1-5 compared to additional impact due to under-ground garage, and reduced impact due to insulation reduction if the house should only have complied with current energy norms in the Swedish building regulation.

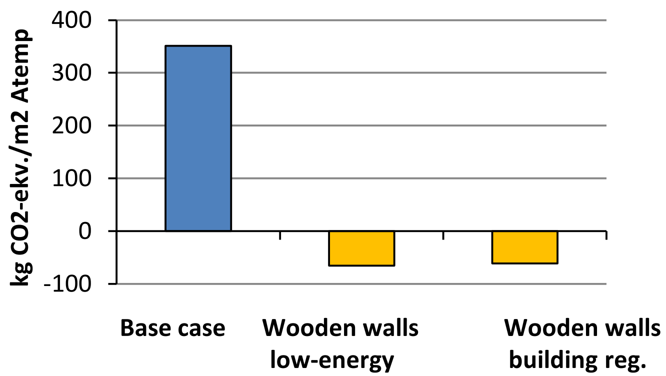


Figure: Module A1-5 compared to potential reductions if part of the façade had been exchanged to wooden instead of concrete.

Additional analyses - Impact of potential changes

A few additional analyses were made in order to better understand the impact of some realistic and interesting changes.

First, the studied building did not have an under-ground parking garage which is the normal case in new multifamily buildings in metropolitan areas of Sweden. Rough calculations indicate that such a garage would add approx. 70 kg CO_2-eq./m^2 heated floor area (A_{temp}), meaning that the garage would cover 16 % of the EG.

Secondly, if the building had been designed to comply with current energy norms in building regulations instead of low-energy operational energy use, the EG would only be reduced by approx, 20 kg CO_2-eq./m^2 heated floor area. Finally, the base scenario is compared to if external walls had been light curtain walls in wood instead of the concrete walls of the case study building. This change would reduce the EG by approx. 60 kg CO_2-eq./m^2 heated floor area.

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Location /climate and or heating degree days / cooling?	Sweden, Stockholm
Building/ Usage type	Multifamily residential buildings, new construction
Energy-standard	Low Energy 54 kWh/m2 Atemp and year (heating, hot water and building electricity)
Gross floor area/ Net floor area	Dwelling area 8 173 m^2 A_{temp}= 11 003 $m^{2,}$
Gross volume/ Net volume	n/a
Reference area for EE/EC	A_{temp}= 11 003 m^2
Surface/Volume ratio (m-1)	n/a
Construction method	Massive construction (concrete)
Thermal insulation	Insulation of walls with 250 mm EPS and roof insulation with 500 mm EPS.
Ventilation system	Automated ventilation with heat recovery
Heating and cooling system	Heating: District heating and electric heating No cooling
Final energy demand electricity	8 kWh/m2$A_{temp\ And\ year}$
Final energy demand for heating and hot water	Room heating 17 kWh/$m^2A_{temp\ And\ year}$ district heating and 4 kWh/$m^2A_{temp\ And\ year}$ electric heating Hot water 25 kWh/$m^2A_{temp\ And\ year}$
Final energy demand for cooling	n/a
Benchmark	n/a
Purpose of assessment	to evaluate the use of Primary Energy and greenhouse gas emissions related to the life cycle of a new mulitfamily residential low energy building in concrete.
Assessment methodology	According to EN 15978
Reference Study Period	50/100 years
Included life cycle stages	A1-5, B2, 4, 6, C1-4

MINIMUM DOCUMENTATION REQUIREMENTS

Parameter	Case Study Description/ Minimum Documentation Requirements (Type 1-4)
Included parts of the building	Principally all since life cycle data is connected to the economic calculation programme.
Scenarios and assumptions used	
	District heating Sw. average 2010-2012, Nordic electricity mix 2011-2012
Databases used	IVL Miljödata, Specific EPDs (for concrete products), Ecoinvent/KBOB 2012/Bath Ice for a few missing data
LCA Software used	
Method of materials quantification	Economic calculation software.
Values and sources of primary energy and emission factors	
Character of the indicator used	
Indicators assessed	Primary energy total (non-renewable + renewable) GHG emissions

United Kingdom

Key issues related to Annex 57:
5. Reduction strategies and significant EE and EG factors at national level
6. Integration of EE and EG in decision-making processes

Case study UK1
Greater London Authority- UK

EBC Energy in Buildings and Communities Programme

KEY OBSERVATIONS

It is very important for the embodied emissions assessment to include product manufacture, supply and construction stages.

The assumptions and scenarios involving the prediction of future greenhouse gas emissions should be rigorous and clearly stated.

greenhouse gas sequestration should be included in all assessments, using a 100-year life span assumption for calculations.

Carbonation should be excluded from calculations, with the exception of the cases where the building's end of life is taken into consideration.

OBJECTIVES

- To present a example of how the Greater London Authority (GLA) has an impact and interest in measuring and reducing greenhouse gas in buildings across its area of influence.
- To present a set of case studies in which the GLA is interested, illustrating the conclusions and the benefits of this analysis.
- To demonstrate the challenges in measuring embodied greenhouse gases in the building sector.
- To support and demonstrate the benefits of the assessment of construction works' environmental performance, including new build and refurbishment projects.

CASE STUDIES (BUILDING AND PURPOSE OF ANALYSIS)

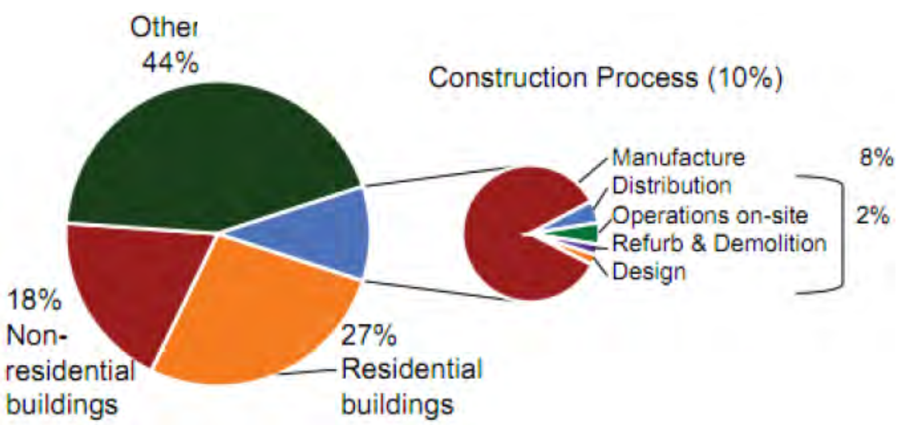
- Rampton Drift: in-use energy savings
- Keynsham Town Hall: informing building design
- Cottington road overbridge: materials' comparison
- Sainsbury's Dartmouth building: end of life assumptions
- Open Academy Norwich: greenhouse gas sequestration

CHALLENGES

- Climate change and the need for sustainability
- Waste
- Resource scarcity

POLICY DRIVERS

- The 2008 Climate Change Act sets the legally binding obligation of a 26% reduction in greenhouse gas emissions by 2020, and at least an 80% reduction by 2050 (compared with the 1990 baseline).
- The 2010 Low Carbon Construction Innovation and Growth Team Report highlights the significance of embodied emissions and the need to include their assessment in the early design stages. This is the content of the following recommendations:
    - o *Recommendation 2.1: That as soon as a sufficiently rigorous assessment system is in place, the Treasury should introduce into the Green Book a requirement to conduct a whole-life (embodied and operational) greenhouse gas appraisal and that this is factored into feasibility studies on the basis of a realistic price for greenhouse gas.*
    - o *Recommendation 2.2: That the industry should agree with Government a standard method of measuring embodied greenhouse gas for use as a design tool and (as Recommendation 2.1 above) for the purposes of scheme appraisal.*



Proportion of total UK CO2 emissions that construction can influence (divided into in-use emissions for residential and non-residential buildings and construction-related emissions). Source: Department for Business Innovation and Skills

THE BUSINESS CASE FOR GREENHOUSE GAS REDUCTIONS

BUILDING LOW CARBON

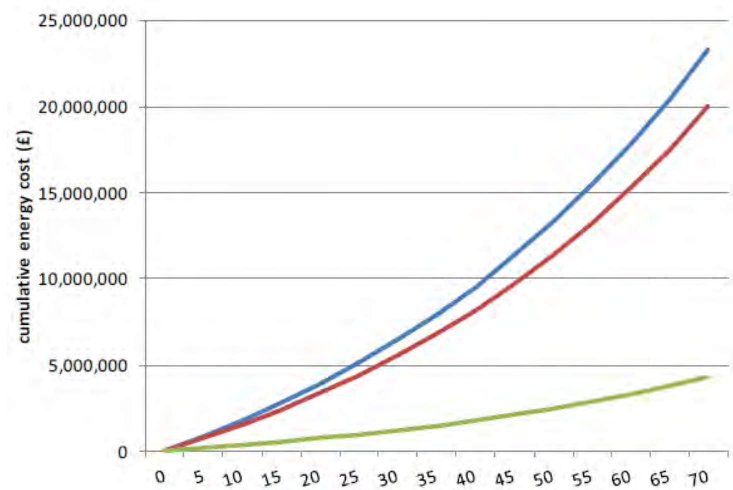
- Construction cost increases as building fabric is improved, but then reduces due to the simplified building services
- Light-weight, low carbon buildings can be cost-effective due to lower material use
- On-site renewable energy provision involves the most significant cost of low carbon buildings
- Environmentally friendly products' prices are constantly decreasing due to the increased interest in them

IN-USE COST SAVINGS

In many cases, the cost involved in low carbon construction might be a burden to different stakeholders than those enjoying the benefit, for example in the case of home owners paying the premium of low carbon construction for properties they rent to different occupants.

CARBON RISK MANAGEMENT

According to research carried out by the Carbon Trust, although low carbon buildings in some cases involve increased risks, they can also present significant opportunities. For example, low carbon buildings offer improved security against increasing energy prices and energy supply problems. Moreover, they are more likely to be in agreement with future environmental requirements, provide better reputational benefits and be less influenced by material price fluctuations. Finally, an increased knowledge of relevant risks, can reduce development time and contingency costs.



Cumulative energy costs for operating three equivalent commercial building designs over a 70 year period. Comparable assumptions on energy use have been made. The performance of the low carbon building is indicated with a green line. This building's operational costs were reduced by 75%, while its embodied greenhouse gas emissions were less than half compared to the other two buildings. Source: Best Foot Forward

PURCHASING POWER

London represents 1% of the global economy and can hence influence markets and chains, not only locally, but also internationally. The procurement expenses of London Boroughs, the City of London and the GLA is approximately £14 billion annually .

RESEARCH AND DEVELOPMENT

London is an area where considerable research and development activities are concentrated, therefore it can provide the opportunities for innovative sustainable production. For example, at the moment London waste is treated in a way that maximises landfill diversion rather than greenhouse gas benefits. However, there is potential to develop commercial and industrial systems needed to enable the reuse of construction waste or excess materials.

PLANNING POLICY

Planning policies and decisions made within the GLA and London Boroughs are very significant, as they can influence infrastructure, developments' density, construction standards and materials and consequently energy and resources use. For example, it is estimated that more strict standards regarding sustainable materials can save 5.07 Mt CO_2 per year, which is the equivalent of the greenhouse gas emissions produced by the residents of Lewisham and Sutton combined.

REFERENCES

Best Foot Forward Ltd, & Greater London Authority. (2013). *Construction Scope 3 (Embodied): Greenhouse Gas Accounting and Reporting Guidance* (Vol. 3). London, UK.

BioRegional, & London Sustainable Development Commission (LSDC). (2009). *Capital consumption: the transition to sustainable consumption and production in London*. London, UK.

HM Government. (2010). *Low Carbon Construction Innovation & Growth Team: Final Report*.

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RAMPTON DRIFT

In the retrofit of these 4 houses, 95% of the retrofit embodied greenhouse gas was due to materials and 4% due to transport from the manufacturer to the renovation site. Using SAP 2009 for the calculation of operational energy use, the retrofit payback period was estimated to be between 4 and 18 months.

KEYNSHAM TOWN HALL

The cross-laminated timber frame of the building was responsible for significant greenhouse gas sequestration, amounting to -0.178tCO_2e/m^2.

COTTINGTON ROAD OVERBRIDGE

The case study compared the embodied greenhouse gas related to expanded clay and expanded polystyrene against a granular aggregate benchmark. EPS is responsible for lower greenhouse gas emissions for transport due to its low density and the fact that is sourced in the UK.

SAINSBURY'S DARTMOUTH BUILDING

The embodied greenhouse gas in Dartmouth supermarket has been assessed, assuming 30 years of building lifetime with 3 fit outs during this period. greenhouse gas sequestration was not taken into consideration. The results showed that the most greenhouse gas intensive stage was the one related to site enabling procedures, with fit-out and building envelope each being responsible for approximately 25% of the total embodied greenhouse gas of the building during its lifetime. Demolition was only responsible for 2% of the total greenhouse gas emissions.

OPEN ACADEMY NORWICH

Three alternative structural systems have been compared in terms of embodied greenhouse gas: traditional concrete frame, steel with precast concrete planks and cross-laminated timber. The conclusion was that even without considering greenhouse gas sequestration, the timber frame solution resulted in considerably lower greenhouse gas emissions.

Key issues related to Annex 57:
1. Strategies for building retrofit
2.2 Which elements of the building retrofit are most significant

Case study UK2

Rampton Drift Retrofit - UK

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

One of the outcomes of this research was the calculation of the retrofit payback times, in terms of energy and greenhouse gas payback times, rather than monetary cost. A comparison was made between the greenhouse gas savings achieved after retrofit and the embodied greenhouse gas spent during the retrofit process. Hence, the greenhouse gas payback times were calculated and found to be **between 6 and 33 months**, with two of the cases having a greenhouse gas payback time of approximately half a year.

The study shows that, in the case of retrofit, most of the greenhouse gas emissions are embodied in the materials, with a small contribution from transport and construction and a negligible amount from waste. However, it is worth noting that in some cases, energy consumed for manufacturing and transport processes has been unknown and therefore omitted. This results in the materials having a higher embodied energy and greenhouse gas compared to other parts of the retrofit process.

The provision of insulation, especially the cavity wall insulation, and the addition of high-efficiency systems represent an important proportion of the overall embodied greenhouse gas of the retrofit.

OBJECTIVES OF CASE STUDY

To conduct a simplified assessment of embodied energy and greenhouse gases in greenhouse gas payback of low-cost retrofit of existing housing.

To calculate the embodied energy and greenhouse gas figures associated with the retrofit materials, including their production, transportation and waste generated on site, using a software tool being developed by the Centre for Sustainable Development at the University of Cambridge.

To calculate embodied energy and greenhouse gas for each property and compare with the changes in operational energy due to retrofit. This aims at identifying the most beneficial schemes and at estimating their payback times in terms of greenhouse gas emissions.

BUILDING KEY FACTS

Intended use: Housing (privately owned)

Location: Rampton Drift, Cambridgeshire, UK

Architect: PRP Architects

Building year: Built between 1950s and 1970s – Retrofit in 2011

Project phase studied: Retrofit

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SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	X	X						X			X			

$$Embodied\_greenhouse\ gas = ECO_{2eq_{mat}} + ECO_{2eq_{trans}} + ECO_{2eq_{waste}}$$

$$Embodied\_Energy = EE_{mat} + EE_{trans} + EE_{waste}$$

LCA BACKGROUND

Databases used: Bath ICE v2.0, ECEB tool (Centre for Sustainable Development, University of Cambridge, UK: Embodied greenhouse gas and Energy in Buildings)

Standards/guidelines: BS EN15978: 2011, PAS 2050: 2011

REFERENCES

Sahagun, Daniela (2011) *Embodied Carbon and Energy in Residential Refurbishment- A Case Study*, MPhil dissertation, Department of Chemical Engineering, University of Cambridge, UK.

Steve Cook, Willmott Dixon: personal communication and company supplied information

Daniel Mayes, ACCE Solutions: personal communication and company supplied information

ACKNOWLEDGEMENTS

We would like to thank Steve Cook and Daniel Mayes for their help and the information provided.

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Department of Engineering

Calculation method: The calculation method used corresponds to a simplification of the PAS approach. The stages considered in this research are the materials' provision and manufacturing, their transportation from gate to site and waste disposal.

Data collection during the production and construction stages: An inventory of the materials and components used in the retrofit was compiled based on information by the design specifications of the different measures to be carried out in each property. Additional information was provided by the contractors through conversations with the site manager and through site visits, as well as by manufacturing companies. Information about the materials and their quantities was given by the main contractors, and was verified by a detailed recording of delivery tickets consistent with the scope of works produced by the design team. The software used was the ECEB tool developed at the Centre for Sustainable Development at the University of Cambridge Department of Engineering. One of the reasons for this choice, was the possibility to use data more appropriate for the context of construction in the UK.

Use and operation stage modelling: The current operational energy and greenhouse gas calculations of the different properties are based on their bills. The energy use after retrofit is the actual energy use as monitored for a year.

End of life stage: Due to the fact that renovation activities generate only a small amount of waste compared to other construction projects, there were no waste management plans. For this reason and in accordance with the method, it was assumed that all the waste generated on site was sent to landfill. Thus, the only contributions from waste arise from its transportation from site to landfill.

PROPERTIES DESCRIPTION – RETROFIT MEASURES

Annex 57

THE HOUSES

Four properties have been selected for this study

Two terrace houses: **68 Rampton Drift, 69 Rampton Drift**

Two semi-detached houses: **1 Rampton Drift, 13 Rampton Drift**

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RETROFIT MEASURES

Improvement Work	**68**	**69**	**1**	**13**
Monitoring Systems - Smart Meters	*	*	*	*
Real Time Energy Display	*	*	*	*
Cavity Wall Insulation	*		*	*
Insulation to Loft	*			*
Insulated Draught Stripped Loft Hatch	*		*	*
Draught proofing - Window / Door Overhaul	*	*	*	*
External wall insulation (behind vertical tiles)	*	*		
Radiator System Installation		*		*
Heat Recovery Fans	*	*	*	*
Socket outlet in roof space- for monitoring	*	*	*	*
Storage Boards	*			*
Flue Gas Heat Recovery Unit		*		*
High Efficiency Combi Boiler		*		*
Solar Hot Water System	*			
Insulated Plasterboard (under the stairs)	*	*		
Through wall vent- background ventilation to gas fire			*	
Replacement cylinder compatible with solar heating	*			
Property Specific Items	*	*	*	*

EMBODIED ENERGY AND greenhouse gas BY STAGE

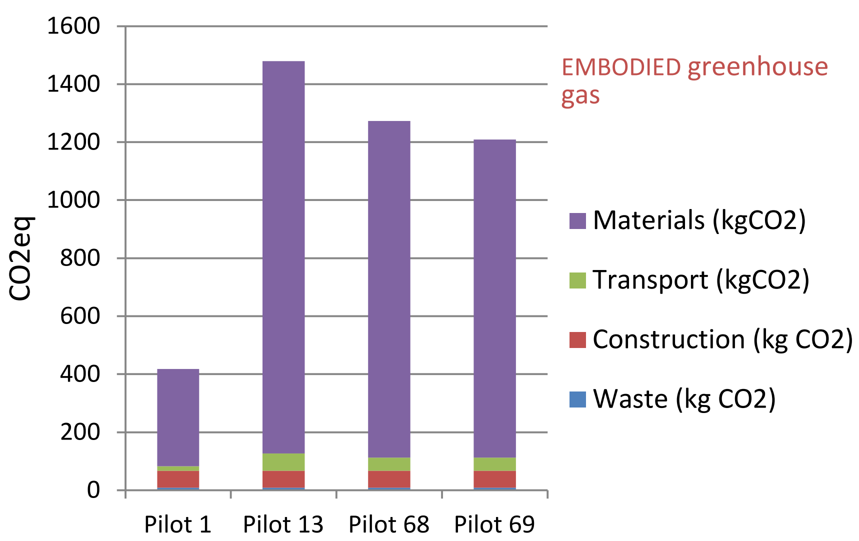
The figures present embodied energy and greenhouse gas values by stage for the four pilot properties. The tendencies are similar for all of them.

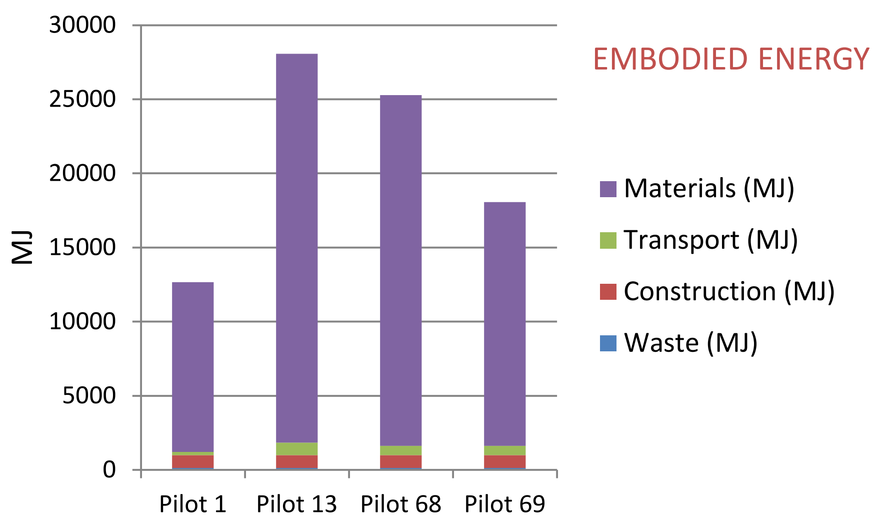
First, it is observed that the majority of the embodied costs arises from the materials. This accounts for approximately 90% of the total.

The embodied greenhouse gas in transportation activities from manufacturing facilities to the renovation site accounts for 4% of the total value. In terms of embodied energy, it represents between 2% and 4%.

The embodied greenhouse gas in construction activities accounts for approximately 5% of the total value, with one exception where greenhouse gas due to construction is responsible of the 14% of the total embodied greenhouse gas . The percentages vary between 3% and 7 % for embodied energy.

In all cases contributions from waste management were negligible.





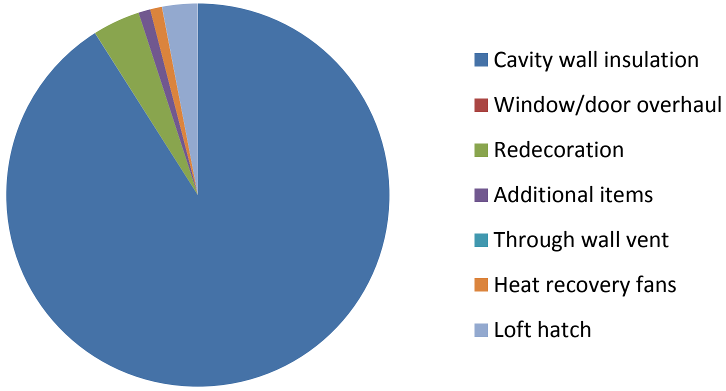
MATERIALS: EMBODIED ENERGY AND GREENHOUSE GAS BY RETROFIT MEASURE

Embodied energy and greenhouse gas of materials have been assessed separately for each property and each retrofit measure, given that materials are responsible for the highest percentage of embodied energy and greenhouse gas for all four pilot properties.

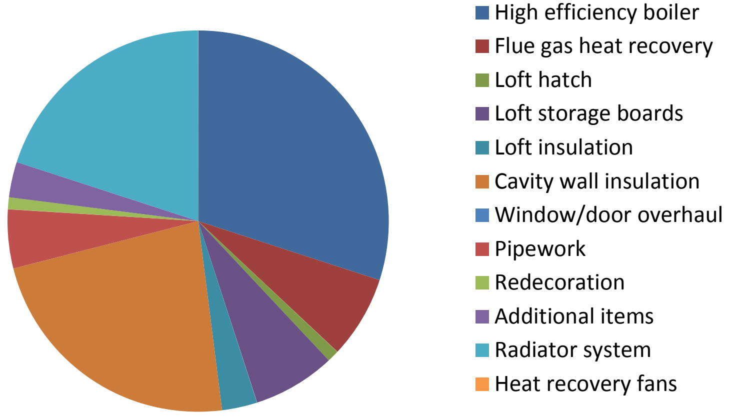
In Pilot 1, where fewer retrofit measures were implemented, the contribution of cavity wall insulation is the most significant, accounting for 91% of its total embodied greenhouse gas. For the rest of the pilot properties, complex components, such as the high-efficiency combination boiler in Pilot 13, the solar hot water system in Pilot 68 and the boiler in Pilot 69 are responsible for the highest proportion of embodied greenhouse gas, with percentages varying from 30% to 41%. In Pilots 13 and 68, insulation still accounts for relatively high percentages of 23% and 27% respectively of the properties' embodied greenhouse gas emissions.

In all cases, a large proportion of greenhouse gas is embodied in the **insulating materials**, especially in the external insulation, mainly due to the large weight of material required. Additionally, it is important to highlight the significant greenhouse gas costs of the provision of **complex or innovative components**, such as the high-efficiency boiler and the solar hot water system.

Pilot 1: Contribution % to embodied greenhouse gas by retrofit measure



Pilot 13: Contribution % to embodied greenhouse gas by retrofit measure

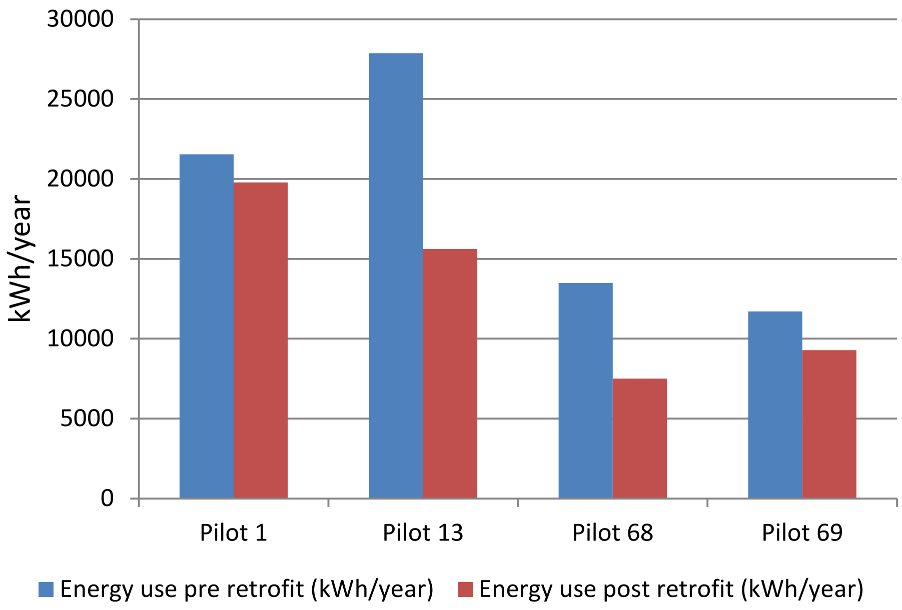


ENERGY AND GREENHOUSE GAS PAYBACK

Embodied energy and greenhouse gases can be considered as an investment in the house. High levels of embodied burdens are environmentally beneficial investments when they result in a home with low operational greenhouse gas emissions. On the contrary, a house with low embodied burdens has a poor greenhouse gas investment when it has high operational emissions.

The time required to recover the embodied burdens varies between 6 and 33 months for the four dwellings. Pilot 69 is the house with the longest greenhouse gas payback time of nearly three years. Properties 1 and 13 have similar payback period of approximately half a year, while Pilot 68 recovers its greenhouse gas investment after 14 months. Especially for Pilot 1, which has less retrofit measures implemented, the fact that it recovers its embodied greenhouse gas so quickly, relates to the fewer actions implemented, rather than its energy efficiency. The figure presents the current and the actual energy use for each one of the pilot properties.

The energy use pre retrofit is based on energy bills, while the energy use post retrofit is based on monitoring. The energy reduction percentage varies between 8% and 44%. The low energy reduction percentage in Pilot 1 (8%) is due to the limited amount of measures that have been implemented, rather than a failure of the retrofit to achieve what was expected.



Key issues related to Annex 57:
1.6 Impact of construction practices
2.1 Importance of different building lifecycle stages

Case study UK3
11 Housing developments- UK

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Data has been collected for 11 developments, constructed by the same contractor, regarding energy and water use, as well as waste production during the construction stage.

The duration of the construction stage and the project valuation do not seem to have a significant influence on the amounts of energy spent and consequently on the resulting greenhouse gas emissions.

The energy use per floor area varies between 2.85 kWh/m^2 and 19.36 kWh/m^2, with an average value of 9.60 kWh/m^2. Similarly, the embodied greenhouse gas involved in the construction process is between 2.38 kg CO_2/m^2 and 12.88 kg CO_2/m^2, with an average of 8.56 kg CO_2/m^2.

OBJECTIVES OF CASE STUDY

The aim of this study is to investigate energy use, greenhouse gas emissions, water use and waste management during the construction stage of 11 housing developments in the UK. The objectives of this analysis are the following:

- To identify the impact of construction practices, such as site energy management
- To investigate water use during building construction
- To investigate waste management during building construction
- To correlate embodied energy and greenhouse gas during building construction with project values, floor area and construction duration.

BUILDING KEY FACTS

Intended use: Residential (11 housing developments)

Size: varies between 303 and 14,136 m^2 GIFA

Number of floors: between 2 and 6

'Footprint' size: varies between 152 and 4,712 m^2

Location: locations vary, UK

Building year: 2010 - 2011

Contractor: Willmott Dixon

Project phase studied: Construction

Cost: varies between £399k and £15.4m

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THE BUILDING

The analysis refers to 11 housing developments in the UK, all of them constructed by the same contractor, Willmott Dixon.

The developments' sizes vary between 303 and 14,136 m^2 of internal floor area, with construction periods between 7 and 19 months. Their monthly valuations for the construction phase are between approximately £399k and £15.4 million, which equals to values between 614£/m^2 and 1,988 £/m^2 of internal floor area.

SYSTEM BOUNDARIES

The information analysed comes from the construction stages. There is separate data specifically for the demolition and excavation phases and for the rest of the construction period.

The type of data available refers to energy use, with reference to specific types (electricity, gas and diesel) and the resulting greenhouse gas emissions.

Moreover, there is data on water usage, waste and waste disposal.

Although there is information available for 11 developments, only 10 of them are included in the analysis of energy use and greenhouse gas emissions. In one of the cases (Project 4), the building has been heated in order to dry the timber frame, which is not a standard practice, so this has been excluded from the energy and greenhouse gas calculations and comparisons. Waste and water data for all 11 developments are included in the analysis.

Finally, contract values and information regarding the duration of construction phases and the building sizes is available. This will allow the correlation of different factors which might have an influence on embodied energy and greenhouse gas for buildings' construction.

REFERENCES

Steve Cook, Willmott Dixon: personal communication and company supplied information.

ACKNOWLEDGEMENTS

We would like to thank Steve Cook for his help and the information provided.

WATER USE AND WASTE MANAGEMENT

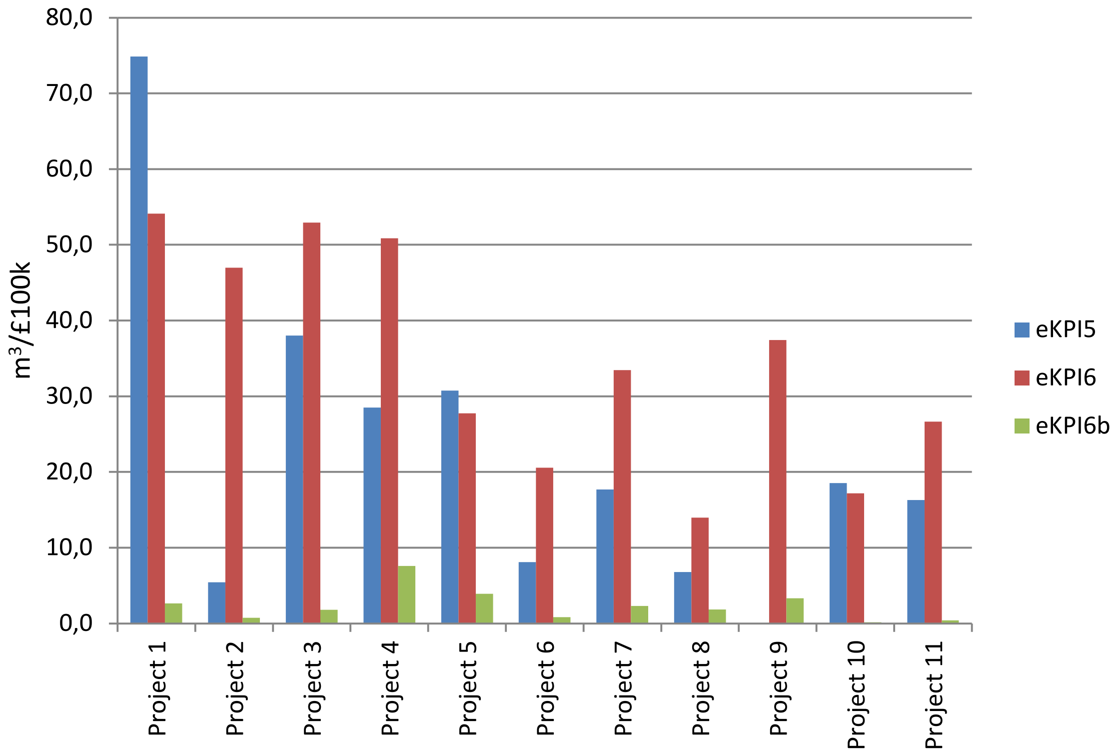
The contractor set specific methods of monitoring their water consumption, as well as their waste production and the amount of waste diverted to landfills. More specifically, they set targets against certain environmental Key Performance Indicators (eKPI), based on water use or waste production per £100k. The following eKPI indicators are of interest for this analysis:

eKPI 5: Mains Water Use during the Construction Process (m^3/£100k)

eKPI 6: Waste during the Construction Process (m^3/£100k)

eKPI 6b: Waste to Landfill during the Construction Process (m^3/£100k)

The Projects are numbered 1 to 11 in order of value (of the total construction phase valuations), starting with that of the lowest value (Project 1) and ending with the one of the highest value (Project 11)



ENERGY USE AND GREENHOUSE GAS EMISSIONS PER PROJECT VALUATION

The energy use during the construction stage, excluding demolitions and excavations, varies highly between the 10 developments and so do the types of energy used. For most of the developments, electricity and diesel were used and it was only in one case that there was use of gas during the construction. In 6 out of 10 cases, both electricity and diesel have been used. The figure below shows the energy use and greenhouse gas emissions per floor area for the 10 developments, excluding the stages of demolitions and excavations. The total energy use per project valuation ranges from 669 kWh/£100k to 4137 kWh/£100k, with an average of 2371 kWh/£100k. The embodied greenhouse gas involved is between 267 kg CO_2/£100k and 1659 kg CO_2/£100k, with an average value of 921 kg CO_2/£100k. The type of energy used obviously influences the associated greenhouse gas emissions, with electricity having a significantly higher conversion rate compared to diesel and gas. Nevertheless, this is something likely to change in the future, depending on the levels of the grid decarbonisation.

For the construction stage (excluding demolition and excavation)

Energy use:

Minimum: 669 kWh/£100k

Maximum: 4317 kWh/£100k

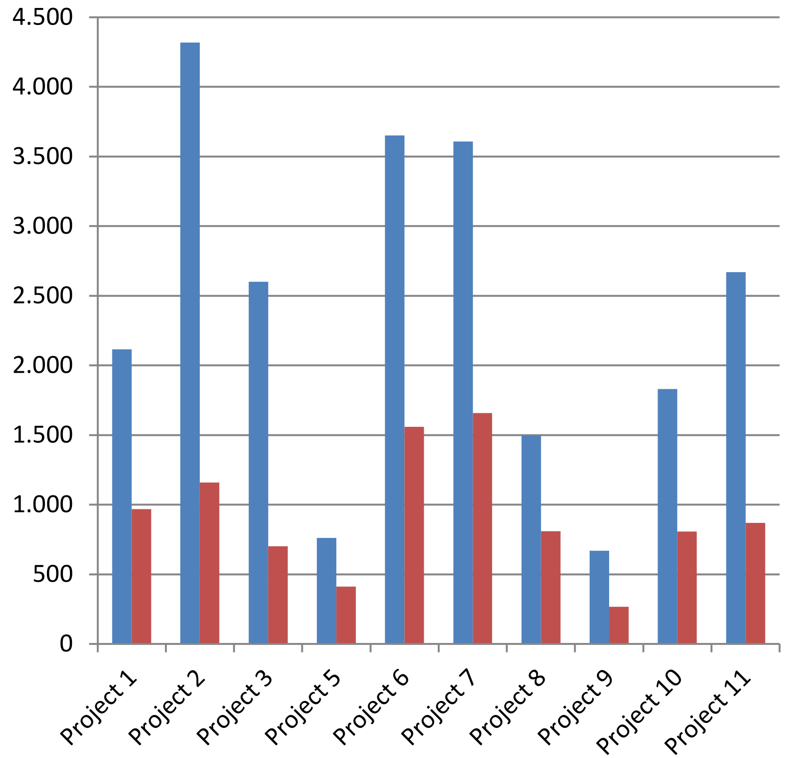
Average: 2371 kWh/£100k

Embodied greenhouse gas:

Minimum: 267 kg CO_2/£100k

Maximum: 1659 kg CO_2/£100k

Average: 921 kg CO_2/£100k



The considerable differences on the conversion from energy to greenhouse gas emissions, is due to the different types of energy used for some of the projects.

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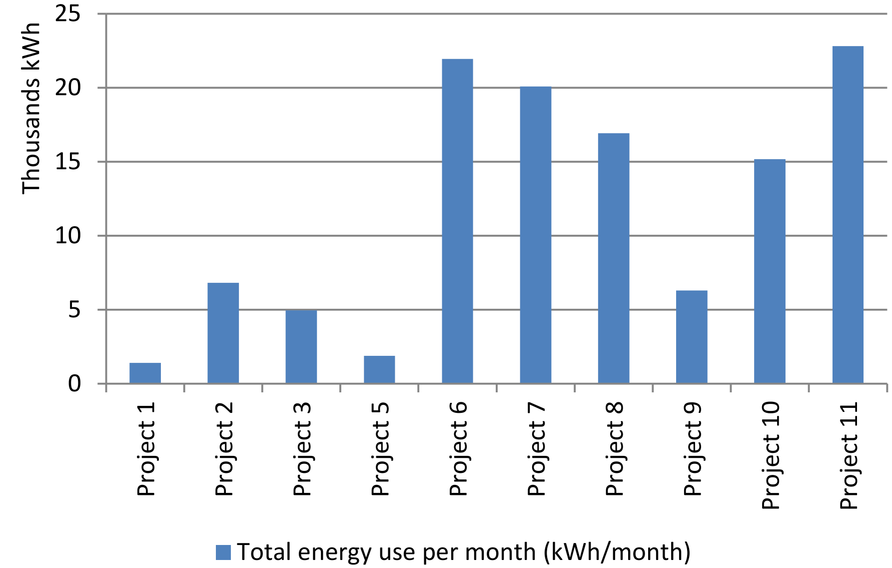
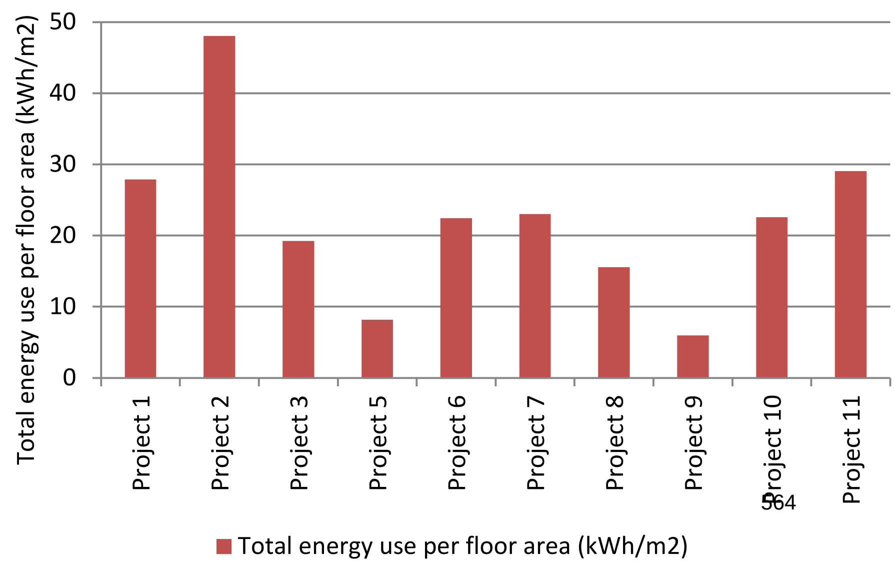
ENERGY USE AND GREEN HOUSE EMISSIONS PER PROJECT AREA AND DURATION

As it became obvious in the previous page, there is no significant correlation between energy use or greenhouse gas emissions and project valuation. Similarly, as shown in the figures, there is no direct connection between energy and duration of construction or floor area. The energy use per month varies between 1,407 kWh for Project 1 and 22,808 kWh for Project 11, with an average value of 11,830 kWh per month.

The energy use per floor area has relatively smaller variations. The lowest energy use per floor area is 6 kWh/m^2, observed in Project 9 and the highest one is 48 kWh/m^2 for Project 2. The average value is 22 kWh/m^2, with half of the projects having an energy use between 19 and 29 kWh/m^2.

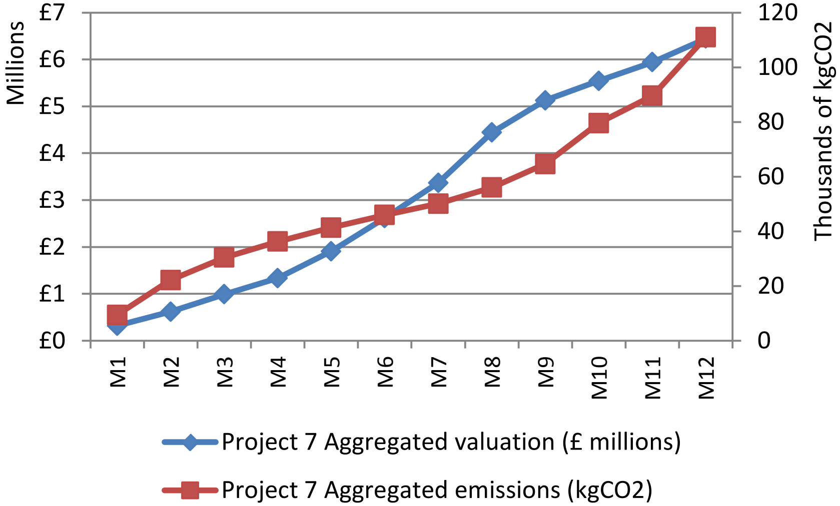


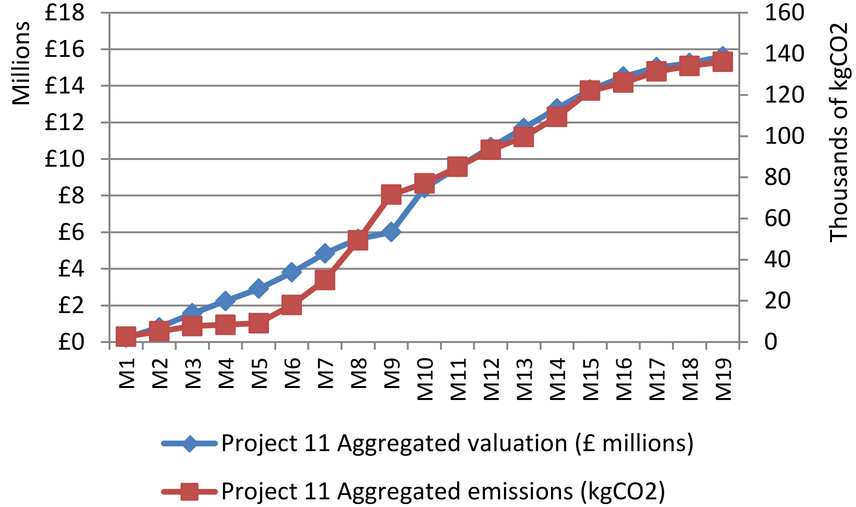


CARBON EMISSIONS PER VALUATION

The carbon emissions highly very between the 10 developments. The emissions per valuation vary between 270 and 1,660 kgCO_2/£100k of total valuation. Despite the fact that all data comes from the same contractor and although there is a consistent system of data collection in place, there are several factors which influence the waste, water, energy and carbon figures. The construction form and the extent of off site prefabrication of elements can have an effect on the construction waste volume. Moreover, the footprint ratio of a building has an influence on the plant which will be needed for horizontal and vertical transportation of materials. Finally, the time of the year during which construction takes place, can have a massive impact on the temporary heating and lighting but also on the dust control.

The two graphs below present the monthly emissions in kg CO_2 for two different Projects (7 and 11), with construction periods of 12 and 19 months respectively. In both examples, there is a close match between the monthly expenditures and the carbon emissions.





Key issues related to Annex 57:
1.1 Selection of materials
4.1 Traditional materials vs. emerging state of the art materials
4.3 greenhouse gas sequestration in wood
6. Decision making processes

Case study UK4

St Faith's School building - UK

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a period of 68 years (2012-2080) and the calculations were conducted right after the end of the construction period. The study showed that during the building's lifecycle, the expected operational energy was approximately **67%** of the total primary energy, as opposed to **33%** which was the total calculated embodied energy. These percentages are **59%** and **41%** for CO_2 equivalent respectively.

Evaluation of different building parts in terms of energy consumption, showed the significance of the superstructure, followed by the fittings, fixtures and furniture and the floor slab.

Evaluation of the different building materials' the production stage showed that for embodied greenhouse gases, minerals came first, followed by plastics, metals and timber.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) by evaluating the use of Primary Energy (PE) related to the life cycle of a new office building in the UK. The study evaluates:

- The significance of the Embodied Energy and greenhouse gases compared to the Operational Energy and greenhouse gases.
- The significance of different life cycle stages
- The percentile contribution of each material to the A1-3 stage
- The impacts related to the different assemblies
- The impacts related to different building materials

BUILDING KEY FACTS

Intended use: Education

Size: 195 m^2 GFA / 171 GIFA

Location: Cambridge, UK

Building year: Completed in 2012

Architect: Verve Architects

Project phase studied: Construction

Structural material: prefabricated engineered timber frame

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SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	X	X			X	X	X	X		X	X	X	X	

* Embodied energy and greenhouse gas waste processing and disposal have been calculated but not accounted for in the final results.

LCA BACKGROUND

Reference study period: 68 years

Databases used: Bath ICE v2.0 , EPDs, Case studies, ECEB tool

Standards/guidelines: BS EN15978: 2011, TC350

REFERENCES

ECEB tool (2013) Centre for Sustainable Development, University of Cambridge, UK: Embodied Carbon and Energy in Buildings.

Gavotsis, Efstratios (2013) The way forward for practical measurement and reduction of embodied energy and carbon in UK buildings: The case study of St Faith's School, MPhil dissertation, Department of Architecture, University of Cambridge, UK.

Symons KE, Moncaster AM, Symons D (2013) An application of the CEN TC350 standards to an Energy and carbon LCA of timber used in construction, and the effect of end-of-life scenarios..

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Production and construction stage modelling: All phases of the production and construction stages have been included in the calculations. This includes the raw material supply, transport to manufacturer, manufacturing, transport to the construction site, on site energy consumption, as well as on and off site waste production. It was only possible to calculate the precise quantities for the minority of the components. The rest of the components were either not identified at all (e.g. electrical, mechanical) or identified but not calculated due to their complexity (e.g. door security systems). Other components were identified but not calculated due to the significant lack of important information (e.g. earthing system) and –finally- some were identified and estimated (e.g. underground drainage).

For the material components, an effort was made to retrieve data from relative to the UK industry sources and inventories. Water usage is not included in any of the calculations. The impact of the production and transportation of materials lost or damaged during the construction and installation process has been included.

Use and operation stage modelling: Use, maintenance and water use modules B1, B2, B7 have not been included in the case study. All components were considered individually as replaceable for stages B3-5, following the methodology of the ECEB tool (University of Cambridge, 2013). It was not possible to measure the actual operational energy due to a number of constraints. However, independent detailed simulation was conducted and compared to the building services engineers' results.

End of life stage and next product system modelling: Stage C containing the end-of-life of materials has been addressed in the study, however, stage D of the building life cycle stages has not been included.

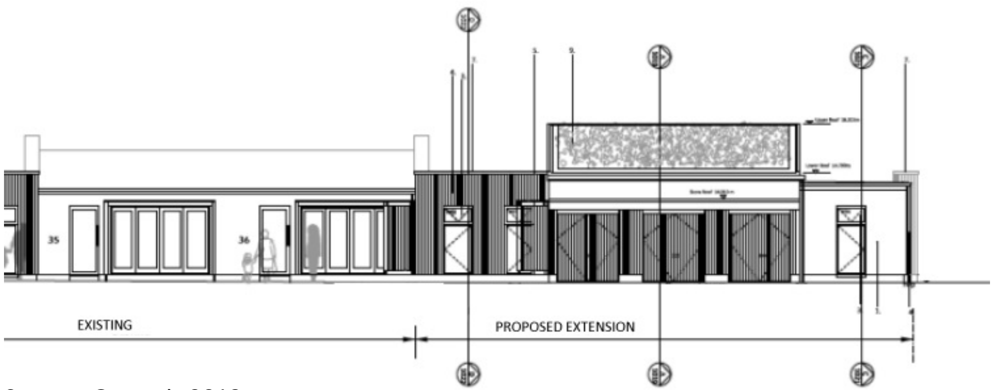
Carbon Sequestration: Calculation has been conducted, but this is not included in the final energy bill.

THE BUILDING

The architects designed a classroom following the Passivhaus principles, exceeding the Building Regulations Part L 2010 requirements. The single-storey building adjoins a 1960s block.

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 incorporated.

The heating system (natural gas-fired boilers) of the classroom under study is also shared between a 1878 building and a neighbouring recently (2011) refurbished 1960s building. All of the buildings use natural ventilation for cooling.



Source: Gavotsis 2013

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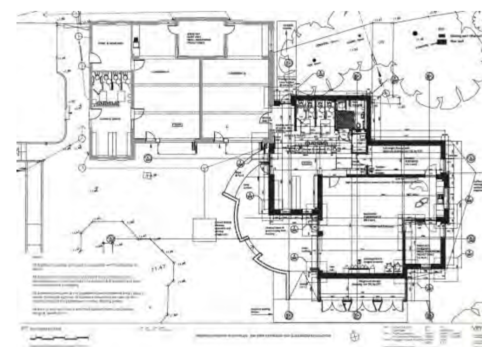

Source: Gavotsis 2013

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MATERIAL USE AND QUANTITIES FOR A1-3 STAGES

Minerals is the dominant material for mass, contributing 85% to the total, with timber and steel following with 10% and 3% respectively.

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MATERIAL USE: TIMBER AND CARBON SEQUESTRATION

The extensive use of timber and its by-products (e.g. cellulose insulation) in the design of the building, as well as the sustainable construction techniques, have been effective in keeping the whole life embodied energy relatively low for the superstructure.

Although the building was intended to make maximum use of timber and local products, minerals still have an important role and almost half of the freight is attributed to products imported.

The carbon sequestration value is given by the following equation:

ECO_{2seq} = (mass kg of timber from stages A5, B3-5, C2-4)*(-1.8+value depending on the end of life scenario)

For all the timber, it was assumed that 33.3% was sent to landfill and therefore a total carbon burden from sequestration and the end of life state of 0.35kgCO_2/kg and that the rest 66.6%, was reused/recycled with a benefit of 1.80kgCO_2/kg timber.

The only exception was the total mass of timber processed at the timber-frame factory, for which it was proved a total carbon benefit of 1.80kgCO_2/kg timber (reuse/recycle).

Timber **sequestration** can make a considerable contribution decreasing the total carbon by up to **9%** in the best case scenario.

Life cycle energy and greenhouse gas impacts of timber products for different End of life scenarios [adapted from (Symons et al. 2013)].

		Energy impact MJ/kg	*Total MJ/kg (S+EoL):*	*Carbon impact kgCO_2/kg*	*Total kgCO_2/kg (S+EoL):*
Carbon sequestered		0		-1,8	
End-of-Life Scenario	recycling	0	0	0	-1,8
	incineration, no energy recovery	0	0	1,8	0
	incineration, with energy recovery	-3,4	-3,4	1,3	-0,5
	landfill	0	0	2,15	0,35

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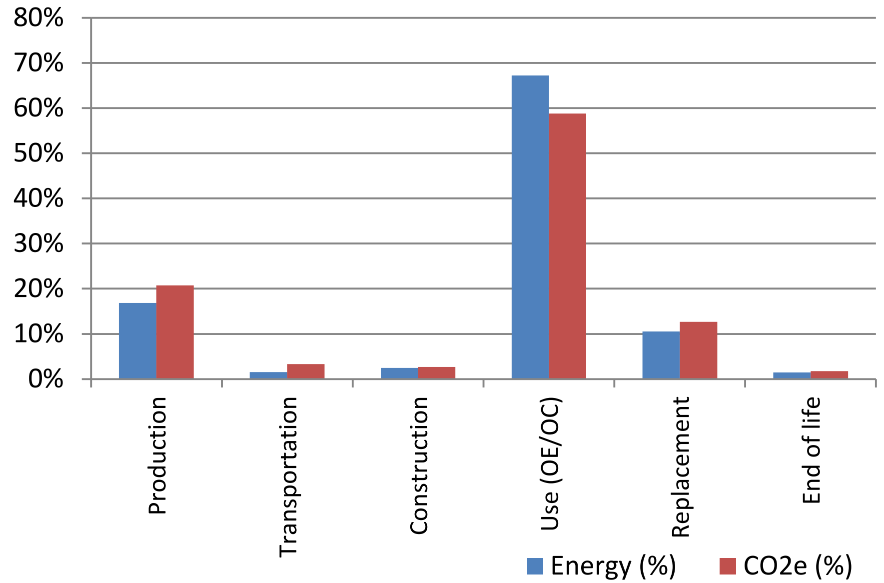
ENERGY AND GREENHOUSE GAS USE BY LIFECYCLE STAGE

Total Primary Energy consumption:
620 MJ/m^2_{GFA}/year
Embodied energy: 33%
Operational energy: 67%

Embodied greenhouse gas :
40 kg CO_2/m^2_{GFA}/year
Embodied greenhouse gas: 41%
Operational greenhouse gas : 59%

Lifetime: 68 years



The values are within or near the wide range of values found in the literature for all the stages, including production, transportation, construction, replacement and end of life.

Construction energy is higher compared to other research and this may be attributed to the assumptions made and the building scale while, the amount of waste produced is close to values from similar studies.

The replacement stage is the second most important contributor to embodied energy and greenhouse gas and produces waste equal to 16.7% of the initial mass of the building with the most important components being the finishes.

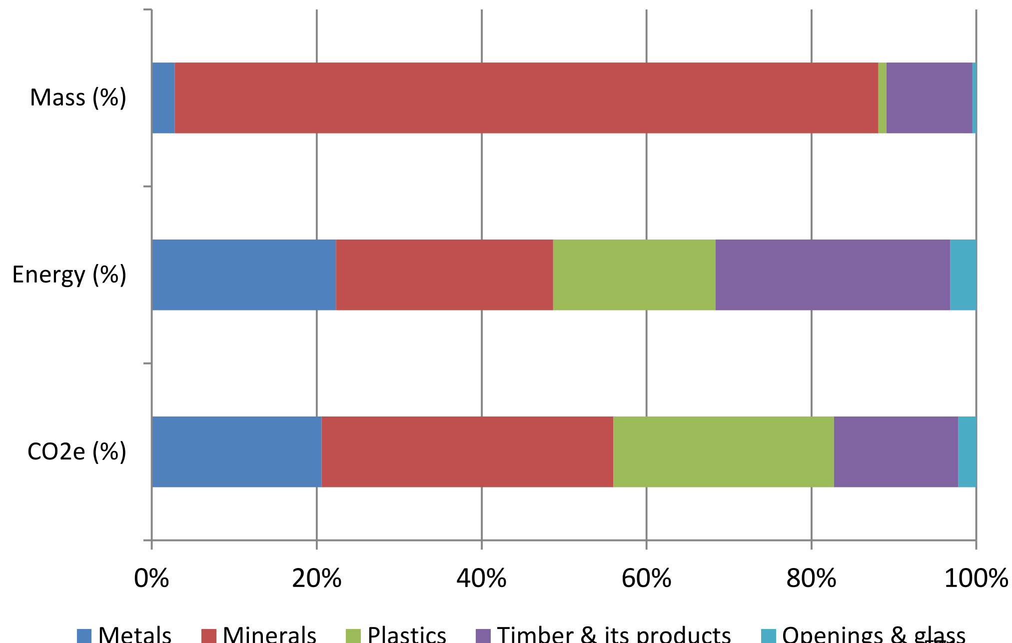
The end of life stage is calculated based on current practices and constitutes the smallest burden out of all stages. This is due to the fact that only energy consumed and greenhouse gas emitted for the demolition and transport of the waste to the final site was included. The downstream impacts were not included due to lack of reliable data. The carbon sequestration is –again- not accounted for. These results could be re-examined based on more rigorous data.

EMBODIED ENERGY AND GREEN HOUSE GAS USE BY MATERIAL TYPE: A1-3 PRODUCTION STAGE

Although minerals is the dominant material in terms of mass, followed by timber and steel with considerably lower percentages, the case is not the same for the total energy. Timber has been calculated as the greatest burden **for the production stage (A1-3)**, without accounting for carbon sequestration. This is attributed to the fact that timber has approximately 10 times higher embodied energy per mass compared to concrete.

Values are different when it comes to embodied greenhouse gas. The values for metals and plastics are 21% and 27% respectively, while the greenhouse gas impact of the minerals outweighs all the rest. Timber comes fourth with 15% of the total embodied greenhouse gas (again, no carbon sequestration included).

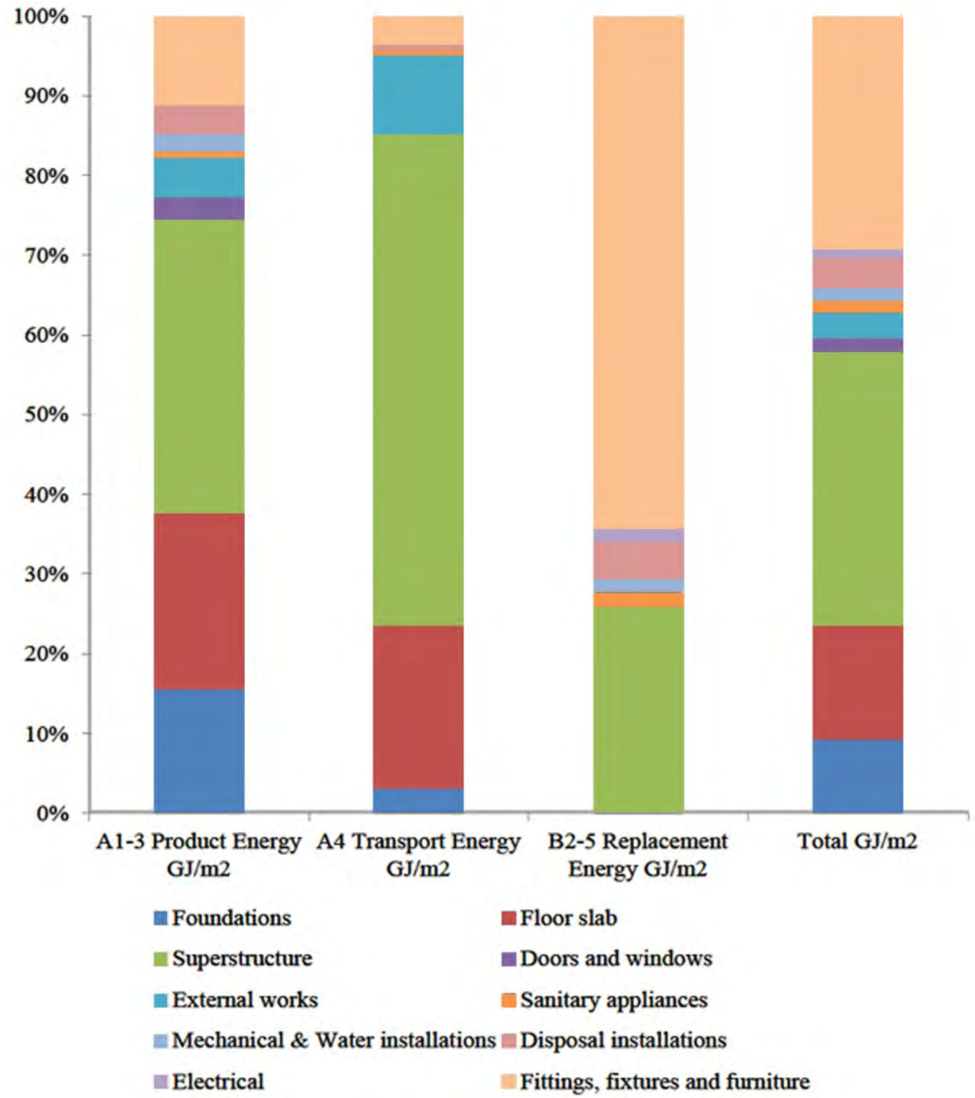
Generally, although metals and plastics have a small percentage in the total mass, they have a significant impact on both energy and greenhouse gas.



EMBODIED ENERGY AND GREEN HOUSE GAS BY ASSEMBLY

The TC350 standards do not explicitly advice the creation of standard categories and components to be included. The study breaks the building in the following assemblies: foundations, superstructure, external works, mechanical & water installations, electrical, floor slab, doors and windows, sanitary appliances, disposal installations, fittings, fixtures and furniture.

The results are shown in the figure. Superstructure consumes a considerable amount of energy in all stages, while fittings, fixtures and furniture are the highest contributor to the energy consumption at the replacement stage.



Source: Gavotsis 2013

Case study UK5
Lingwood development - UK

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

A house constructed using a panellised timber frame construction, had 26% lower embodied energy and 34% reduction in embodied greenhouse gas than the equivalent traditional masonry house.

Embodied greenhouse gas savings in buildings' construction can be made by:

- increased offsite components' manufacturing
- selection of sustainable materials or materials with reduced environmental impact

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OBJECTIVES OF CASE STUDY

To quantify the energy and greenhouse gas embodied in the construction and technologies of low carbon homes compared to conventional new build houses.

To identify the importance of embodied energy and greenhouse gas in the built environment on a national level.

BUILDING KEY FACTS

Intended use: Housing (affordable rent/shared ownership)

Two house sizes: 71/83 m^2 internal floor area

Location: Lingwood, Norfolk, UK

Building year: 2008

Design and construction by Flagship Housing Group Ltd

Project phase studied: Design and Construction

Structural material: offsite engineered structural panel timber frame

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Building life cycle stages included in the study, according to EN15978

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	X	X						X						

LCA BACKGROUND

Reference study period: 20 years. A 20 year time period was selected because no significant refurbishment or replacement of the homes and the technologies used in them would be required. It also coincided with the available projected data for decarbonisation of the electricity supply.

Sources and Databases used: published Government carbon emission factors, The Inventory of Carbon and Energy (ICE) version 1.6a, EcoInvent database, U.S. Life-Cycle Inventory (USLCI).

Standards/guidelines: ISO 14040/44: 2006

REFERENCES

Monahan, Jennifer (2013), Housing and carbon reduction: Can mainstream 'eco-housing' deliver on its low carbon promises?, PhD thesis, School of Environmental Sciences, University of East Anglia, UK.

Monahan, J. and J.C. Powell (2011), An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework, Energy and Buildings 43(1)

The analysis of embodied energy and greenhouse gas is based on one of the Lingwood case study houses, a three bedroom semi-detached house of 83m^2 internal floor area. **Three scenarios** are used: (1) the Modern Methods of Construction (MMC) case study as constructed with a larch facade; (2) the larch as a facade material is substituted by brick; and (3) a conventionally constructed house using masonry cavity construction.

Production and construction stage modelling:

The study includes the cradle to site emissions from the following: materials and products used in construction, final transport of the materials and products to site, materials' waste produced on site, transportation of waste to disposal and fossil fuel energy used on site during construction and in components' manufacturing. The calculations don't include internal elements, such as walls and doors, finishes, such as paints, plasterboard, skirting board and fittings, such as bathrooms, lighting and kitchens. The study assumes these will be identical for all of the compared construction types and can therefore be excluded from this analysis.

Use and operation stage:

A calculation of whole house energy and greenhouse gas were undertaken for the basic case study. The calculation was carried out using National home Energy Rating (NHER) Plan Assessor V4.2.28 software incorporating SAP 9.81 (BRE 2005). Moreover, meter readings were taken from the electricity and gas consumer units, water meters and PV inverters, providing quantitative data on actual energy used, total water consumption and annual PV production.

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THE DEVELOPMENT

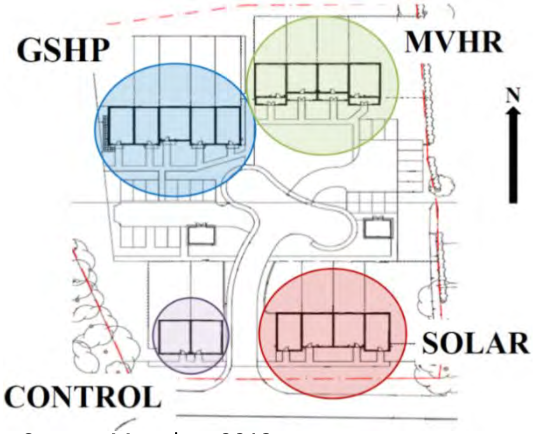
The case study comprises 15 newly constructed low energy affordable homes. They have been constructed using an off site engineered structural panel timber frame construction with additional insulation materials to exceed current minimum building regulation standards.

DESIGN STRATEGIES

Design aspects included high levels of insulation and airtightness, ventilation via vents incorporated into window frames, optimised solar orientation, energy efficient gas boilers, LZC (solar hot water, photovoltaics, and ground source heat pumps), dedicated fixed low energy lighting, offsite manufactured timber frame, larch weather boarding and FSC certified timber.

There was also a reduced use of high embodied energy materials, such as masonry and concrete. There are communal recycling facilities and water efficient strategies (grey water use and low water use) in place. Finally, the aim was to keep the development at **affordable levels**, both to build and to run.

The 15 homes comprised four blocks of terraced homes all constructed to the same specification using the same innovative offsite panellised construction system but each block had a different low and zero carbon (LZC) technology for providing heat or power. This is shown on the figure on the right. Two homes acted as controls with conventional condensing gas fired instantaneous combi-boilers (CONTROL); 4 homes had the same boiler in conjunction with solar hot water systems and photovoltaics for power (SOLAR); a third block also had the same gas boiler but with a thermal sunspace to the south facing elevation and a mechanical ventilation system with heat recovery (MVHR); in the fourth block they were all electric with a ground sourced heat pump providing all heating and hot water needs.



Source: Monahan 2013

CONTROL: homes acting as controls with conventional condensing gas fired instantaneous combi boilers

SOLAR: same boiler in conjunction as above, with solar hot water systems and photovoltaics for power

MVHR: same gas boiler but with a thermal sunspace to the south facing elevation and a mechanical ventilation system with heat recovery

GSHP: all electric with a ground sourced heat pump providing all heating and hot water needs.

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PRIMARY ENERGY AND EMBODIED GREENHOUSE GAS FOR 3 SCENARIOS: TIMBER VERSUS CONVENTIONAL COSNTRUCTION

Scenario 1: **Modern Methods of Construction** (MMC) case study as constructed

Scenario 2: Larch facade material substituted by **brick**

Scenario 3: Conventionally constructed house using **masonry** cavity construction

This study found that a house constructed using a panellised timber frame MMC construction, had 26% lower embodied energy and 34% reduction in embodied greenhouse gas than the equivalent traditional masonry house. This is mainly attributed to the use of materials, in this case softwood timber in the wall component, with relatively lower embodied greenhouse gas and lighter mass requiring less substructure than conventional.

Despite the different construction method, the percentages of materials' contribution to embodied greenhouse gas compared to waste, energy and transport is quite similar in all 3 scenarios. Scenarios 1 and 2 are presented in the figures below.

Total Primary Energy consumption:

Scenario 1: 5.7 $GJ/m^2_{\text{usable floor area}}$

Scenario 2: 7.7 $GJ/m^2_{\text{usable floor area}}$

Scenario 3: 8.2 $GJ/m^2_{\text{usable floor area}}$

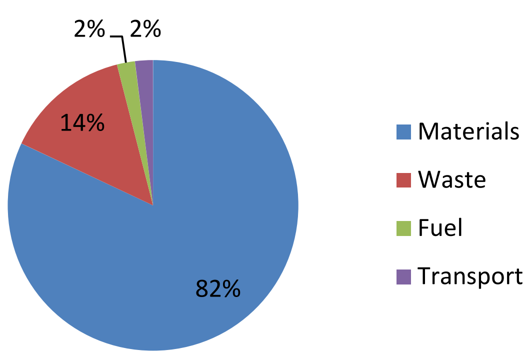
Embodied greenhouse gas :

Scenario 1: 405 kg $CO_2/m^2_{\text{usable floor area}}$

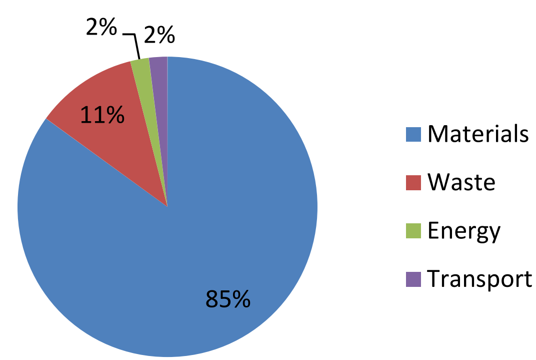
Scenario 2: 535kg $CO_2/m^2_{\text{usable floor area}}$

Scenario 3: 612 kg $CO_2/m^2_{\text{usable floor area}}$

Scenario 1 Embodied greenhouse gas contribution in construction (%)



Scenario 2 Embodied greenhouse gas contribution in construction (%)



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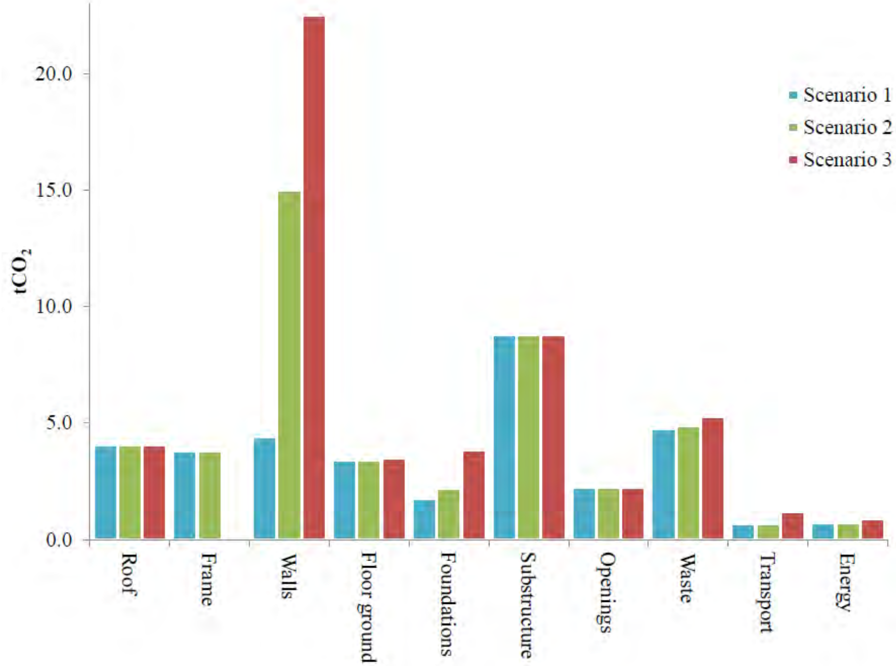
PRIMARY ENERGY AND EMBODIED GREENHOUSE GASES FOR 3 SCENARIOS: EMBODIED ENERGY AND GREENHOUSE GASES BY BUILDING PART



Source: Monahan 2013

Reductions in embodied greenhouse gases can be made by increasing the amount of manufacturing off site and by reducing the amount of waste on site.

Despite the high proportion of timber throughout the structure, half of the materials related embodied greenhouse gas is associated with the construction of the substructure, foundations and ground floor. The relative importance of these substructural components reduces with the increase of greenhouse gas intensive materials in other components, for example in Scenario 3 the proportion attributed to these elements is lower than 35%. Finally, reductions in embodied greenhouse gas can be made by increasing the amount of manufacturing off site and by reducing the amount of waste on site.

Case study UK6
Four school buildings - UK

FACTORS IMPACTING ON DECISIONS

Decision processes were analysed for the construction processes of four schools. Two of them used reduction of embodied energy and greenhouse gas as a key design target and two had no discussion about embodied energy and greenhouse gas.

Factors which impacted on the decisions around sustainability in general and embodied energy/ embodied greenhouse gas in particular included:

- Procurement route - the impact on differential power of each of the team players
- Social individuals – power, charisma, relationships
- Client knowledge and interest
- Aligned motivations - merging with the reduction of embodied greenhouse gas

The results of these four case studies led to comparisons and assumptions regarding the impact of procurement and tools, as well as the impact of professions and expertise on sustainability and its implementation in the construction sector.

OBJECTIVES OF CASES STUDIES

To investigate some of the socio-political background to the decision making processes which determine whether embodied energy/ embodied greenhouse gas is considered.

Through analyses of four UK school building projects, procured at the same time through different processes, the case study offers insight into why embodied greenhouse gas and energy was taken into account for two of the schools and excluded from the others.

Other aspects of sustainability for schools, as derived from an analysis of Government policy statements and reports (Moncaster, 2012), are also assessed.

BUILDING KEY FACTS – CASE STUDY BOUNDARIES

Intended use: Secondary State School Buildings
Project Total Costs: between £12 and £20m GBP
Location: East of England, UK
Building year: Completed between 2007-2010
Project phase studied: Design and construction

PROJECT KEY FACTS

CS1 KEY FACTS

Project cost: £21m
Location: Hackney, London, UK
Architect: Jestico + Whiles
Structural material: steel frame

No of pupils: 1500
Procurement: Building Schools for the Future (BSF)
Contractor: Willmott Dixon
Building year: Completed Summer 2010

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CS2 KEY FACTS

Project cost: £20m
Location: Norwich, Norfolk, UK
Architect: Sheppard Robson
Structural material: cross-lam timber (CLT)

No of pupils: 950
Procurement: National Academies Framework
Contractor: Kier Eastern
Building year: Completed Summer 2010

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CS3 KEY FACTS

Project cost: £12m
Location: Cambridge, Cambridgeshire, UK
Architect: Mouchel
Structural material: steel frame

No of pupils: 1350
Procurement: Local framework agreement
Contractor: Willmott Dixon
Building year: Completed Summer 2010

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CS4 KEY FACTS

Project cost: £13m
Location: Peterborough, UK
Architect: GSS
Structural material: cross-lam timber (CLT)

No of pupils: 850
Procurement: Direct capital grant
Contractor: Kier Eastern
Building year: Completed Winter 2009

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BACKGROUND TO PROJECTS

CS1 THUMBNAIL SKETCH

A large successful school in inner London, with 1960s buildings in need of repair. One of the first projects in Hackney to be put through the BSF procurement. The majority of the project involved the refurbishment of the existing building, combined with the construction of a new build (20%). Strong committed Local Authority client, school governors and leadership team, and local residents, all with a focus on environmental and social sustainability in terms of inclusion of all sectors of society and importance therefore of stakeholder participation in the design. Principal requirement for school was to repair old buildings, support continuing success and to obtain 100% disabled access.

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CS2 THUMBNAIL SKETCH

A new Academy, 100% new build, intended to replace existing school in deprived area, and built on Sports Field of existing school. Procured through the National Academies Framework, Project Managed by an experienced civil engineer working for the Local Authority, 'sponsored' by local entrepreneur with a focus on Christian evangelism leading to considerable disharmony with local community. Principal requirement for school was to provide a sense of pride and give the children a future.

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CS3 THUMBNAIL SKETCH

A fairly successful and long-established large secondary school in Cambridge. Previously two schools on opposite sides of a busy road, project was initiated by school, first because North side buildings were in poor condition compared with South, and had problems of access for disabled children, then decided to relocate the buildings on the south site, selling the released land for housing. Procured through a local framework agreement with the Local Authority, which was re-tendered part-way through the design stage. Planning issues delayed school by over a year.

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CS4 THUMBNAIL SKETCH

A project to rebuild (50%) and refurbish (50%) an existing Catholic secondary school with buildings in exceedingly poor condition. Procured through a direct capital grant from Government because of faith status, but as part of a general improvement of all secondary schools in Peterborough, one of the most deprived cities in the UK. School was performing poorly, and failed its Office for Standards in Education, Children's Services and Skills (Ofsted) inspection during the project, leading to the Head teacher and Governors leaving.

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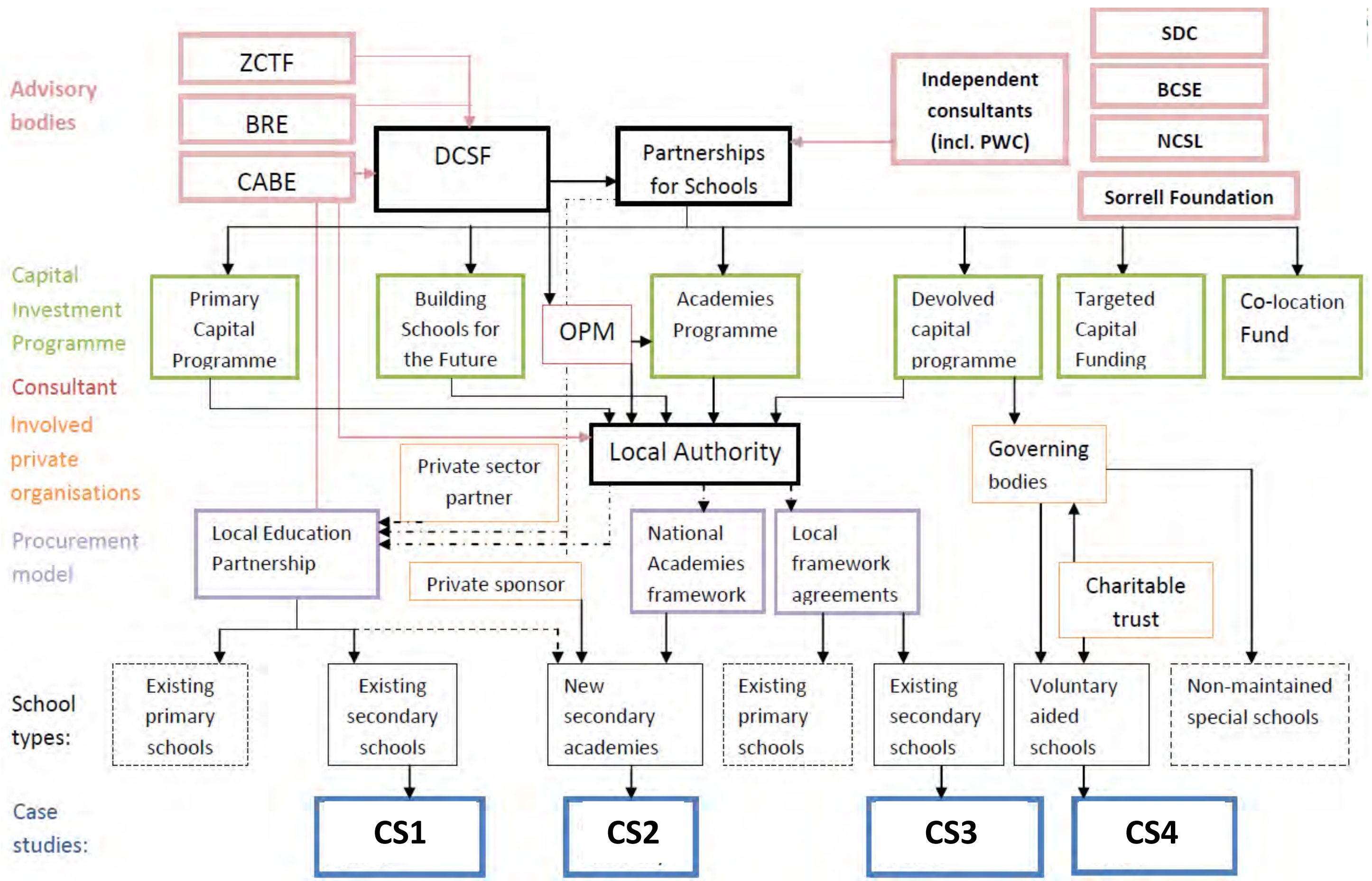
PROJECT CHARACTERISTICS AND OUTCOME

Case study:	CS1	CS2	CS3	CS4
Procurement route:	Building Schools for the Future (BSF) – Local Education Partnership (LEP)	National Academies Framework	Developed capital funding from local authorities	Central Government funding to RC Diocese
'Low carbon' technologies	Biomass boiler + conventional gas	Biomass boiler + conventional gas	Ground source heat pump	Ground source heat pump
Likely impact cf. gas	Higher greenhouse gas emissions	Lower greenhouse gas emissions	Higher greenhouse gas emissions	Higher greenhouse gas emissions
Embodied greenhouse gas	No consideration	Reduced through CLT		Reduced through CLT
Likely greenhouse gas impact cf. standard		Lower greenhouse gas emissions	-	Lower greenhouse gas emissions
BREEAM rating	'Very Good'	'Excellent'	Based on initial desktop study only	'Very Good'
Stakeholder engagement	Design Quality Indicator (DQI) used Medium	Design Quality Indicator (DQI) used Good	Poor	OK
Disabled access	A key aim, but failed to deliver	Regulatory standard	Initial driver, but design standard only	Regulatory standard

IMPACTING FACTORS 1: PROCUREMENT

Annex 57



Demonstrating the procurement routes for UK schools and the case studies
Source: Moncaster 2012

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CS1 PROCUREMENT

This project was part of the BSF programme. A feasibility study assessed areas of the existing building for different levels of refurbishment and set out the budget based on this. This study was used to procure the Local Education Partnership (LEP), a public-private partnership between the Local Authority (10%), BSF Investments LLP (10%), and a private sector partner who would lead the design and development. The contract to form the LEP was substantially judged on the quality of the design submission. However the bidding teams had not been involved in the development of the earlier feasibility stage design and the confidentiality clauses severely restricted consultation. While the school was particularly keen to include parents and pupils in the design, the procurement process had severely limited the possibilities for this. The stated key aim of the project to create 100% disabled access was the cause of considerable delay during the design and construction process – the aim was never met due to the restrictions of the funding, determined during feasibility stage.

CS2 PROCUREMENT

The original buildings that were constructed in the 1960s were to be demolished, after a new building for the academy built on the existing sports field. The new buildings were procured by the County Council through the National Academies Framework. This type of procurement led to the appointment of an Overall Project Manager (OPM), to develop the education brief. The Academies programme also encouraged individual sponsors for the new schools, in this case a local business entrepreneur and the Anglican bishop. The County Council used the national specification documents, and held a limited competition for teams of contractors and designers who had already successfully bid to be part of the national framework agreement. They appointed a contractor with whom they had a good relationship on a previous hospitals programme. The contract was let as a Design and Build, and so led by the Contractor.

CS3 PROCUREMENT

Due to the legal responsibility of the Council to bring the buildings up to current standards for disability access, a refurbishment scheme was suggested, then a new option of rebuilding part of the school, reducing the school from ten to eight form entry and developing the rest of the school site for housing. The school appeared to be in a strong position; its agreement to surrender part of its site for housing released a capital sum of money to spend on new buildings, and directly benefited the Council through the saving of the essential capital investment needed by the old buildings. Although both sites were owned by the County Council, it was clear that they were unlikely to have carried out the project without the agreement of the School. The design team was initially led by the Council in-house; a planning issue led to a year's delay in the design process, after which the design and build contract was let through a local framework agreement.

CS4 PROCUREMENT

On the basis of the outline design the RC diocese applied for 'targeted capital funding' from the Department for Education and Skills (DfES) in 2005. The application was successful and they were awarded just under £13m, a far bigger project than the diocese and their buildings consultant had managed before. EU regulations required the project management contract to be let, and the appointed PM then led the appointments of the design team. Design was substantially completed before the Design and Build contract was let, with novation of architects and structural engineers to ensure continuity.

CS1 FOCUS

Sustainability was a particular focus for several key organisations involved; the Council had a strong vision for sustainability from the beginning; the school felt it was an important issue for the community and believed that new knowledge should involve sustainability, including embodied energy. Finally, the architects' approach to sustainability covered environmental and ecological conservation, minimisation of resource use, reduction of energy use through passive and active measures, and specification of materials with respect to their embodied energy. However, the implementation left everyone unhappy in terms of how sustainability had been implemented. The technology chosen to address the planning requirement for 10% energy from renewable sources and identified as 'sustainable' was a biomass boiler, chosen by the client and their design advisors. The contractor suggested a CHP plant, however time and cost issues didn't allow its implementation.

CS2 FOCUS

The vision of CS2 included some broader principles that could be interpreted as aspects of sustainability. The client requirements for sustainable development focused on environmental issues: environmental assessment, water and energy conservation, the reduction of waste during construction, renewable energy, higher recycled content and the use of materials which minimise embodied greenhouse gas impact. Moreover, the project manager was very keen on achieving a BREEAM rating of 'Excellent'. The CLT option was strongly supported by the architects and the structural engineer. In fact, the structural engineer had been appointed, according to themselves, instead of a major firm of structural engineers due to their experience in CLT and their calculations demonstrating the embodied greenhouse gases of the material. The contractor, considered the timber frame, together with the biomass boiler, lighting controls, rainwater harvesting and solar photovoltaic panels as the main aspects of sustainability encompassed in the project.

CS3 FOCUS

There was no consideration of embodied energy and greenhouse gas in this project. Sustainability was considered a synonym of renewable energy. The County Council had the power to make decisions and there was no opportunity for the school users to have any input in the decision making process. Possibilities of using photovoltaics or other types of renewable energy, have been completely disregarded. The County Council had been accepted as the client by the project team and thus the mechanical engineers accepted their suggestion to use GSHPs, due to the lower cost. However the cost had been estimated at a very early stage, by services engineers who were, as they admitted themselves, no experts in the field and thus reality was very different to their predictions. Other aspects regarding sustainability were all, either imposed by regulation or planning requirements, either conventional 'good practice' within the sector.

CS4 FOCUS

The school had stated that the project should be sustainable in social, economic and environmental terms, which in practice mainly focused on the environmental aspect of sustainability. The brief even included mention of embodied energy and greenhouse gas, other than fabric quality and renewable energy issues which are more usual aspirations. The funding requirement for the project to achieve 'BREEAM Very Good' was also among the drivers for sustainability. Architects defined sustainability as thinking about the long term effect of the school building project, while other professionals viewed sustainability as their own remit. The building services engineers focused on using less energy, using renewable energy and on supplying energy efficiently. Finally, the structural engineers interpreted sustainability as the reduction of embodied energy and thus recommended the use of CLT, rather than conventional construction structural methods.

CS1 SOCIOLOGY

A Design Quality Indicator exercise enabled input by the school, to ensure that their opinions were taken into account in the design. However the participants found the process confusing and frustrating, with the tool not allowing the introduction of new topics, other than the ones predetermined. The lack of involvement of the students at this stage was a particular issue: they could only comment on specific issues, after decisions have been made, so they didn't have a significant input in the actual process. The Council had retained their power, in a conflict against the wishes of the school. Finally, the structure of the funding model, focusing on capital cost rather than either long-term cost or on a detailed assessment of the greenhouse gas emissions, was partly to blame for the over-riding of specific advice from the experts.

CS2 SOCIOLOGY

The Design Quality Indicator exercise was used, with the client project manager and design advisors, as well as the sponsors, to evaluate what qualities the building should achieve and the impact of the building on people, the users, stakeholders and the community. However, due to different reasons, not all stakeholders were present. The council project manager had experience, both in teaching and in the construction sector, making her an experienced and effective client. The Council and the project manager had worked with the contractor before and had a good working relationship with them. Finally, the principal and the architect had ensured that the pupils were involved throughout the design stage, setting up teams to work on different areas such as landscape, interiors and building services.

CS3 SOCIOLOGY

The school's Chair of Governors at the time was a structural engineer and director of the large local office of a major design consultancy, who therefore had an advanced understanding of the project. However, he appeared to have no authority to issue instructions. It was actually the County Council Officer who, due to his position and personality was mainly making the decisions, without the opinion of the school users (teachers, children and their parents). The formal mechanism for the stakeholders to have input to the building design was the consultation process. This was limited and the physical tools used, room data sheets and architectural drawings, may have constrained the feedback from actors who were not familiar with these forms of communication. Finally, the architects' team that already worked with the Council on several projects, knew what they wanted in their schools and appeared to accept their authority without questions.

CS4 SOCIOLOGY

This was a small schools estate, which had employed an independent buildings consultant to manage their school building projects. Rather than having a professional qualification in a construction-related area, the consultant had been a head teacher for many years, with an interest but little specialist knowledge in sustainable building. European regulation meant that the project management role now had to be tendered through the Official Journal of the European Union, hence a highly experienced manager had been appointed. The independent consultant meanwhile was retained as the client's representative. The Project Manager was assigned particular responsibility for 'Energy management and sustainability issues'.

CS1 ALIGNED MOTIVATIONS

The council's priorities and those of the school and governors were developed through a 'visioning' exercise. The school's resultant priorities included a desire for 'sustainability' at this early stage, but related to a BREEAM assessment rather than to any other particular aspect. The aspirations by the school were that 'the building should contribute to the development of new knowledge and be used itself as an educational tool, in its construction and providing good practice examples, including sustainability.' Due to the process followed for the BSF procurement, there were an unusual number of stakeholders involved in the project and this is continued even after the preferred bidder had been appointed. This caused confusion and fragmentation between stages, with the project team often wondering who the client was. There was clearly conflict, but rather than 'power' being held by one or more actors, the results seemed to be determined by the structures, tools and processes imposed.

CS2 ALIGNED MOTIVATIONS

The 'Vision' for CS2 appears to have been mostly driven by the sponsors. While it doesn't mention sustainability, it does include several aspects which might be interpreted as part of the broad definitions of sustainability. The second part of the brief was the Education Brief, a process led by the Overall Project Manager with considerable input from the sponsors and the County Council, also mentioning environment and engineering. There were two community consultations; however none of them was particularly well attended and successful. Finally, the architect was quite negative about BREEAM and didn't believe it would necessarily lead to a more sustainable building.

CS3 ALIGNED MOTIVATIONS

Project team members and stakeholders of the project perceived sustainability in very different ways. From the architect's point of view it is a provision of renewable technologies. The County Council, despite having the power over the decision making, perceived sustainability as a mere necessity due to planning regulations and had very limited knowledge on the subject. This was a reason of conflict between them and the City Council, who were keen on prioritising sustainability. However the County Council only required a rating of 'Very Good' to be achieved, giving no incentive to improve on this. Furthermore, it is highly unlikely that this has been realised in practice, with the most likely scenario being an increase in emissions. Finally, the contractor, that valued sustainability very highly, due to the flexibility of the contract, was able to allow for changes towards this direction even later in the project.

CS4 ALIGNED MOTIVATIONS

The school head and leadership team, the governors, and the student school council had been involved in developing the initial brief and had formed the requirements for sustainability. As the design developed, sustainability continued to be a key part of the discussions and decisions. However it became clear that different team members had different ideas and definitions of sustainability, linked to their own areas of expertise. The services engineers viewed it as a synonym of renewable energy and the structural engineers focused on the use of CLT due to its advantages in terms of embodied energy and greenhouse gas.

CS1 CONCLUSIONS

Although sustainability, has been the priority of different stakeholders in this school, in practice, sustainability was limited to the regulatory minimum requirements. The BSF procurement system fragmented the process and created delays and increased cost, with the project team feeling confused about who the actual client was. Despite the attempt to have consultation procedures in place, this mainly happened when the important decisions have already been made, not allowing the building users to actually participate in the design process.

CS2 CONCLUSIONS

While the contractor had made the decision to use CLT, this was mainly due to the reduced time on site that this material entailed, rather than its sustainability credentials. On the other hand, the timber has been appealing, both to the sponsor and to the architect due to its visual effect. There was no evidence suggesting that the material itself was of decisive importance for the selection of the structural engineering team. Finally, interestingly, BREEAM was regarded as a tool that does not necessarily produce more sustainable buildings, while the difficulty in actually certifying materials and processes meant it could have the unintended effect in some cases of deterring the use of innovative and non-standard components, resulting in an outcome which is less environmentally sustainable than if the tool had not been used.

CS3 CONCLUSIONS

Although this was an example of a successful school with technical expertise in its governing body and with additional power due to being in position to exchange land for new buildings, the process followed in practice did not allow them to reach their potential. Hierarchical power from the County Council dominated over the technical expertise of project team members and the practical professional experience of the teaching staff and the school business manager. Thus, there was a continuous struggle over power between the City and the County Councils, resulting into the actual users of the building (teachers, children and their parents) being excluded from the process.

CS4 CONCLUSIONS

Although some of the time saved from the speed of erection using CLT was lost again due to coordination issues with services, the project was completed on time. The first Ofsted report after moving back mentioned the positive impact of the new school buildings on behaviour. The focus on sustainability throughout the building project had also spread to different areas of the school and had encouraged the school to join the Eco Schools programme and to actively recycle. The use of CLT was seen as sustainable, not only due its low embodied energy, but also due to the absence of waste from the construction site, as well as the fact that it clearly improved the working environment on the construction site itself.

IMPACTS OF PROCUREMENT AND TOOLS ON SUSTAINABILITY

The procurement processes for CS1 and CS3, although significantly different, brought up similar outcomes. The stakeholders of CS1 had prioritised sustainability, unlike those of CS3. On the other hand, in CS3, the tool used for consultation defined sustainability in a wider sense and allowed for interpretations, while for CS1, the tools defined the aspects of sustainability very strictly and didn't allow for the users' suggestions. Nevertheless, in both cases, the sustainability aspect only covered the regulatory minimum requirements in practice. The BSF procurement system in CS1 also had the effect of fragmenting the design process, leading to separate teams being responsible for each stage. The funding model also seems to have limited the choice of renewable energy technologies. One specific effect of the focus on renewable energy was to clearly define sustainability as a technical issue. However this does not seem to have resulted from the technical experts' opinions. Actually, both the installation of the GSHP at CS3 and of the biomass boiler at CS1 were clearly the choice of the Council clients. Instead of rational, technical expertise wielding power, power made judgements on what technologies were rational. The tools and processes which structured CS1 and CS3 have certainly shaped the outcome; they have also structured and limited what has been considered. Carefully controlled and constrained, neither school appears to have achieved the outcome that they would have liked.

IMPACTS OF PROFESSIONS AND EXPERTISE ON SUSTAINABILITY

Case studies CS2 and CS4 were very different to CS1 and CS3, primarily in the sense, that most of the stakeholders saw sustainability as an important issue. In terms of the use of CLT instead of more conventional structural solutions, the structural engineer was based on the material's low embodied greenhouse gas to promote it. He calculated the embodied greenhouse gas of various building constructions, based on the materials phase, thus demonstrating and validating his expertise in calculation. This was the issue that had been excluded from policy, but which, however, was well-known to most of the industry. The topic of sustainability was a field where the various professionals were trying to prove their expertise, promoting their own areas' tools as sustainable solutions for this project. They were trying to define themselves not only in relation to their clients, but also in relation to other professionals. An interesting fact that came out as a comment by different professionals, was related to the limitations of BREEAM in its assessment of sustainability, given that it didn't include aspects of their own fields of expertise. For example, the assessment of the reduced energy greenhouse gas due to the use of timber was not included in the BREEAM assessment, while the use of renewable sources of energy is currently easier to assess. Finally, the collective professional expertise of the design team had held the balance of power at CS4, supported through the procurement structure which allowed the late appointment of the contractor and the following novation of the design team, who had developed by then extensive knowledge of the existing buildings and the detailed design. CS2 had a different trajectory, since being a framework project, the bid was managed by a team led by the contractor.

REFERENCES

Moncaster, Alice (2012); Constructing sustainability: connecting the social and the technical in a case study of school building projects; PhD thesis ; School of Environmental Sciences, University of East Anglia, UK.

Case study UK7
School sports hall - UK

KEY OBSERVATIONS

Material sources, selection and waste management at the end of the building life are the most important stages within the lifecycle of the structural elements of a building. Therefore, these stages also provide the highest potential for embodied energy and greenhouse gas reduction. On the contrary, labour transportation and demolition stages are not as significant and they are likely to be even less crucial when operational energy and greenhouse gas are included in the calculations.

The aim of this study was not to identify the best option between timber and steel as structural materials. The case study building is very specific and the results obtained should not be generalised without careful consideration. However, the embodied energy and greenhouse gas results obtained should motivate designers and engineers to make the best use of any given materials, for example to reuse steel and use cement replacements, rather than to encourage the debate about which material is 'better' than any other.

OBJECTIVES OF CASE STUDY

To analyse the lifecycle embodied energy and greenhouse gas of a building's structural elements.

To investigate the most significant lifecycle stages of a building's structural elements by analysing the total embodied energy and greenhouse gas, including initial, recurring and demolition as well as end-of-life energy recovery and greenhouse gas offsetting potential.

To identify the stages within a building's life which offer the most opportunities for embodied energy and greenhouse gas reduction.

BUILDING KEY FACTS

Intended use: School

Location: UK

Project phase studied: Design and Construction

Structural material: two design options: **steel** or **timber**

Building life cycle stages included in the study, according to EN15978

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	X	X		X	X					X	X	X	X	X

LCA BACKGROUND

Reference study period: 60 years

Databases used: Bath ICE Beta 1.5

Standards/guidelines: TC350

REFERENCES

Vukotic, L., Fenner, R.A., Symons, K. (2010) Assessing embodied energy of building structural elements. Proceedings Of The Institution Of Civil Engineers Engineering Sustainability, 164, 147-158.

Production and construction stage modelling: This study focused only on structural elements. It is worth mentioning that the structure itself can be influenced by other factors, such as the robustness of the elevations or the use of heavier equipment. Similarly, different types of structure would possibly influence the elevations as well. Finally, different structural materials may have a significant effect on the longevity of the building.

Moreover, especially during the operational stage of a building lifecycle, other materials might have a high contribution in terms of embodied energy and greenhouse gas. This also has to be taken into consideration when the whole building analysis is performed.

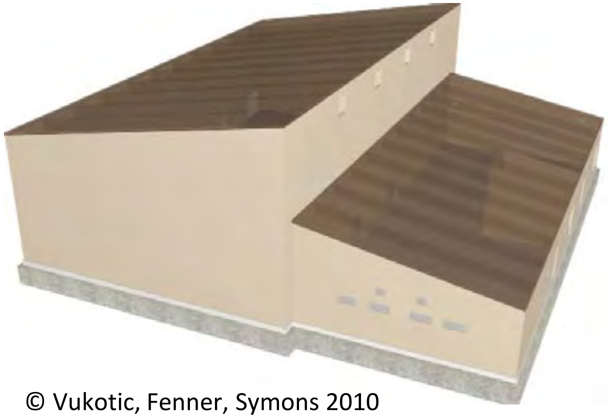
Most data regarding material quantities were obtained from structural engineering drawings, and when data were not available from drawings, assumptions were made in consultation with structural engineers directly involved in the project.

Use and operation stage modelling: Building operational energy and greenhouse gas resulting from heating, cooling, ventilation, appliances and lighting were not included in the study.

End of life stage and next product system modelling: Information regarding demolition was provided by specialised companies or obtained from the relevant literature.

THE BUILDING

A new school sports hall in the UK was used as a case study to compare embodied energy and greenhouse gas for two design alternatives, based on different structural material selection. The first design option consisted of a timber load-bearing panelled wall system with glulam beams supporting the timber roof panels. The second design consisted of a steel frame with 215 mm thick concrete blockwork infill walls and steel purlins supporting profiled steel roof sheeting. Both design options required identical mass concrete strip foundations and reinforced concrete ground bearing slab. Both options were progressed to the detailed design stage, but eventually the timber option was constructed. Both designs have the same function, structural performance and 60-year design life.



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STUDY PERIOD

The study period was 60 years, during which no replacement is needed for the two design options. It was concluded that building life should be extended to approximately 75 years in order to achieve significant greenhouse gas reductions.

STRUCTURAL MATERIALS

This study specifically focuses on the comparison of steel and timber as structural elements for a specific building used as a case study. Therefore, any other materials that are not influenced by the structural design option are not included in the analysis.

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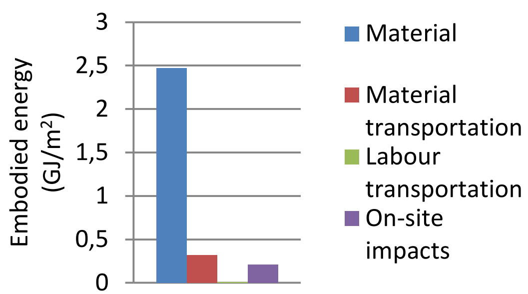
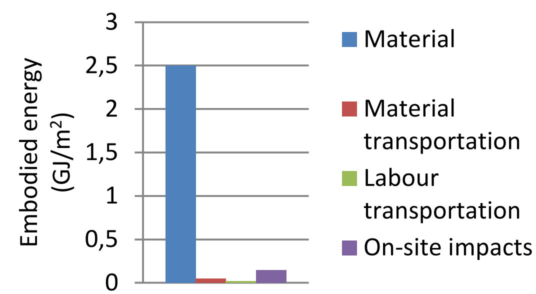
EMBODIED ENERGY AND GREENHOUSE GASES DURING THE MATERIAL PRODUCTION AND CONSTRUCTION

The figures below show that the materials' embodied energy and greenhouse gas are the greatest factors in this lifecycle stage for both designs during the production and construction stages. Material transportation and on-site impacts are considerable, while labour transportation has very little impact. Timber panels were actually delivered from overseas, while steel was assumed to be sourced within 150 km. The two designs have similar embodied energy, with the timber option having 2.47 GJ/m^2 and the steel one having 2.50 GJ/m^2. For the timber option, materials are responsible for 79% of the total embodied energy, while this percentage becomes 88% for the steel option. However, the embodied greenhouse gas associated with the timber design, 178.5 kg CO_2/m^2, is significantly less than the one of the steel design, which is 254.8 kg CO_2/m^2. It is important to mention that this analysis does not include the effect of carbon sequestration during tree growth. However, this is included in the deconstruction stage analysis.

Timber

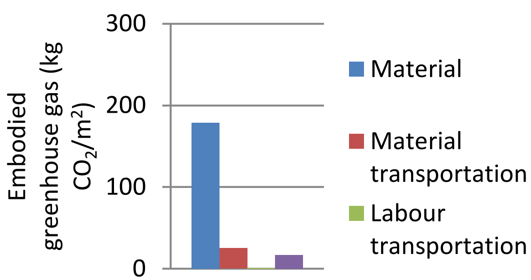


Product and Construction embodied energy

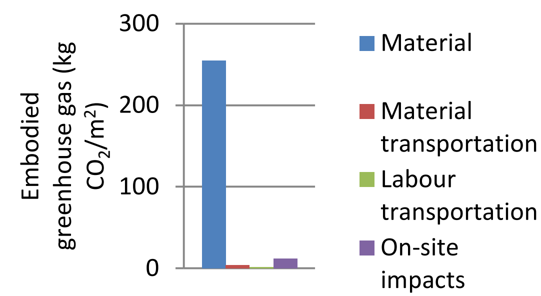


Steel

Timber



Product and Construction embodied greenhouse gas



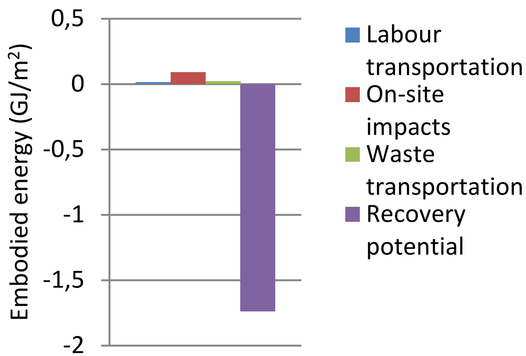
Steel

END-OF-LIFE EMBODIED ENERGY AND GREENHOUSE GASES

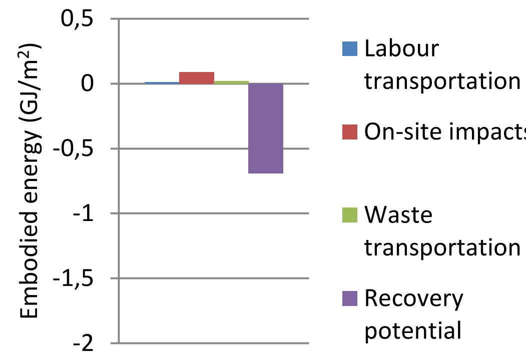
This stage has the greatest degree of uncertainty because of the difficulty of estimating how demolition and waste management will work in the future. As shown below, impacts associated with the actual demolition process are not an important part in the building's lifecycle. However, end-of-life recovery potential is crucial.

Credits for material recyclability can generally be awarded either to a current product or to a product used in the next lifecycle. For the purposes of this study, current construction materials were rewarded for their ability to offset energy and greenhouse gas emissions in the future, as recognised by the BRE methodology. Timber combustion and steel recycling were identified as the most probable scenarios for each material.

Timber

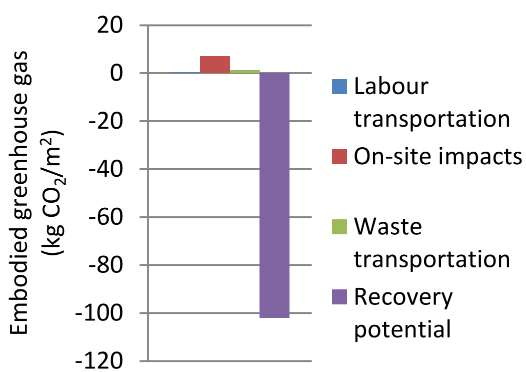


End-of-life embodied energy

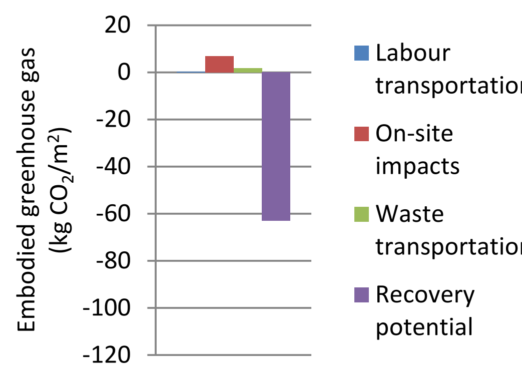


Steel

Timber



End-of-life embodied greenhouse gas



Steel

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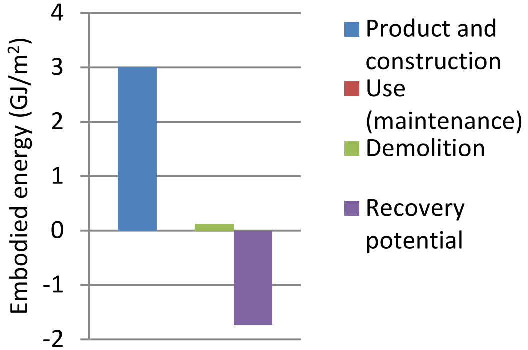
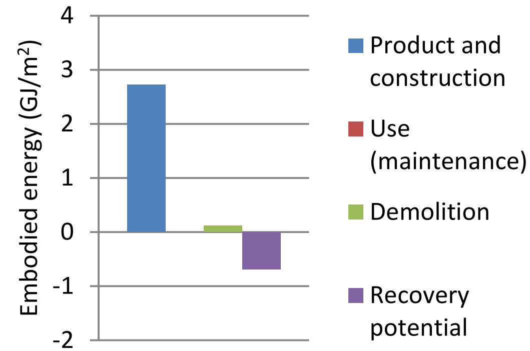
MATERIAL RECOVERY DURING THE BUILDING'S LIFECYCLE

The energy recovery and greenhouse gas offsetting potential is shown below for timber and steel design options. Timber performs better for both embodied energy and greenhouse gas. Steel recycling recovers approximately 0.69 GJ/m^2 and 63 kg CO_2/m^2, while timber combustion recovers 1.74 GJ/m^2 and 102.0 kg CO_2/m^2. This accounts for 56% and 44% of total embodied energy and greenhouse gas. Both design options show that the end-of-life recovery potential is important for the embodied energy and greenhouse gas analysis. The end-of-life material recovery is a significant consideration when analysing building embodied energy, as it recognises and rewards materials with high recovery potential. However, the uncertainty in the prediction of future demolition and waste management practices poses a significant difficulty in this analysis.

Timber

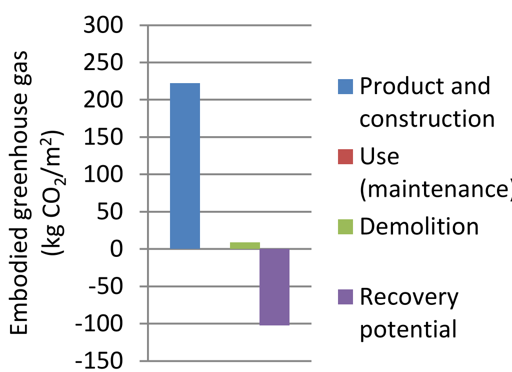


Lifecycle embodied energy

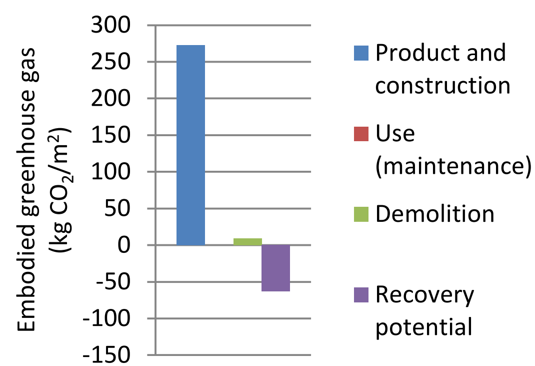


Steel

Timber



Lifecycle embodied greenhouse gas



Steel

Key issues related to Annex 57:
1. Strategies of building design
4. EEand EG reduction strategies for materials and components
6. Integrating EE and EG in the project decision-making

Case study UK8

Olympic Park and the ODA - UK

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

Sustainability has been set as a **priority very early** and hence all processes included it in their assessment procedures. The **procurement** for the Olympic Park was a balanced scorecard approach which assessed how the contractors would deliver the values identified by the ODA. The **contractual system** used should also allow for the early engagement of the supply chain in the project, hence facilitating the integration of sustainability targets and collaborative work.

The **early collaboration** of design teams, contractors and suppliers meant that targets are clarified early, when design changes are still possible. The use of reclaimed gas-pipes for the Stadium construction, was 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**.

OBJECTIVES OF CASE STUDY

The aim of this case study are the following:

- Identify the ways in which embodied energy and greenhouse gas are managed in design and construction projects.
- Identify working practices that might enable the integration of embodied energy and greenhouse gas in projects.
- Understand how the organisational structure related to a project can facilitate the integration of embodied energy and greenhouse gas in the decision-making of a project.

PROJECT KEY FACTS

Intended use: sporting venues for the London 2012 Olympic Park

Venues: Velodrome, Aquatics Centre, Olympic Stadium

Location: London, UK

Building year: 2007 - 2012

Project phase studied: Design and Construction

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Building life cycle stages included in the study, according to EN15978

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	X	X	X	X	X	X	X	X						

LCA BACKGROUND

Reference study period: 50 years

Databases used: Bath ICE v1.6 normalised by benchmark carbon factors for specific materials

Production and construction stage:

Velodrome: The construction of a light-weight cable net structure instead of a steel arch system, saved 1,500 tonnes of CO_2 through the reduced steel and 1,100 tonnes CO_2 through the reduced concrete foundations.

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.

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.

Use and operation stage modelling: The greenhouse gas emissions factors for the calculation of greenhouse gas emissions are taken from the Building Regulations Part L 2006. It has been assumed that natural gas is used for heating, with a boiler efficiency of 84%. Electricity is assumed to be supplied from the grid, with a greenhouse gas emission factor of 0.422 $kgCO_2/kWh$.

End of life stage and next product system modelling: The disposal or reuse of materials has not been assessed due to the lack of relevant information.

REFERENCES

Knight, H.M., (2013). How can sustainability be managed in design and construction to reduce the carbon footprint of buildings? Using the Olympic Delivery Authority as a case study. University of Cambridge.

Office of Government Commerce. (2003). Achieving excellence in construction procurement guide 04: Risk and value management.

Tryppick, G., & Johnson, P. (2012). London 2012 Learning Legacy Masterclass: Olympic Stadium slides. London, UK: UK GBC.

SUSTAINABLE DEVELOPMENT STRATEGY

The Olympic Delivery Authority (ODA) was responsible for the delivery of the construction works in the 2012 London Olympic and Paralympic Games. Environmental sustainability and legacy were the two ‘priority themes’ originally identified by the ODA as relevant to the three pillars of sustainable development: environment, economic and social aspects.

Delivery responsibility was on a project level, however key policies and processes were decided and implemented on a programme level. For example all projects had **specific deliverables in terms of sustainability** and followed specific cost and progress reporting.

The ODA Sustainable Development Strategy which had already been discussed and circulated within design teams in 2006, committed to twelve themes, six of which were environmental: greenhouse gas; water; waste; materials; biodiversity and environmental impacts (land, air, water, noise). Within the Sustainable Development Strategy, each of the objective areas had specific construction-oriented targets to be achieved; for example 90% by weight of material from demolition works should be reused or recycled.

In terms of greenhouse gas, the aim was to achieve a 50% reduction of greenhouse gas emissions for the built environment by 2013. This was described in detail in the ODA Energy Statement, explaining the measures used in this process would include energy efficiency, low carbon energy and renewable energy. No mention in embodied energy was made at this stage.

The strategy mainly focused on operational carbon, but there were other parameters, related to **embodied emissions**:

- Sustainable transport (50% of materials by rail or water)
- 90% of waste reused or recycled
- Designing out waste
- 25% recycled content in materials
- Using legal and sustainable timber

VALUE ENGINEERING

‘Value engineering’ is the process during which all construction processes and components are evaluated to decide the availability of alternatives of better value (Office of Government Commerce, 2003). It can be applied during any stage of a project, nevertheless **early implementation** of value engineering, especially in the design phase can maximise its benefits.

Despite the fear of some practitioners towards value engineering, **core values** of the projects, for example sustainability in the case of the Olympic works, are maintained through the process of value engineering.

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Source: [Flickr]

BUILDING KEY FACTS

Architects: Hopkins Architects

Engineers: Expedition (structural) and BDSP (building services)

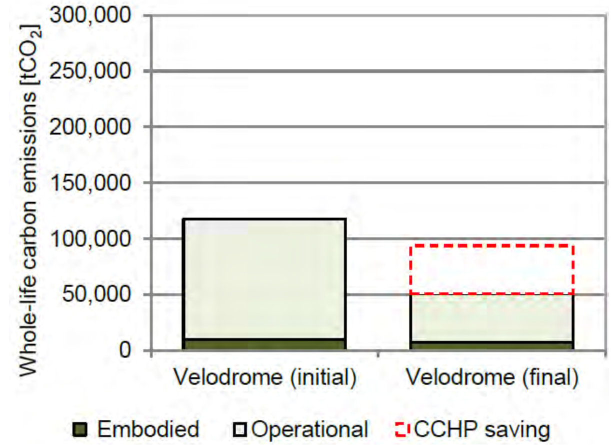
Tier One contractor: ISG

6,000 seats

Key materials: concrete, steel, timber

Delivery of materials by rail: 78% by weight

BREEAM Excellent



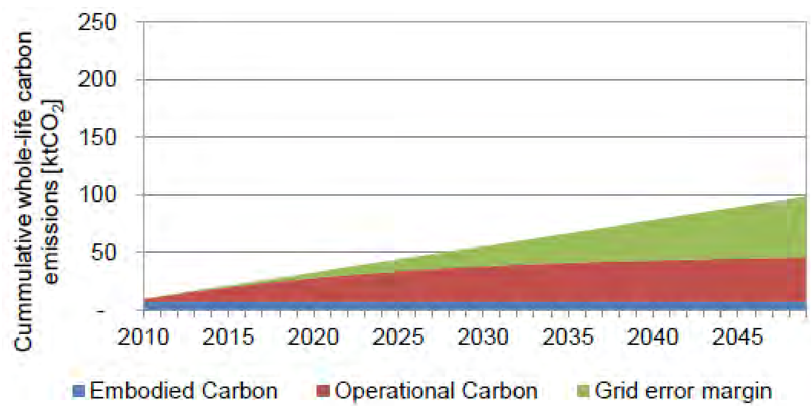
Source: Knight 2013

VALUE ENGINEERING AND DECISION-MAKING

Four different roof types have been considered in the value engineering process for the Velodrome:

- tensioned cable-net;
- compressive steel arches;
- glulam timber arches;
- cable and timber hybrid system.

The comparisons demonstrated that the cable-net roof would save £1.5 million and **reduce the programme by 20 weeks**. The overall savings achieved through the cable-net option compared to the steel structure one, was **2,600 tonnes CO_2**, which is equivalent to 26% savings.



Source: Knight 2013

Switching to cable-net roof meant that photovoltaics could not longer be integrated in the roof design due to weight restrictions. The PVs estimated to offer approximately 650 tonnes of greenhouse gas emissionssavings over 25 years, which is significantly lower to the embodied greenhouse gas saved through the change of structure (the embodied greenhouse gas in the PVs themselves has not been calculated).

© George Rex

BUILDING KEY FACTS

Architects: Zaha Hadid

Engineers: Arup

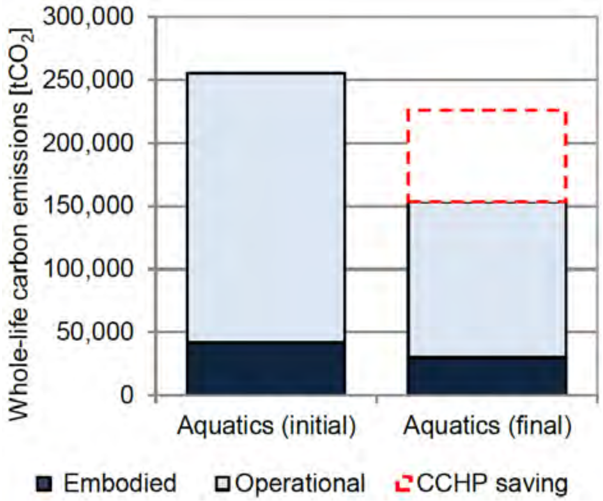
Tier One contractor: Balfour Beatty

17,000 seats reducing to 3,000

Key materials: concrete, steel, timber

Delivery of materials by rail: 56%

BREEAM Excellent



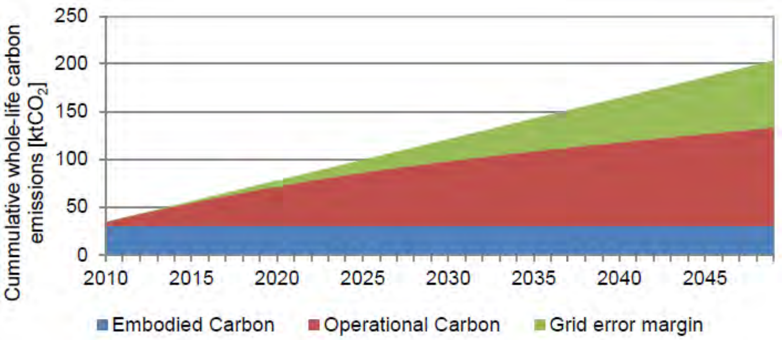
Source: Knight 2013

VALUE ENGINEERING AND DECISION-MAKING

A number of different materials and spans have been tested for the Aquatics Centre; however, due to site and time constraints, the option implemented was driven by **buildability and cost decisions**, rather than structural efficiency.

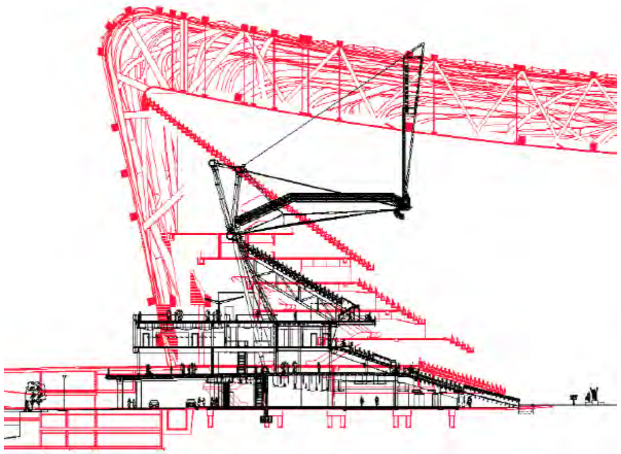
The savings on materials due to optimising the roof were limited; the most significant **material reduction** came from the temporary stands and a switch to reusable standard sized scaffolding.

The possibility of installing PVs on the roof has been examined, however the cost of £2.2 million would be paid back in a period of time between 24 and 159 years, depending on the future electricity costs. This timeframe was considered too long, so this idea was not implemented.



Source: Knight 2013

LONDON 2012 OLYMPIC STADIUM



Comparison of the Beijing Bird's Nest Stadium (in red) to the London 2012 Stadium (in black) (Tryppick & Johnson, 2012)

BUILDING KEY FACTS

Architects: Populus

Engineers: Buro Happold

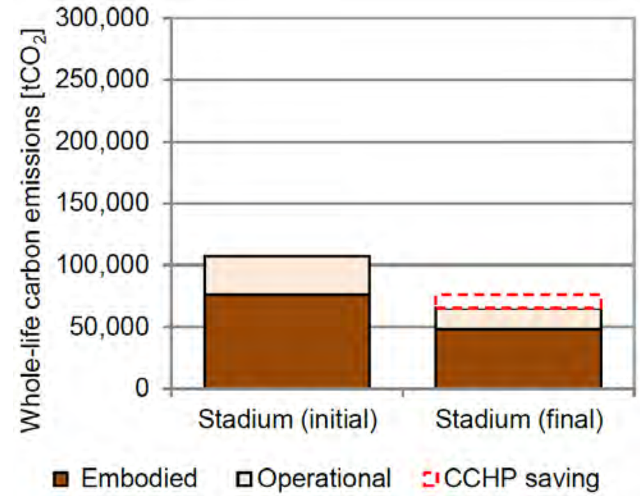
Tier One contractor: Sir Robert McAlpine

80,000 seats reducing to 25,000

Key materials: concrete, steel

Delivery of materials by rail: 49%

BREEAM Excellent



Source: Knight 2013

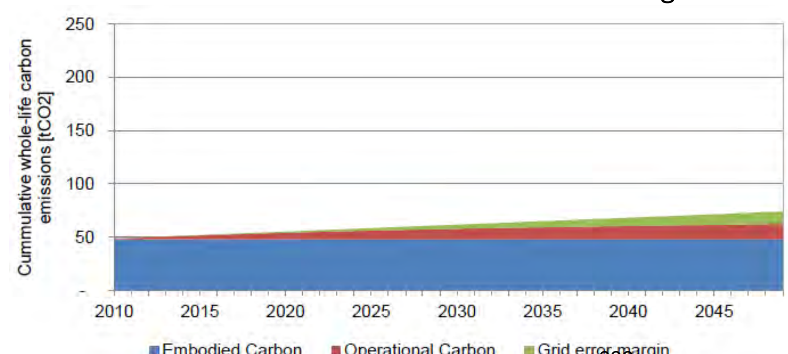
VALUE ENGINEERING AND DECISION-MAKING

The architects and engineers had previous experience on the importance of embodied greenhouse gas over operational in whole-life stadia design.

The Stadium was originally designed to reduce its number of seats from 80,000 to 25,000. Therefore, the structural frame was made in a way that would make it **easier to deconstruct**, including the bolted connections and seats bolted in the steel structure rather than grouted.

The overall height of the Stadium has been reduced through the location of internal servicing externally in temporary pods. This also significantly reduced the overall height of the Stadium.

The fact that these decisions were made in the design stage allowed **savings in excavations and materials**, through for example influencing the final design of the building and limiting the amount of material used for its structure.



Source: Knight 2013

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ORGANISATIONAL STRUCTURE FOR DELIVERING GREENHOUSE GAS SAVINGS

The study of the organisational and management structure of the ODA for the London 2012 Olympic Games identified some elements that can contribute to greenhouse gas reductions in construction projects:

- the **early specification** of sustainability targets , values and policies;
- strategic frameworks that define the **core values** and integrate them in projects, while prioritising them along cost and time;
- **procurement method** assessing how contractors contribute to the project core values already defined;
- use of **value engineering** which drives resource efficiency, without endangering the projects' core values;
- a **contractual system** which allows the early engagement of the supply chain in the project, as well as the integration of sustainability targets and collaborative work;
- a **sustainability management system** enabling the delivery of targets in practice;
- regular reporting enabling the ODA to identify any potential difficulties or delays in achieving the defined targets, as design and construction progress

EARLY INVOLVEMENT OF PROFESSIONALS

The importance of the **early collaboration** between professionals and their involvement from early design stages has been demonstrated through two projects in the London 2012 Olympic Park:

- The stadium, where the design team has collaborated early with Watson's Steel, who introduced the reclaimed gas-pipe idea. This option involved design changes and would not have been possible to implement if the different professionals had not initiated their collaboration early.
- The Velodrome, where the designers and the contractor worked together during the early design stages to decide on a roof structure and to integrate the building services achieving the desired levels of energy efficiency.

Key issues related to Annex 57:
1.1 Selection of materials
3.5 & 4.3 Carbon sequestration in wood
6.1 EE and EG integrated into decision making process

Case study UK9
Bridport House- UK

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

It has been concluded that it is appropriate to consider 100% carbon sequestration during timber growth in the LCA process for timber sourced from sustainably managed forests.

The EG of the Cross Laminated Timber (CLT) option is almost 61% lower compared to the reinforced concrete structural option for the specific case study.

The use of CLT has been very successfully used by the developer to reduce their responsibility for the provision of on site renewable energy.

The choice of treatment has a significant effect on the CLT option's EG. The EG for different treatments ranged from -959 tCO_2e for re-use to +244 tCO_2e for incineration without energy recovery, resulting in a differential with the reinforced concrete frame building of between 2270 tCO_2e and 1067 tCO_2e. However, all treatments resulted in lower total EG for the CLT structural option.

OBJECTIVES OF CASE STUDY

To compare the green house gas benefits of a Cross Laminated Timber (CLT) solution to a conventional reinforced concrete solution, for the case of a multi-storey residential building

To identify the impact of different end-of-life scenarios on the EG values of the two solutions.

To discuss the carbon sequestration during timber growth and its inclusion in the timber structure's LCA process.

BUILDING KEY FACTS

Intended use: Residential building

Size: 4,154 m^2 GIFA

Location: Hackney, London, UK

Building year: Completed in 2011

Project cost: £6 million

Project phase studied: Design and Construction

Structural material: constructed with CLT – alternative analysis with reinforced concrete

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Building life cycle stages included in the study, according to EN15978

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	X	X								X	X	X	X	X

LCA BACKGROUND

Databases used: Institut Bauen und Umwelt (IBU) (2008 – 2012), EPDs, European Reference Life Cycle Database, Industry data for steel and concrete

REFERENCES

Darby, H., Elmualim, A.A., Kelly, F. (2013) *A case study to investigate the life cycle carbon emissions and carbon storage capacity of a cross laminated timber, multi-storey residential building*. Sustainable Building Conference, SB13, 23-25 April 2013, Munich, Germany.

Miller, G. (2012). Cross-laminated timber: the sky's the limit. Retrieved February 14, 2014, from http://www.theguardian.com/sustainable-business/cross-laminated-timber-built-environment?newsfeed=true

Steve Cook, Willmott Dixon: personal communication and company supplied information

ACKNOWLEDGEMENTS

We would like to thank Steve Cook and Howard Darby for their help and the information they provided.

Production and construction stage modelling: The focus of this study is on structural elements, however, the non-structural elements affected by the two structural solutions are also included in the analysis. For example, the CLT structure provides the internal leaf of the external walls and the internal walls, but the reinforced concrete structure does not. Therefore, in the latter option, the lightweight steel stud and plasterboard walls have been added. Architectural finishes, electrical and mechanical installation materials do not form part of this analysis. All GHG emissions are included in emissions data when relevant information is available. Alternatively, only CO_2 emissions are calculated.

Use and operation stage modelling: Embodied green house gas is considered from cradle to grave, to include the whole lifecycle of the building, with the exception of the operational carbon during the building's use.

End of life stage and next product system modelling: End-of-life options are generally in accordance with the industry's waste hierarchy obligation of prevention, re-use, recycle, other recovery and disposal. Concrete is recovered (excluding non-recoverable foundations), metals are recycled, bricks are re-used by 50% and down-cycled by 50%, timber and foam insulations incinerated with energy recovery and plasterboard, plaster and other types of insulation go to landfill.

Carbon Sequestration: 100% carbon sequestration has been considered during timber growth in the LCA process for timber sourced from sustainably managed forests.

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THE BUILDING

The case study is an 8 and 5 storey residential building containing forty one affordable homes. It has been completed in 2011 to Code for Sustainable Homes Level 4 standard.

The building has concrete piles and ground beams, as well as an in-situ concrete ground slab supported on ground beams.

It has been constructed with CLT external and internal walls, floors and roof panels, however in the case study, a reinforced concrete option has also been analysed. The external balconies are steel construction.

The external walls are made of CLT, with insulation and brick cladding, with internal plasterboard lining. The main internal walls between housing units consist of CLT with insulation and plasterboard lining on both sides.

© Karakusevic Carson Architects
Source: http://karakusevic-carson.com/work/bridport-house

THE CONCRETE FRAME OPTION

The alternative reinforced frame option analysed in the case study, consists of 275mm thick flat slab floors with screed and 600x250mm reinforced concrete columns on an approximately 6x6m grid. The flat slab at roof level is reduced to 200mm thick. Lightweight steel stud and plasterboard is used for all internal walls and for the inner leafs of external walls. The external balconies are steel construction as built.

Overall, this option requires a heavier superstructure, longer piles and a larger transfer structure over the sewer. The CLT frame was erected in 10 weeks, while the reinforced concrete option is assumed to take 14 weeks instead.

© Karakusevic Carson Architects
Source: http://karakusevic-carson.com/work/bridport-house

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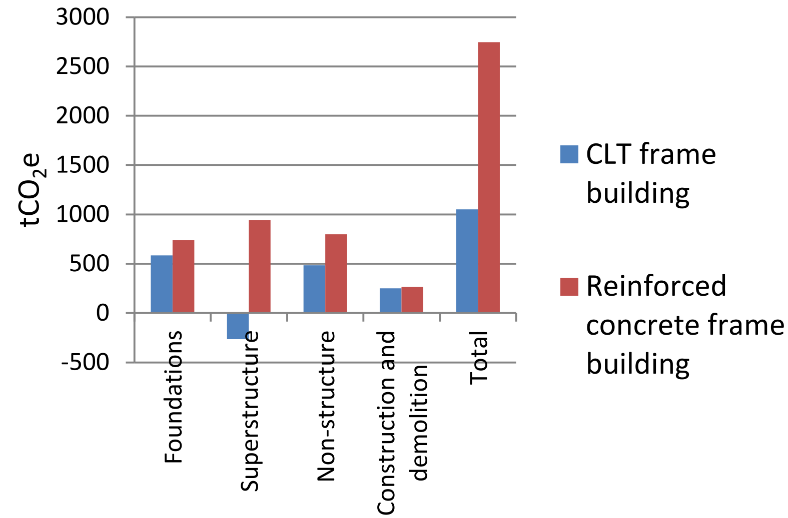
TIMBER VERSUS CONCRETE: EMBODIED GREEN HOUSE GAS

The figure on the right demonstrates that the CLT frame option saves almost 62% of EG compared to the reinforced concrete one. The reinforced concrete option has slightly higher EG in each one of the analysed categories, including foundations, superstructure, non-structural and construction and demolition. As expected, the main difference in EG comes from the category of ‘superstructure’, since the rest remains almost the same for the CLT and the concrete building. This is based on the assumption that carbon sequestration in the case of the CLT frame is taken into account 100%.



CARBON SEQUESTRATION

There is a debate about taking carbon sequestration into consideration for timber buildings. This is mainly due to timescales and due to the doubt on whether timber source is replaced or not. Softwood spruce timber, which is typically used in the CLT, is produced on a 40 to 60 year rotation and is sourced from sustainably managed forests. Moreover, this type of forests are increasing on a European level; there is hence no reason to restrict the use of softwoods. Given these data, it is reasonable to consider 100% of the sequestered carbon, particularly in a LCA where the emissions at the end of life are accounted for. The figure on the right shows the EG for the CLT frame at the end of construction, for different levels of sequestration.

	100% sequestration	50% sequestration	0% sequestration
Growth	-1248	-624	0
Production and transport	165	165	165
Construction	45	45	45
Total	**-1038**	**-414**	**210**

Source: Darby, Elmualim, Kelly 2013

END-OF-LIFE SCENARIOS FOR TIMBER

The effect of the following end-of-life scenarios for the CLT frame option have been considered:

- Re-use in its existing form
- Re-engineering the panels into smaller sections and re-use
- Incineration without energy recovery
- Incineration with energy recovery
- Landfill, assuming 20% of the timber decays and no energy recovery from landfill gas

The results in terms of EG are on the figure on the right.

Based on this analysis, re-use of CLT panels is the most beneficial option in terms of green house gas emissions, since this could decrease the building's EG to 477 tCO_2e and increase the differential to 2270 tCO_2e. The worst option is the incineration without energy recovery. This scenario increases the total EG of the building to 1680 tCO_2e, with the differential reduced to 1067 tCO_2e.

	To end of life (tonnes of CO2)				
	reuse	**re-engineer**	**incinerate**	**incinerate with energy recovery**	**landfill**
To end of construction	-1038	-1038	-1038	-1038	-1038
Demolition	22	22	22	22	22
Transport	12	12	12	12	12
Manufacture		10			
Transport		12			
Construction	45	45			
Combustion			1248	1248	
Energy from combustion				-628	
Emissions from landfill					1013
Total	**-959**	**-937**	**244**	**-384**	**8**

Source: Darby, Elmualim, Kelly 2013

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Case study UK10

Embodied Greenhouse Gas tools in the UK

KEY OBSERVATIONS

Due to the increased interest in embodied emissions in the built environment, there is a variety of products aiming to address this issue. **Academic, research and commercial** organisations have developed databases, software and tools aiming to provide information on material, component, product or building level.

Some tools include not only embodied emissions information, but also other **environmental impact** data, as well as **cost** and **operational energy** information.

Due to the variety of available options, the user has to define his needs and decide on the type and **level of detail** for the information required, depending on the purpose of the assessment.

Finally, due to the **complexity** of the assessment, there is a need for high **transparency** in the data used and the assumptions made when using different databases, software and tools.

OBJECTIVES OF CASE STUDY

- To identify the challenges in integrating embodied carbon information, through the use of the appropriate tools, in the construction sector, especially during decision-making and the early design stages.
- To present relevant reports aiming to increase the interest and to improve the knowledge of stakeholders who are key in delivering low embodied emissions buildings.
- To demonstrate some of the available options for LCA and embodied energy and green house gas calculations, focusing on the construction sector and differentiating between different types of tools used for various purposes.

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CHALLENGES IN THE INCLUSION OF EMBODIED EMISSIONS IN THE CONSTRUCTION SECTOR

- Which standard and methodology to use?
- Which tool is most appropriate?
- Is there benchmarking information and case studies available for comparison purposes?

In order to respond to the numerous questions by different stakeholders as to **why** to include embodied emissions in the building sector and most importantly to provide a response on **how** to do this, organisations and **public authorities** have published relevant reports and guidelines. They generally aim to explain embodied emissions and their importance, as well as to enable stakeholders select the appropriate tool and eventually use it in the process of making relevant **decisions**. Moreover, **professional organisations** have prepared guidelines and reports for the same purpose, including the Royal Institution of Chartered Surveyors (RICS), the Royal Institute of British Architects (RIBA), the Institution of Structural Engineers (IStructE) and the Institute of Civil Engineers (ICE).

Report	Recommendations and guidance	Benchmarking	Case studies	Reference to tools	Website
Best Foot Forward Ltd, & Greater London Authority. (2013). Construction Scope 3 (Embodied): Greenhouse Gas Accounting and Reporting Guidance (Vol. 3). London, UK.	✓		✓	✓	www.london.gov.uk
Waste & Resources Action Programme. (n.d.). Cutting embodied green house gas in construction projects. Banbury, Oxon.	✓		✓	✓	www.wrap.org.uk
Embodied green house gas Task Force. (2014). Embodied green house gas Industry Task Force Recommendations: Proposals for Standardised Measurement Method and Recommendations for Zero Carbon Building Regulations and Allowable Solutions.	✓		✓	✓	www.asbp.org.uk
HM Government. (2010). Low Carbon Construction Innovation & Growth Team: Final Report.	✓				www.gov.uk
RIBA. (2009). Climate Change Toolkit: 08 Whole Life Assessment for Low Carbon Design. London, UK.	✓	✓	✓	✓	www.architecture.com
Royal Institution of Chartered Surveyors. (2014). RICS Professional Guidance: Methodology to calculate embodied green house gas.	✓	✓	✓	✓	www.rics.org/uk
Institution of Structural Engineers. (2011). A short guide to embodied green house gas in building structures. London, UK.	✓			✓	www.thenbs.com
Institution of Civil Engineers. (2012). Energy Briefing Sheet: Embodied Energy and green house gas.	✓				www.ice.org.uk

SOFTWARE, TOOLS AND DATABASES 1

In order to respond to the increasing interest in embodied emissions, especially in the construction sector, various organisations, academic and commercial, consultancies and research institutes have developed relevant databases, software and tools to be used for this purpose. These highly vary, depending on the use they are intended for.

For example, some of the tools only provide information on material or product component level, while others combine their own data, or data taken from other databases and conduct calculations on a building level. In some cases, although less often, calculations are conducted on development and even on company level if required. For example the Embodied Carbon Metric (ECM) tool by AECOM and Davis Langdon, enables designers to make decisions not only on building level, but also on development level at the very early, pre-design stage.

The most well known databases in the UK at the moment are the ones developed by the University of Bath (Inventory of Carbon and Energy) and by the Building Research Establishment (Green Guide to Specification). Nevertheless, material and product embodied emissions are very country specific and there is a inherent difficulty in calculating accurate figures.

Moreover, some tools integrate information on other environmental impact, rather than only green house gas emissions, as well as on cost, operational energy and green house gas. For example, the University of Bath Inventory includes other factors relevant to environmental impact and enable the design to make well informed decisions from more perspectives, regarding materials and products.

Furthermore, the level of detail varies; some tools are intended to be used for life cycle analysis and embodied green house gas calculations at the design stage and hence are characterised by a high level of detail; others focus on decision making processes during concept, pre-design stages. In this latter case, tools usually provide more diverse information, not focusing merely on embodied emissions, but including cost and operational energy, even if the calculations are less accurate. This is the case of the 'Carbon Critical Buildings Tools' developed by Atkins.

SOFTWARE, TOOLS AND DATABASES 2

Database/tool name	Developed by	Function	Stage	Level	Includes cost	Operational carbon	Website
Embodied Carbon Metric (ECM) tool	AECOM and Davis Langdon	Tool	Concept + Design	Whole building and development	No	No	www.davislangdon.co.nz
EVOCE (Embodied vs Operational Carbon Emissions tool)	ARUP	Tool	Design	Whole building	No	Yes	www.arup.com
EcoCalculator + Impact Estimator for Buildings	Athena Sustainable Materials Institute	Database + tool	Design	Whole building	No	No	www.athenasmi.org/
Carbon Critical Buildings Tools	Atkins	Tool	Concept	Whole building and development	Yes	Yes	www.atkinsglobal.co.uk
Bath Inventory of Carbon and Energy	University of Bath	Database	Design	Product or component	No	No	www.bath.ac.uk
Boustead Model	Boustead Consulting Ltd.	Database + tool	Design	Product	No	No	www.boustead-consulting.co.uk
Construction Carbon Calculator	Build Carbon Neutral	Tool	Concept	Whole building and development	No	No	www.buildcarbonneutral.org
Envest	Building Research Establishment (BRE)	Tool	Design	Whole building	Yes	Yes	www.bre.co.uk
Green Guide Calculator + Green Guide to Specification	BRE	Database + tool	Design	Product or component	No	No	www.bre.co.uk
IMPACT	BRE	Database	Design	Component or material	No	No	www.impactwba.com
ECEB (Embodied Carbon and Energy in Buildings)	University of Cambridge	Database + tool	Design	Whole building	No	Yes	www-csd.eng.cam.ac.uk
Ecoinvent	Ecoinvent Centre	Database	Design	Component or material	No	No	www.ecoinvent.org
Carbon calculator for construction projects	Environment Agency	Tool	Design	Whole building and organisation	No	No	www.gov.uk
European Life Cycle Database (ELCD)	Institute for Environment and Sustainability (IES)	Database	Design	Component or material	No	No	http://eplca.jrc.ec.europaeu
CES Selector	Granta Design	Database + tool	Concept + Design	Component or material	Yes	No	www.grantadesign.com
OpenLCA	GreenDelta	Tool	Design	Whole building	No	No	www.openlca.org
Rapiere	greenspaceLive, BDSP, Sweett Group, Architype	Tool	Concept + Design	Whole building	Yes	Yes	http://projectrapier.com
GreenSpec	GreenSpec	Database	Design	Component or material	No	No	www.greenspec.co.uk
CapIT Carbon and Cost	Mott MacDonald	Database + tool	Concept + Design	Whole building	Yes	No	www.franklinandrews.com
LifeCYCLE	Mott MacDonald	Tool	Design	Whole building	Yes	No	www.eru.mottmac.com
GaBi	PE International	Tool	Design	Component or material	No	No	www.gabi-software.com
SimaPro	SimaPro	Tool	Concept + Design	Whole building	No	No	www.simapro.co.uk

Key issues related to Annex 57:
1. Selection of materials – concrete
4.2 Improved processes for concrete products
6.1 LCA/EE+EG integrated into the design process, different steps and different decisions

Case study UK11
Olympic Park - UK

Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The Olympic Delivery Authority (ODA) collaborated with the concrete supply chain to develop sustainable concrete mixes. This resulted in saving approximately 24% (30,000 tonnes) of embodied greenhouse gas and eliminating more than 70,000 of road vehicle movements.

Intelligent and efficient design resulted in a reduction of the concrete demand, hence saving 120,000 tonnes of aggregate and 20,000 tonnes of embodied greenhouse gases.

Early supply chain collaboration, involvement of designers and contractors at an early stage and setting sustainability goals high in the agenda of the client, achieved the use of sustainable concrete and the reduction of embodied greenhouse gas in the London 2012 Games construction project.

OBJECTIVES OF CASE STUDY

The aims of this case study are the following:

- To analyse the barriers to the implementation of sustainability in construction projects, focusing on the material level.
- To identify the opportunities, key actors and factors that can contribute to achieving sustainability of materials in the construction sector.
- To identify and estimate the savings in embodied greenhouse gas of concrete, achieved through reduced demand, sustainable concrete mixes and efficient transports in the case of London 2012 Games construction project.

PROJECT KEY FACTS

Intended use: sporting venues and supporting infrastructure for the London 2012 Olympic Park

Location: London, UK

Building year: 2007 - 2012

Project phase studied: Design and Construction

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SYSTEM BOUNDARIES AND SCOPE

Building life cycle stages included in the study, according to EN15978

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	X	X												

From Henson, K. (2011). Learning legacy: Lessons learned from the London 2012 Games construction project. London, UK: 'A single concrete supplier provided concrete to all projects on the Park which increased security of supply and sustainability credentials .'

The case study focuses specifically on the product and construction process stages of concrete structures for the buildings of the 2012 Olympic Park. Concrete was the second most used material in the park, in terms of mass, after engineered fills.

Use, end-of-life and next product system have not been taken into consideration in this analysis. The aim of the ODA was to make the use of concrete more sustainable, through minimising the use of concrete itself, improving the concrete mix used in terms of embodied burden and finally reducing the transports involved.

THE PARK CONTEXT

ODA's Sustainable Development Strategy:

- Responsible sourcing
- Embodied impacts
- Healthy materials
- Recycled content
- Delivering 50% of materials to site by sustainable means

LCA BACKGROUND

Database used: Bath ICE v1.6a. This was only used to calculate the baseline embodied greenhouse gas

REFERENCES

Henson, K. (2011). Learning legacy: Lessons learned from the London 2012 Games construction project. London, UK.

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PROCUREMENT PROCESS AND CONTRACT AWARD

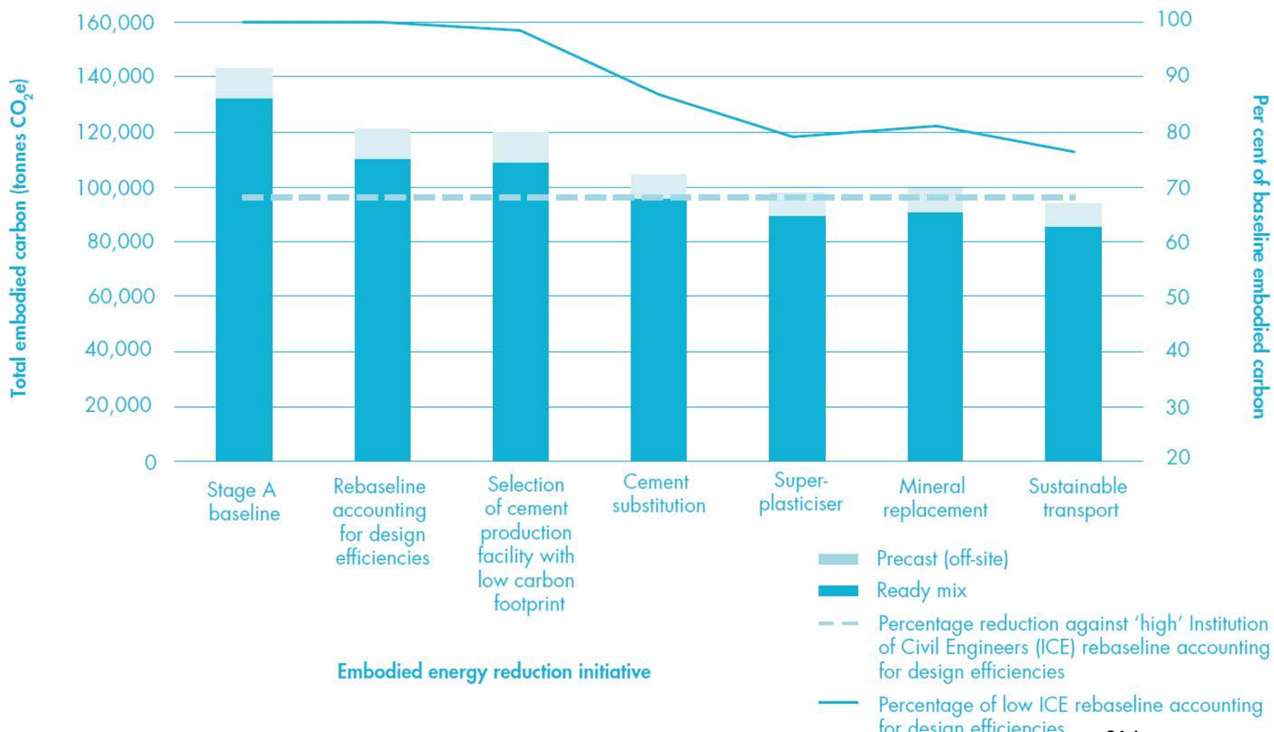
- The procurement process, managed by ODA, raised the standards for sustainability, with sustainability requirements making up 20% of the technical assessment in the tender evaluation.
- The supply chain had to secure a cost-effective, local source of recycled aggregate, use cement substitutions without significantly increasing cementitious content and identify options for rail delivery to site. All contractors on the Park were obliged by contract to use the specific concrete supplier and this highly facilitated the process.
- Although precast concrete is usually perceived to involve lower construction times and waste reduction, the London 2012 Games demonstrated this can also be achieved through a well-managed ready-mix concrete supply chain.

BARRIERS TO IMPLEMENTATION AND STRATEGIES TO OVERCOME THEM

- The proposed use of stent, a by-product of the china clay industry, as a substitution for coarse aggregate in the ready-mix concrete, was one of the greatest concerns for the contractors. However, this has been implemented successfully on the Media Press Centre, the Aquatics Centre and the Stadium.
- Similarly, the use of high percentages of cement substitutions created concerns regarding the strike times and finish quality. Nevertheless, this was done with great success in the challenging case of the Aquatics Centre. The use of high percentages of cement substitutions created issues regarding programmes and the efficiency of formwork. Especially when exceptional finish quality is not required, then a balance between these three elements can be more easily found.
- Although there is an increasing interest in using recycled construction and demolition waste in concrete, there are still concerns involving quality control and material consistency. At the moment there is limited interest in reprocessing this waste to a quality of material suitable for structural concrete. This might need to be reviewed, based on research and followed by the relevant changes in standards.
- In terms of concrete aggregates, transportation distances are the main factor regarding embodied greenhouse gas and cost. Tight budgets and time limitations made it difficult to increase substitutes at a later stage; however, upfront specification of sustainability requirements can lead to better partnerships and support between contractors, designers and clients.

OUTCOMES AND ACHIEVEMENTS

- Resource efficiency: a 25% reduction of the volume of concrete used versus the one initially estimated, was mainly due to design initiatives and improved masterplan rationalisation.
- The selection of an energy efficient cement supplier, resulted in a 2.2% reduction of the concrete's carbon footprint compared to the UK average.
- Cement substitution resulted in approximately 11.6% of embodied greenhouse gas savings.
- Overall, due to the various limitations on coarse aggregate substitution and despite the use of 60 to 100% coarse aggregate substitutions in some situations, the total aggregate substitution achieved was 21.9%. This was mainly through the use of stent, with small contributions from glass sands and recycled concrete aggregate in precast.
- Sustainable transport saved 5.1% of greenhouse gas, with more than 70,000 heavy vehicle movements being removed from the motorways and local roads.
- Overall, the embodied greenhouse gas associated with the Park concrete was reduced by approximately 24% compared to an industry average concrete.
- More than 95% of the complete concrete supply chain, including raw material suppliers, operate under an externally accredited responsible sourcing scheme.



From Henson, K. (2011). Learning legacy: Lessons learned from the London 2012 Games construction project. London, UK.

RECOMMENDATIONS FOR FUTURE PROJECTS

- Delivering sustainability requires a client with vision and sustainability ambitions, as well as supplier, designers and contractors engaged in the same targets.
- The design team has a major role in specifying the right characteristics for materials, in this case concrete. They also need to encourage contractors and suppliers to invest in the skills needed to improve their sustainability agenda and their products' attributes.
- The introduction of new sustainability practices and products initially involves extensive testing, which results in higher expenses and longer time periods. As sustainability is gradually integrated into common practices, these issues are resolved. In the case of concrete, the increased use of cement substitution and recycled aggregate in order to improve concrete's sustainability credentials can be achieved, but designers and contractors need to be actively engaged and persuaded that this is possible.

From Henson, K. (2011). Learning legacy: Lessons learned from the London 2012 Games construction project. London, UK.

- The scale of the specific project facilitated certain processes in making concrete more sustainable; nevertheless, some of the opportunities identified can be scalable and transferable. The most crucial factor for concrete, is to reduce the quantity of the product itself, through intelligent and efficient design.
- Understanding concrete and aggregates' use in a given project at an early stage is an advantage allowing the designers to write specifications and the suppliers to ensure the specific requirements can be met. This also caters for potential delays or difficulties, with ongoing update and review enabling contractors to employ remedial action as necessary.

Case study UK12

Retrofit solid wall buildings - UK

EBC
Energy in Buildings and Communities Programme

KEY OBSERVATIONS

The LCA was calculated for a period of 60 years. The study showed that the operational greenhouse gas savings achieved through the insulation installation varied between 1.57 and 1.66 tCO_2e/year for the whole house, depending on the insulation product used. The greenhouse gas savings achieved during the 60 years of the building's lifetime are calculated to be in the range of 93 to approximately 98 tCO_2e.

The outcome of the study is that the embodied greenhouse gas spent in excess to achieve a product with better thermal conductivity, is very low compared to the operational greenhouse gas that will be saved during the building's lifetime. The **greenhouse gas payback** time varies for the four products from **9 to 13 months**, which is negligible compared to a building's lifetime.

Based on the specific study, the retrofit of solid wall insulation, either externally or internally, can save on average **46.6 tCO_2e in 30 years**.

OBJECTIVES OF CASE STUDY

To perform a Life Cycle Assessment (LCA) of different insulation products suitable for solid wall retrofit (internal or external) of existing solid masonry buildings.

To compare the trade-off between the embodied energy and greenhouse gas of these insulation materials and the operational energy and greenhouse gas saved through the energy efficiency improvements that they achieve.

BUILDING KEY FACTS

Intended use: Residential

Size: 70 m^2 GIFA

Location: Southeast, UK

Project phase studied: Retrofit

Construction type: solid masonry wall

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Building life cycle stages included in the study, according to EN15978

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	X	X		X	X	X	X	X		X	X	X	X	

LCA BACKGROUND

Reference study period: 60 years

Databases used: Bath ICE v2.0, The Green Guide to Specification, ECEB tool

Standards/guidelines: BS EN15978: 2011, TC350

REFERENCES

Anderson, J., Shiers, D. and Steele, K. (2009) "The Green Guide to Specification: An environmental profiling system for building materials and components." John Wiley & Sons Ltd, UK.

ECEB tool (2013) Centre for Sustainable Development, University of Cambridge, UK: Embodied Carbon and Energy in Buildings.

Moncaster A. M., Symons K. E., Soulti E., Mubarak G. (2013) Retrofitting solid wall buildings: energy and carbon costs and savings, Proceedings of SB13 Graz, 25-28 Sept, Graz, Austria.

Moncaster, A. M. and Symons K. E. (2013) A method and tool for 'cradle to grave' embodied energy and carbon impacts of UK buildings in compliance with the new TC350 standards. Energy and Buildings, 66:11, pp514-523.

Production and construction stage modelling: All phases of the production and construction stages have been included in the calculations. This includes the raw material supply, transport to manufacturer, manufacturing, transport to the construction site and on site energy consumption. Primary data sources from LCAs were used where possible, but as this data is not widely available, the Bath ICE database was the primary source of information. Assumptions have been made about the locations of building product factories, taken from typical examples where possible, including allowances for imported goods, used with an in house created transportation distance calculator. The method of transport has also been assumed and DECC/DEFRA GHG conversion factors have been used for fuels based on 2011 data, together with an in house created transportation distance calculator.

For the building construction, the calculation has been based on building footprint and size and on data taken from benchmarked construction site energy use data from Willmott Dixon.

Use and operation stage modelling: Operational water use has not been included in the case study. Additional embodied greenhouse gas has been calculated to allow for materials and products in the building that may need to be replaced within the building's design life. Data on expected lifetimes of building materials and products has been taken from BLP's product database.

End of life stage and next product system modelling: Demolition or deconstruction of the building and end of life for the materials within the building. This is calculated using assumptions based on the embodied greenhouse gas of the construction phase of the building as well as typical destinations for waste processing for demolition waste.

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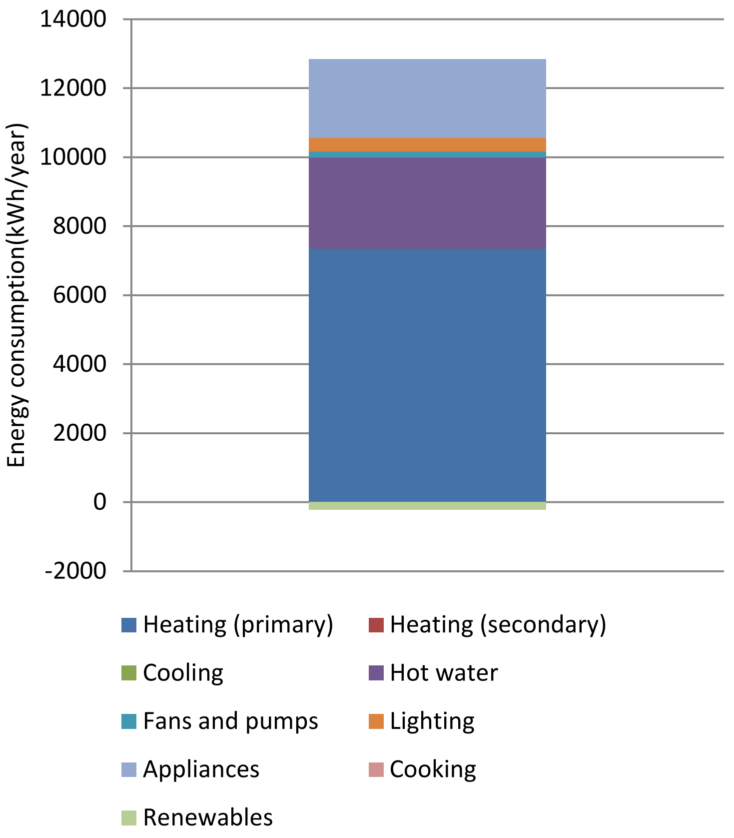
THE BUILDING: ASSUMPTIONS AND OPERATIONAL ENERGY USE

All four options of insulation systems have been simulated on the same hypothetical building, so that the results would be comparable and lead to reliable conclusions on materials' energy efficiency compared to their embodied energy and greenhouse gas. All of the insulation materials were of the same specified thickness (100mm).

The Butterfly Tool was run on a two-storey block of terraced houses, containing three dwellings, with a total gross internal floor area of 200m^2. Results are presented on a per dwelling basis, with a dwelling gross internal floor area of 70m^2. The location is set to be in the Southeast of the UK and the construction's design life is 60 years.

The building had solid masonry wall construction and softwood double glazed windows. Moreover, the building was fitted with photovoltaic panels. The quantities of materials in the building have been calculated from the building model based on default assumptions and user inputs. Information on materials has been used to quantify both the embodied greenhouse gas and the characteristics determining operational greenhouse gas, such as U-values. In all of the options tested, it has been assumed that the walls were externally finished with cement render and internally finished with plasterboard.



THE FOUR INSULATION MATERIALS

Option 1: ThermoShell rock mineral wool (External use)

This product incorporates a rock mineral wool slab with thermal conductivity of 0.038W/mK, containing a water repellent additive to ensure that no water is able to pass through the slab and reach the substrate during installation and construction. However mineral renders and rock mineral wool insulation are breathable, allowing moisture to permeate through the system in use.

Option 2: OPTIMA system with ISOVER glass wool product (Internal use)

The OPTIMA System consists of a metal frame, ISOVER glass wool insulation with a thermal conductivity of 0.035W/mK, a vapour retarder and air tightness layer. To avoid condensation damage in the structure, the vapour retarder and air tightness layer are installed on the inner facing surface of the insulation layer (i.e. the warm side).

Option 3: ThermoShell EPS Board (External use)

ThermoShell EPS Board is a graphite impregnated expanded polystyrene bead board with a thermal conductivity of 0.032W/mK. The boards can be either adhered and mechanically fixed or just mechanically fixed to the substrate and then overlaid with a mesh and a render system.

Option 4: Speedline Thermal Laminate Plasterboard (Internal use)

This is a composite product of 12.5mm tapered edge gypsum plasterboard factory bonded to polyisocyanurate foam (PIR) insulant with a thermal conductivity of 0.022W/mK. The PIR foam is faced on both sides by a multi-layer kraft paper and aluminium foil to create a vapour resistant product which can be either adhered or mechanically fixed to the wall.

ASSUMPTIONS

The wall build-up modelled for each of the 4 options includes an external cement render layer and an internal plasterboard layer, and all options have a total thickness of 350mm; the difference between the options is therefore only in their thermal performance. Each of the four solid wall insulation options produce a U-value similar to that of a standard insulated cavity wall.

EMBODIED VS OPERATIONAL GREENHOUSE GAS – GREENHOUSE GAS PAYBACK TIME

In order to directly compare the embodied greenhouse gas to the operational greenhouse gas payback, the greenhouse gas payback period has been calculated. This was defined as how long after implementing the insulation product, its embodied greenhouse gas is negated through the operational greenhouse gas savings. The payback time has to be lower than the lifetime of a product in order to make it worth installing from a greenhouse gas emissions point of view. The table below demonstrates the greenhouse gas payback time for the different options: in all four cases, it is approximately only a year.

U-value (W/m^2K)	Description	Operational carbon (regulated) (tCO_2e/yr)	Total embodied carbon (tCO_2e)	Relative embodied carbon (tCO_2e)	Carbon payback (months)
2.09	Solid wall, no insulation	3.93	33.23	-	-
0.29	Option 1	2.36	34.41	1.18	9.0
0.28	Option 2	2.35	34.65	1.42	10.8
0.26	Option 3	2.33	34.56	1.33	10.0
0.20	Option 4	2.27	35.07	1.84	13.3
0.25	Cavity brick and block with 100mm cavity fill mineral wool insulation	2.32	32.31	-0.92	-

The retrofit of solid wall insulation, either externally or internally, can save on average 46.6 tCO_2e in 30 years, based on the specific study. This doesn't vary considerably between the four products. The range is between 45.9 and 48 tCO_2e.

ACKNOWLEDGEMENTS

We would like to thank SIG Energy Management for their support and the information provided.

The tool used to model the building is a whole life cost, energy and greenhouse gas tool is called 'Butterfly' and it has been developed as part of an industrial-academic research consortium led by BLP Insurance and including the Centre for Sustainable Development at the University of Cambridge, the Energy Institute at UCL and UK major contractor, Willmott Dixon.

www.iea-ebc.org

Energy in Buildings and Communities Programme

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