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Strategic investment of embodied energy during the architectural planning process

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Proefschrift

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Preface

It is an interesting time in the building industry; for more than one decade sustainability is a planning parameter that essentially impacts construction related processes. Reduction of operational energy was initiated after the oil crisis and changed the type of construction by including heat transmission as one function of the building skin. The IPCC report added another motivation to produce less emissions: today we know that the amount of greenhouse gases increased during the last 150 years and developed a dimension that changes natural processes and by that, threatens stability enabling human livelihood. Regulations have been developed that define change in design and construction of the built environment: by 2021 new buildings should use nearly zero energy to operate the building. This addresses the operational energy and supports to exploit its potential. Furthermore it shifts the focus to building's substance: if buildings use nearly zero energy for operation the ecological quality of a building is defined by its materials. The production and demolition of the building substance involves the use of resources and emissions which are quantified with a method named life cycle assessment. The unit to indicate the extent of environmental impact is embodied energy or embodied greenhouse gases. This method monitors material flows and quantifies its ecological consequences. This is especially relevant since 70% of the building mass of new constructions should be reusable or recyclable by 2020.

The concept of embodied energy is the background for a series of design and construction decisions. For example it highlights the potential of modularity and prefabrication as they provide good potential for later reuse and by that they reduce the amount of used primary resources. Furthermore it recommends to support closed material cycles by considering the appropriate level of connectivity for adding materials or engages an information management system to enable building element reuse and material recycling.

This thesis outlines the relevance of the building substance as factor for the overall sustainable performance of the built environment. It wants to sensibilize the designer for the ecological dimension of planning decisions and to show how to optimize them. Design and construction of buildings include harvesting resources and producing emissions and stating a burden to nature. This can be perceived equivalent to a financial investment where the monetary value has to express adequately the real one. The planning decision has an ecological value which must justify its relevance by function and has to be optimized within its scope. Environmental impact and desired building quality must be alanced in order to establish a sustainable solution. All means to optimize need to be evaluated. In order to do so the designer needs to be aware of his impact and has to strategically invest embodied energy during the architectural planning process.

Contents (extensive)

PART 3 Findings and their integration into the architectural planning process

1 Introduction

§ 1.1 Research background

The ecological potential of the building sector is gaining increasingly more political, industrial and social acceptance. The fact that 50% of the global resources and 40% of the world's available energy are related to this discipline initiated stronger regulations and a variety of building certificates over the last four decades. (Hegger, Fuchs, Stark, & Zeumer, 2007; Marino, 2012; Roodman & Lenssen, 1995)

These regulations address the operational energy as seen in the EU building "Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings" which declares that by 2020 all buildings are not to consume more (non- renewable) energy than they produce ("nearly net zero energy buildings"). With the reduction of the operational energy demand, the energy linked to the building substance gains more relevance. While the operational energy over 20 years currently equals approximately the amount of energy needed for the erection and demolition of a massive residential building, this relation will dramatically change when the required energy to operate the building will drop to almost zero. The environmental impact will then be defined by the choice of construction and material used.

Additionally, the building industry works in a linear manner rather than circular. 60% of the global waste is created by the building industry which bears a high potential of volume reduction and the conservation of primary resources. (Hegger et al., 2007)

§ 1.2 Problem statement

Embodied energy is a young topic in the field of architecture. This is due to the pace of natural processes, the scientific progress, political circumstances, and the reaction of the designers.

1 Consequences of architectural decisions on the environment are rarely tactile. The causes of ecological impact are not immediately recognisable. Cause and effect are delayed because the levying of human action on nature is complex. The relevance of one's own action is not regarded as serious because the ecological consequences are not tangible. Hence, a position that includes ecological aspects is voluntary.

2 The ecological impact of building materials is hard to trace. In contrast to performance energy, which is easily traceable by the energy bill the energy linked to the building substance requires an assessment of the amount of energy bound in the building. In terms of operational energy, economical and ecological interests work together. The benefit of a strategic consideration of embodied energy is not equally visible.

3 Pressure to act and uncertainty. Political regulations as well commercial competition significantly increase the pressure to behave ecologically. Action is needed but the uncertainties are still great. Although companies might not have a clear understanding of sustainability they use green catch phrases in order to promote their service or product. This caused the phenomenon of "green washing" which confounds customers (and, quite possibly might affect the architect in the building context as well).
This research focuses on the visibility and application of embodied energy as described in point 2.

The discussion of the relationship between nature and mankind reveals how environmental interference causes uncontrollable consequences and should therefore take place only when absolutely necessary. The building sector contributes a high share to the problem; it needs to develop a greater awareness of the parameters causing such interference.

The ecological impact of a building can be determined by the sum of the amount of energy used to operate the building and the energy needed to produce and demolish the building structure. While operational energy is a well-reflected parameter, embodied energy is not yet a part of the architectural planning process.

§ 1.3 Research objective

The goal of this thesis is to initiate advancement of quality and ecological impact in the building sector. It demonstrates the potential of optimising the ecological impact by integrating embodied energy as a parameter influencing the design process. It will support design decisions for new constructions and refurbishments in Western Europe. The findings will be derived from the evaluation of case studies. 25 office buildings which are designed by students are investigated, which provides a meaningful yet manageable number of examples. The evaluation will stress the relevance of the building envelope and will focus on façade design.

The topic of embodied energy attracts more and more attention. Several studies on embodied energy have been conducted for building material, element and complete buildings. The findings are detailed as they are derived from specific scenarios. The transition from complex evaluation results to application in the design phase is missing.

The chosen format are guidelines as they contain the essential content and offer the appropriate volume for practical use. Too much information tends to be overwhelming while simple solutions are easy to generate but often too superficial. The balance between complex content and practicability led to the decision for this strategy format.

The design phase sets constrains and defines the most important parameters such as type of construction and choice and amount of material. Guidelines follow this level of detailing. The guidelines will inform the designer rather than give mono-tracked solutions. The goal is an understanding of the interrelation of design and ecological impact rather than the identification of ecologically friendly versus unfriendly product choices. The guidelines should be applicable for a broad variety of ideas.

This thesis delivers a comprehensive overview of the coherence of design and ecological impact. It stresses the sensitivity of ecological information and the importance of defining the subject of discussion concerning its context. (The LCA language calls this the functional unit.) The thesis will try to guide the designer to generate both; a product with high quality as well as low ecological impact.

The main objective of this thesis is subdivided in three sub-objectives.
The first part gives an overview of the background. The history of environmental impact, the society's reflection on this and the consequences for the building industry are here discussed. This part sets out the normative framework for the consideration of the building substance.
The second part contains the framework for the ecological evaluation of the building substance and the evaluation itself.
The third part bears the translation from the evaluation results into strategies that are applicable in the architectural planning process.

§ 1.4 Research question

This thesis aims at bridging the gap between scientific findings and planning practise. It provides a systematic methodology to integrate the parameter of embodied energy into the planning process.

The methodology developed in this thesis is based on the main research question, which is:

Which strategies in the architectural planning process are suitable to optimise the environmental impact caused by building materials and construction method?

The research question can be divided in three questions:

What is the motivation to improve the relation between built and natural environment? What is the background for the ecological relevance of the building substance?

Which parameters are suitable for ecological evaluation of the building substance?

How can the evaluation's findings be translated into the planing process?

This is divided in sub-questions:

What is the motivation to reduce the ecological impact caused by building construction?

What is an adequate methodology to rate ecological impact? Where In the building industry can the LCA methodology be applied?

What is an adequate method to rate the ecological impact of the building material? What parameters are suitable for the ecological evaluation of the building substance? How can the parameters be communicated?

How can the ecological impact of materials be categorised?

What is an adequate method to rate the ecological impact of the building substance? What parameters are suitable for the ecological evaluation of the building substance? How can the parameters be communicated?

What are the characteristics of embodied energy in the building substance? Which building elements have the highest potential to improve the environmental impact? How is embodied energy distributed over the building elements for office buildings?

What is an adequate method to rate the ecological impact of the façades? What parameters are suitable for the ecological evaluation of façades? How can the parameters be communicated?

What are the characteristics of embodied energy in façades? Does the type of façade define the environmental impact? How can embodied energy in façades be optimised?

How can the information about the embodied energy in the building context affect the design process? How can knowledge about embodied energy be translated into strategies for the design process?

What perspective for applying the strategies can be drawn?

§ 1.5 Research approach and methodology

In order to answer the research questions the thesis is subdivided into three categories. (The chapters follow this structure in a more detailed manner.)

One – Background and methodology of assessing the environmental impact

Two - Assessing the life cycle impact of materials, assessing the life cycle impact and identification of elements with the potential to improve buildings and façades

Three- Application in the design process

Part One "Background and motivation" explains the motivation for environmental sensitivity and specifies the background of this research. The methodology of life cycle assessment (LCA) and common procedures are explained. The information are based on literature research. Scientific studies and standards are the main source for this chapter.

Part Two "Evaluating the building substance" contains the framework for LCA evaluation on building material, building and façade level. It further presents the LCA evaluation of materials, the assessments of 25 office buildings and 20 façades each with two variations. The framework bases on the criteria that are derived from the standards introduced in Part One. The material evaluation uses the open source data base Ökobau.dat provided by the German Government Institution BMVBS (Bundesministerium für Verkehr, Bau und Stadtentwicklung). The case studies for the office buildings and façades were originated during my research and teaching activities at the Detmolder Schule für Architektur und Innenarchitektur in Germany.

Part Three" transfers the findings from Part Two into the planning process and makes the conclusions accessible for designers. This part is based on the evaluation in Part Two. It translates the interdependencies of construction characteristics and environmental impact into planing strategies.

§ 1.6 Outline

This first chapter explains the structure of this thesis. Ten content chapters are to follow.

Chapter 2 gives a general introduction into the topic of environmental awareness. It explains the background, the development of political and social change. It describes scientific findings and their implications, particularly with regards to the building sector.

Chapter 3 introduces the LCA method. It explains the general concept and its normative background. It describes the differences in assessing buildings, building elements and building materials. The methodology's scope and different tools are introduced. The limitations of the application lead to the next chapter.

Chapter 4 contains the assessment methodology for materials, and explains system boundaries and indicators.

Chapter 5 introduces the ecological impact of building material by giving an overview of European data. It provides a basis for a general ecological understanding of materials. The material is structured in groups. Extreme examples are highlighted.

Chapter 6 contains the assessment methodology for buildings, and explains system boundaries and indicators.

Chapter 7 contains the evaluation of 25 office buildings and provides a profound background for the analysis of relevant planning parameters. It illustrates the typical distribution of embodied energy and explains why some building elements have more optimisation potential than others.

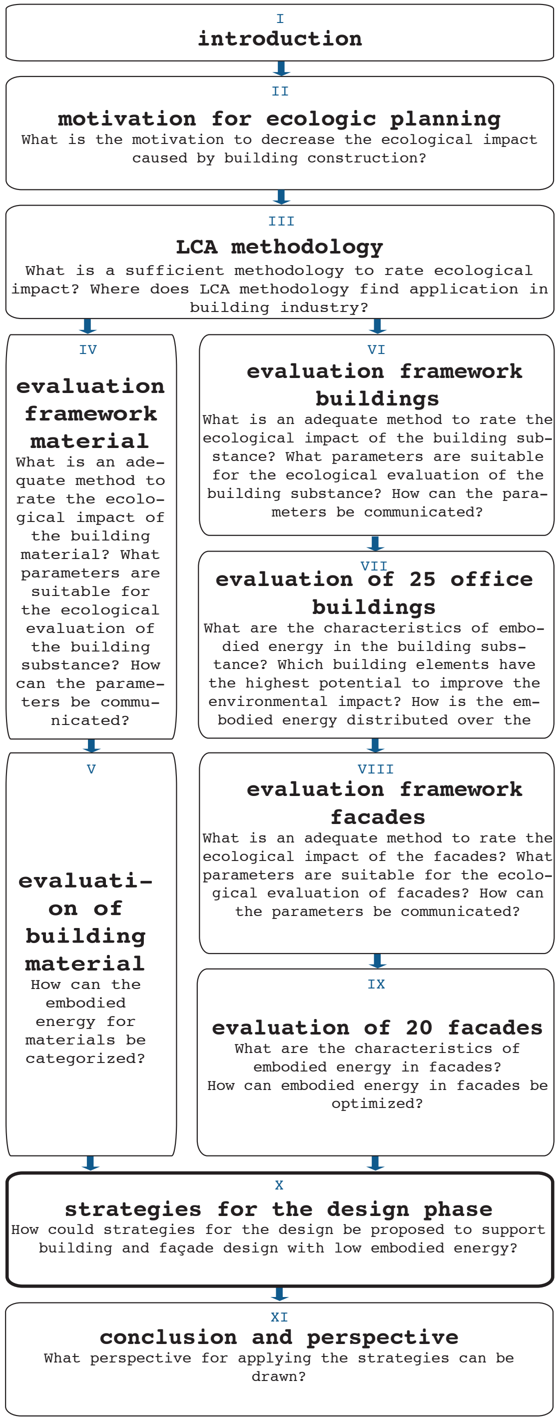


Figure 1
Scheme of the dissertation

Chapter 8 contains the assessment methodology for façades. System boundaries and indicators are explained as well.

Chapter 9 follows the analysis method of the previous chapter. 20 façades, organised according to their typology are analysed. The characteristics and the optimisation potential are shown at the end of the chapter.

Chapter 10 transfers the findings into a strategy structured for application in the architectural design phase, the construction design phase and the materialisation.

Chapter 11 derives a perspective for the application of embodied energy in the design phase.

PART 1 Background and motivation

2 The complex history of sustainability

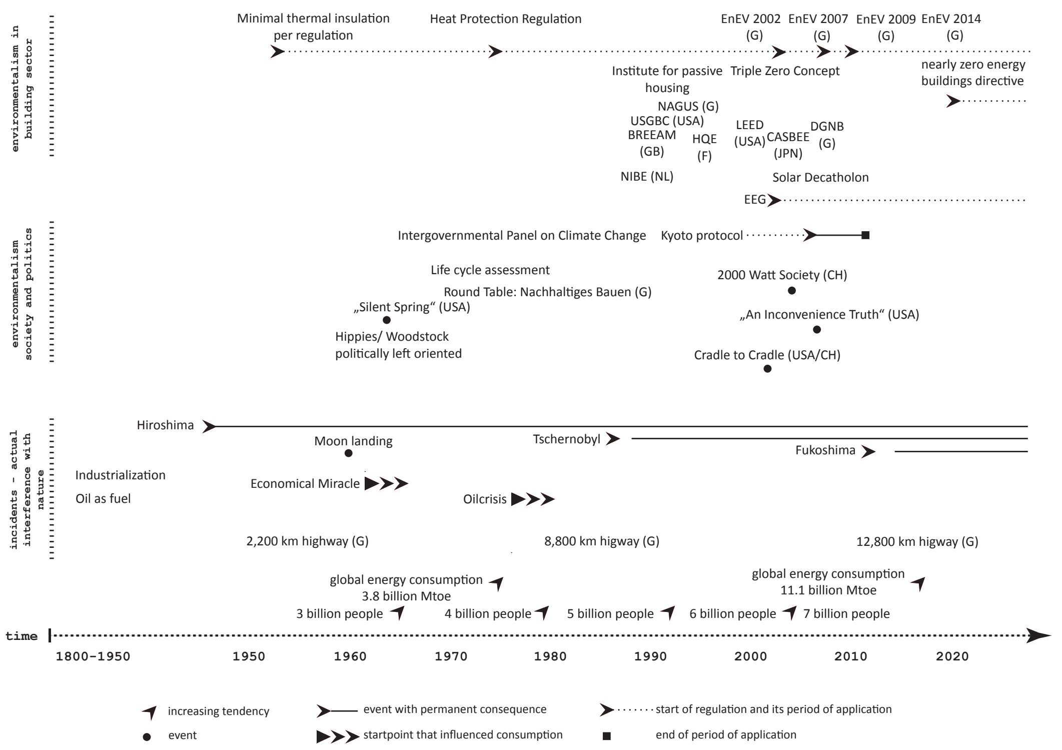


Figure 2
Environmental impact and in developing awareness about it. (A bigger image can be found in the Appendix, Figure 216 on page 398)

During the last millennia mankind has learned to cultivate the broad variety of resources nature offers. The dimension of consumption increased with the industrialisation and interfered with a stable system, thus causing a change that is unpredictable, irreversible and potentially constrains the quality society has reached. While the massive influence on nature took place during the last three hundred years, the consciousness about that effect only developed in the second half of last century. In the past fifty years politically and socially motivated environmentalism has become a new focus.

This chapter follows this pattern and explains the history of ecological impact, the development of an environmental consciousness and the consequences for the building industry. The current situation and the requirements of the future will be explained to form a background for the main part of the thesis.

§ 2.1 History of ecological impact

Interference with nature is needful to provide a living basis for societies. Results of this interference are either intended (for example generating energy), others are unintended, which happened due to incidents or are related to an act of war. The relation between man and nature changed over time essentially and consequently the level impact. These developments are of complicated nature and only a brief extract will be discussed in this subchapter.

§ 2.1.1 Sustainability

The term sustainability is used frequently in scientific and commercial contexts. Yet, the intended meaning can vary and it sense needs clarification. The term sustainability is used with two meanings; the first is derived from forestry, the second one involves the dimension.

1 The term sustainability was introduced in 1713 (by Hans Carlowitz) in the context of forestry (Carlowitz, 1713). It described the dimension of wood harvest. The amount of wood withdrawn from the forest should not exceed the amount growing back.
The Oxford Dictionary gives the following description for the verb to sustain Simpson & Weiner, 2010) :

" [...] - cause to continue for an extended period or without interruption [...]"

Measures or products are considered sustainable if they can be applied over a long period of time.

2 Sustainability comprises the dimensions of ecology, economy as well as social factors. Only the consideration of all three aspects can result in a sustainable solution.

1

2

Figure 3
(1) Carl von Carlowitz (image: by German Forestry Council in public domain), (2) The three aspects of sustainability

§ 2.1.2 Ecology

Ecology is one part of sustainability. It is defined as

a. The science of the relationships between organisms and their environments. Also called bionomics.
b. The relationship between organisms and their environment (Simpson & Weiner, 2010).

The impact of ecology in the realm of architecture is rated by the life cycle assessment. Indicators for ecological impact can be primary energy, non-renewable or carbon dioxide equivalents, among others. The method to rate ecological impact and to indicate the harm caused by a service or product is called life cycle assessment and will be discussed in chapter 3.

It is important to clearly state whether the complete sustainable rating or an ecological rating is applied. Building certificates address sustainability; ecological evaluation is just one parameter as described in § 3.2.4

This thesis focuses on the ecological assessment of buildings and building elements and relates them to a functional context.

§ 2.1.3 Levels of impact

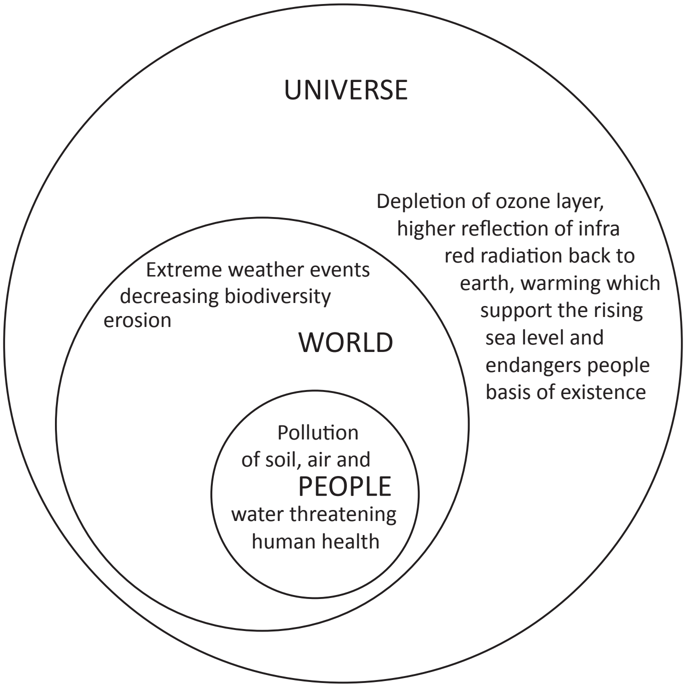


Figure 4

Consequences of an action can be categorized by its level of impact. The level is defined by the distance form origin to the perceivable effect. Direct impact takes place of the people level. The effect is prompt and directly traceable. An effect that has distance in time or location to its origin is here described world level. The highest distance in time and location is reflected in the universe level. Here origin and effect are hard to connect and need extensive examination.

In the following, the consequences of the interaction between mankind and nature are distinguished as direct, medium and long term global consequences. This differentiation is a simplified concept in order to clarify the development and current situation of natural impairment.

Direct pollution is a regional event causing in situ consequences with immediate effects; for example the contamination of the River Themes in the 19th century. The consequences were immediate; people became sick and a significant number died from resulting diseases.

Medium-term consequences mark a broader range of time and place. An event changes nature, and this harms human life. An example: The deforestation of tropical regions is leading to soil erosion and the formation of hurricanes. The consequences for human life might not be immediate and directly detectable on site but they can be related to a certain man-made impact.

The third way of characterising consequences is long-term or taking place after a certain time-delay and affecting the entire globe. Man-made emissions, which cause a chain of events, can be categorised in this way. The emissions further global warming (greenhouse effect) and, as one consequence, the sea level is rising, causing adjacent areas to flood and threatening people's lives.

This differentiation helps to understand the complexity of effects. While direct harmful consequences require immediate reaction, the distance in time and space from occurrence to reaction requires knowledge about the effects and a responsible mind.

Events of all three categories affect individual lives as well as political regulations. The time of occurrence influences the regulation process; the earlier a harmful consequence of a product is experienced, the earlier a regulation is found to prevent repetition.

Therefore, direct action on certain type of impacts has been broadly regulated over the last four decades in order to generate safety and health. For example, the World Health Organisation (WHO) categorised volatile organic compounds (VOC) and defined safety limits in 1987 (WHO, 1987).

Medium-term consequences are more difficult to regulate, as their origins can be multi causal and the outcome can involve various effects. Certificates and norms were developed to approach these. One example is the Forest Stewardship Council (FSC), which awards compliance with ten criteria with a certificate (Sayer, 2013). The FSC aims at conservative harvesting of the tropical rain forest in order to positively impact the climate and the preservation of social rights of current and future generations.

As human beings we have learned about extreme climate events, and that fossil resources are limited which evened the path for a media and political discussion about sustainability. Consequences of former phases and natural events touch the self-help capacity and raise awareness of both, the fragility and destructive power of the ecosystem. Whether these events are in fact related is to be judged by experts. Nevertheless, there is a raised awareness for nature and its vital characteristics.

§ 2.1.4 Historical development of the relation between man and ecosystem

Figure 5
Yosemite National Park, Inspiration Point. 85 million years old.

§ 2.1.4.1 Holocene period

The ecosystem works in cycles and has changed tremendously throughout the last million years. (In this context ecosystem means substance on the earth including plants and animals, or all life and the necessary environment except mankind.) Mainland became water, continents changed their position and size, and temperatures varied from hot to cold extremes while today a moderate, human-friendly climate (defined by average weather) can be experienced. The causes and consistency of theses cycles are very complex. National institutes deal with the history of climatic processes in order to understand the parameters and the interdependencies of global and cosmic coherence today. For the time prior to climate records, evidence can be found in the consistence of ice cores records, boreholes, plants, as well as calculations and reports. It is obvious that the earth is subject to cosmic processes such as solar radiation or its position relative to other planets, for example. It is believed that three factors are essential for the global condition. They relate to the variation of the earth's position and repeat themselves after a certain amount of time (the number is given in the brackets). Named after the originator, the Milankovitch cycles contain the following: the precession of the earth (22,000 years), its obliquity (changes of the angle) from 22.1-24.5 degrees (41,000 years) and the eccentricity variation from circular to egg shaped (100,000 years) (Yu, Sui, Li, Liu, & Wang, 2008). The sun's variability and volcanic activity are also mentioned as important factors affecting the global climate. These parameters interact with each other and cause reactions on both sides, orbit and earth.

Over the last 12,000 years, this system developed a human friendly climate on earth. This period began after the last glacial epoch and is called Holocene or interglacial. In this phase, minor climate shifts could be experienced such as temperature variation and less intensive cold periods, for example during the 16th and 17th century (Feulner, 2011). Animals and plants consumed and emitted substances to a degree that generated stability, in the sense of closed life loops, the reservation of bio-diversity and restoration of resources. Approximately 200,000 years ago the existence of human life occurred as a new parameter in the system earth (Smithsonian, 2011). Mankind explored the earth and withdrew what was essential to secure survival. Nomads moved to places which offered easily accessible resources. Permanent population had to develop tools to supply what was necessary when the living conditions were adverse.

§ 2.1.4.2 Industrialissation

In the 19th century mankind was able to connect technical knowledge to the discovery of natural resources for the organised production of energy. Inventions such as the steam engine enabled mass production at speeds and in quantities that never existed before. The period of industrialisation entailed huge amounts of resource consumption and the production of emissions, more than had been caused by mankind ever before. In this period the impairment of nature drastically changed to a critical level. The resources being used were non-renewable resources such as coal and oil. One immediately noticeable result of the mass fabrication was pollution. Air and water were polluted by factories and dense population. Water pollution (see e.g. London's Great Stink 1855) had immediate life-threatening consequences for nature and human beings. Organising material flows with, for example, the introduction of a sewage system reduced the harm for mankind and nature.

The level of resource consumption and emissions established during the industrialisation only increased over time. The number of factories in Europe grew and with them the living standard and the impact on nature. During the 20th century various new processes and inventions were made which helped to make life safer in terms of health and comfort, in order to establish a convenient living standard. The atmosphere, too, showed clear signs of changing conditions. The CO_2 pollution increased by 35% from 1880 (Intergovernmental Panel on Climate Change (IPCC), 2007). On earth, the changing climate parameters were evident on a global and a regional level. "An analysis of the last ITTs of SAT [surface air temperature] and total precipitation (...), indicates that a warming trend has become highly significant across most regions of the world in the late 20th Century"(Shi & Xu, 2008). A majority of climatologists found evidence for a global variation in temperature. "For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s (0.35°C), and more strongly from the 1970s to the present (0.55°C)."(IPCC, 2007) For example, the ground surface temperature in the Czech Republic changed during the last 250 years, more specifically a warming of 0.01-0.03 K/year since 1960 was assessed by boreholes examined in 1997 (Bodri & Cermák, 1997).

§ 2.1.4.3 Economic miracle to today

The economical boom in the 1950s made electrical appliances available to a broader part of society. Manual power was replaced by electrical power, which created the need for individual power supply. The industry was able to provide a broad variety of products, which led to mankind consuming natural resources and polluting rivers with sewage, land with waste and air with gaseous immutable substances.

Different scientific resources document a rising number of natural catastrophes or extreme weather events along with the increasing temperature: "Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s" (IPCC, 2007).

For residential living, heating became available which also required access to resources and the machinery to burn them. The new energy demand was met with the invention of nuclear power. Comparing coal based and nuclear emissions over the generation, nuclear power plants are advantageous in terms of gaseous emissions. The risk of immediate contamination cannot be avoided completely as the tragedy of Tschernobyl in 1985, as well as others have shown. The biggest credible nuclear accident ever, the one of Fukoshima in 2011 affected broad parts of Japan and the international consequences are yet to be evaluated.

As the living standard increased, so did the per capita energy consumption. The most relevant factor is the growing world population (of currently more than 7 billion (Kolb, 2012) which today results in a global energy consumption of 500 exajoule.

The earth is considered a human friendly environment. Changes are judged by their impact on human living standard. If an event is considered threatening, the process is to be constrained. The temperature rise has consequences on the sea level, on flora and fauna, which in turn has indirect consequences on mankind. People living in areas near the coast and at levels close to sea level are threatened directly.

Knowledge about the balance and interrelation of man-made and natural cycles is still limited. Mechanisms can be described and single phenomena explained. Nevertheless, the changing climate is a valid observation, and must be related to the period when mankind started increasing its impact on nature. Origins for nature-made processes are rarely controllable. All the more, man-made developments have to be steered carefully in order to manage the risk a particular decision might pose.

§ 2.2 Environmentalism in politics and society – developing awareness

The growing respect for nature and its integration into decision-making processes on different levels (individual, industrial, political) are stimulated by miscellaneous aspects. Extreme weather conditions, increasing energy prices and subsequent energy revolution have raised a new awareness for nature, highlighting the dependence on a well-functioning ecosystem. Social pressure has now reached a level at which the industry has to react with ecologically friendly products. Transported by media, the topic of environmental protection has been widely discussed. Today's society is well informed about the reciprocal effect of consumption and environmental impact. Hence, environmentalism has become a marketing topic.

Awareness of the environmental consequences developed in Europe in the 1960s in a politically left oriented group. The group aimed at attention for nature and proclaimed its value. Rachel Carson's Silent Spring was published in 1962. With this book she drew attention to the harm of pesticides, and was deemed to be the trailblazer for environmentalism in the USA. The beginning of social and political awareness originated in this decade. The oil crises in 1973 demonstrated the limits of natural resources on an international level, and hence stimulated awareness for conservative usage.

In 1972 the Club of Rome published The Limits of Growth; drawing a dramatic picture of the near future. Although later the predictions were proven to be too drastic (e.g. shortage of oil by 1990 (Meadows & Meadows, 1972)) the book's translation into 30 languages demonstrates the international concern. The Brundtland report (Brundtland, 1987) raised awareness with a frequently quoted definition of sustainability: "Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

In 1990 the IPCC published the First Assessment Report (FAR) which had a major impact on political activity. The IPCC collected and evaluated international climate data. It is the broadest composition of data concerning the environmental change. FAR documented the increasing amount of green house gases (GHG) in the atmosphere, and explained the relevance of human activity. By now, the IPCC has updated its reports and asserts very clearly in the Fourth Assessment Report: Climate Change 2007 (AR4) the anthropogenic climate change ("Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."). The first Kyoto Protocol was initiated on the basis of this report. In 1997 it stated that all nations listed in Annex B are committed to reduce their overall GHG emissions by 5% below the level of 1990 in the period from 2008 to 2012. Based hereon, global and national reduction goals were defined. The EU's goal was a reduction of 8% (with the former constellation of EU states EU-15) which was fulfilled in 2007 with an improvement of 9.3% (EU-27). The German Government declared a cut down by 20%. In 2009 a national CO_2 emissions reduction of 28.7% was achieved. According to IPCC the amount of GHG should be reduced by 80-95% until 2050 in order to keep this 2° K limit (Copenhagen Accord). Currently, no follow-up treaty has yet been ratified. Countries such as China, India and the USA contribute a high share of the global emissions and have not defined a reduction strategy, nor did they specify any goals. Without their engagement it is not possible to reach global GHG reduction. The arguments to refuse the resolution often contain doubts about anthropogenic cause for climate change. Depending on specific parameters, the correlation of the greenhouse effect supporting gases and temperature can be called into question. It is found, that while the GHG increases temperature falls. This differs from the IPCC report, which explains higher temperatures with rising amounts of GHG in the atmosphere. Additionally, the anthropogenic emissions are relatively low; all emissions from man-made pollution contribute about 1-3% of the natural GHG.

An example of the social awareness of ecological issues is the popularity of the movie An Inconvenient Truth (2006). Former Vice President Al Gore stimulated environmental sensitivity with his movie showing illustrative pictures about climate change. Although the movie contains misleading statements, it explains the urgent need to reduce destruction of nature and encourages society's willingness to contribute. The movie gained international recognition and won an Academy Award in 2007 illustrating the interest in this topic.

The tragedy of Fukoshima supported the debate on the operation of nuclear power plants, and the first Japanese party with a critical position toward nuclear power was founded. In Europe, political consequences are already noticeable. Germany is the first country to have committed to finalise the nuclear phase out and prepare for the "energy turnaround" (German: Energiewende).

§ 2.3 Environmentalism in the building sector

§ 2.3.1 Introduction

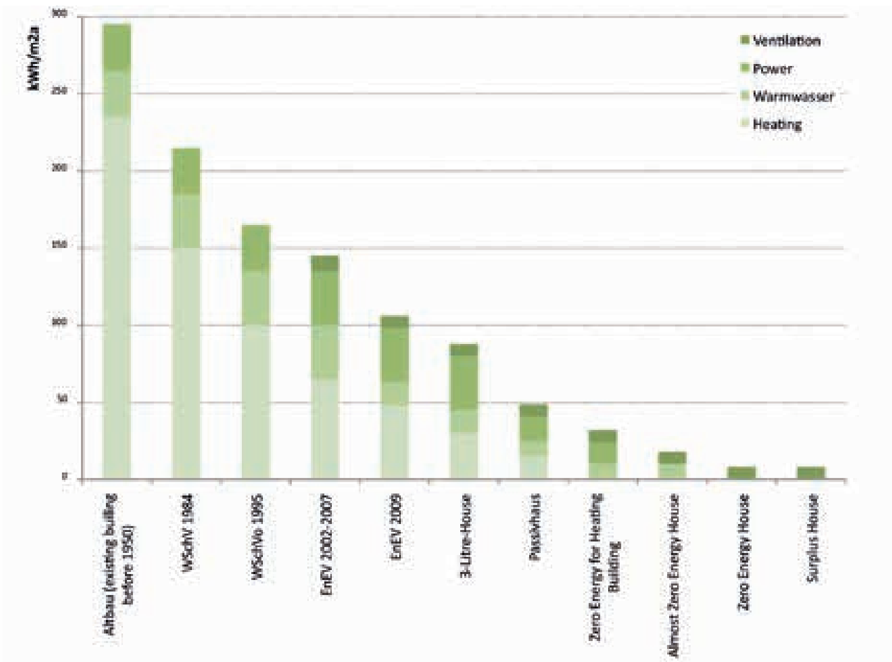


Figure 6

Development of operational energy in Germany (Schwickert, 2011). The amount of operational energy sank while the level of comfort rose.

Looking at global resource consumption and emissions (gaseous, fluid and solid), the building industry contributes a significant share; 50% of the resources find application in this sector and 60% of the global waste is produced here (Hegger et al., 2007). The resources are either manufactured to become a product that is part of the building substance or are applied in the energy generation process.

Energy generating economy is closely tied to the building sector since a huge share is consumed by this discipline. In the US, for example, it accounts for 49% of the total consumption (Mazria, 2012). The characteristics of this relationship became visible in the 1970ies during the oil embargo in the winter of 1973/74. This event entailed awareness of the dependence on resource imports, and led to a series of tighter regulation standards in order to limit the consumption, thus limiting the level of dependence. One example is the first Wärmeschutzverordnung in Germany which was adopted in 1976 (BGBI, 1976). This regulation focused on the relevance of heat loss via transmission through the building envelope. Beside the reduction of energy, the regulation aimed at increasing the level of indoor comfort. Over the years, higher standards were developed in Europe on national levels. The American Society of Heating and Ventilating Engineers (ASH&VE) was founded as early as in 1922, which illustrates the United State's manner of generating comfort on one hand, and the strong dependence on resources for a long period of time on the other. In 1973, the ASH&VE was renamed as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and since then has been regulating indoor comfort (www.ashrae.org). Heat-loss via transmission or air-movement is still not regulated by law until this day. Only voluntary certificates stimulate preventative measures.

In 1999 the Integrated Product Policy (IPP) was introduced, which emphasised the relevance of ecologically friendly materials. The IPP stressed the significance of life cycle assessment and initiated the International Reference Life Cycle Data (ILCD) handbook (see § 3.1.3), a series on technical guidance for LCA application. In 2002 the cradle to cradle approach was introduced by Braungart and McDonough. It formulated the ideal of closed loops (Braungart & Mc Donough, 2002). Cradle in this context means the origin of the materials. Ultimately, they state that after the period of usage materials should inhabit the same level of quality as in their initial state. This supported the consideration of a life cycle approach.

The politically and socially open attitude towards sustainability affected the building industry. Nowadays, several institutions focus on different aspect of sustainability. Activity is noticeable on regional, national and international levels. Institutions have been founded to work on sustainability aspects (for example the United Nations Environmental Program (UNEP/SETAC), the World Green Building Council, BRE DGNB, Milieurelevante Productinformatie (MRPI), several research studies on building products and building as a complete system have been conducted. Numerous LCA software applications are available but the information about ecological friendly planning decisions lies with the building product industry and research institutions. This knowledge has to be implemented into the phase where the environmental impact of the building sector can be steered; the architectural planning process must consider the interdependencies, and strategically invest the impairment related to the building material.

§ 2.3.2 Ecological parameters in the building context

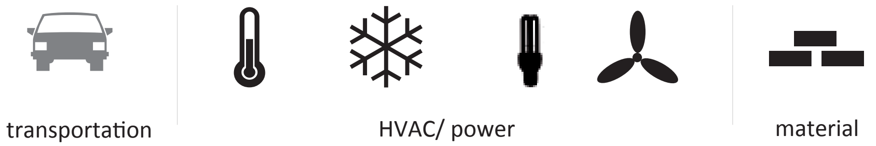


Figure 7
The energy consuming and emission generating components in the building context can be distinguished in the groups transport, operation and material.

The level of ecological impairment in the building context is influenced by three parameters; transportation, operational energy and materials.

1 Transportation: The urban context defines the amount of energy/emissions for transportation. The denser an area is populated, the more likely it is to find an efficient public transportation system as well as walk and bicycle paths. Distance to work and facilities will be shorter in densely populated areas.

2 Operational energy: The amount of energy to operate a building is called performance or operational energy. It includes the amount of energy used for heating, ventilation, air conditioning (HVAC) and electricity. The amount to operate a building depends on the climate zone, the desired indoor air qualities and the passive features of the building, the building envelope and the inhabitant's behaviour.

3 Materials: The effort to manufacture the products which form building elements and subsequently the entire building are embodied in the building material and represent an essential part of the over ecological impact.
Transportation energy is subject to urban planning, and is not considered here.

Operational energy is a well-reflected parameter in the planning process as it correlates with costs and is limited by law. The energy related to materials is not yet part of the planning process although it is a rather relevant parameter for the overall energy consumption since for a massive residential building (with the German EnEV 2007 standard) and a usage phase of 20 years operational energy and embodied energy are equal. With decreasing amounts of energy for operation the relevance of materials rises.

Operational energy is steered by the architect but ultimately controlled by the inhabitant's behaviour. The ecological impairment related to the building substance is completely influenced by the designers' decision. He bears the entire responsibility.

§ 2.3.3 Labels

During the last three decades, green building certificates were introduced into the building industry aiming at displaying the level of sustainability. Prösler (2008) gives a good overview of the labels and the legal background. Regulations are introduced as labels and legal restrictions. This chapter explains the labels, legal restrictions follow under § 2.3.5. The regulations introduced here address voluntary certificates. The norms define the included information of the certificate format. It aims at the uniformity of one format. The European norm catalogue distinguishes between three types of certificates.

- Type I follows the ISO 14024 Environmental labels and declarations -- Type I environmental labelling -- Principles and procedures. The label is awarded for positive ecological qualities and has to be evaluated by a third party; a professional committee, for example. Well-known labels are the Nordic Swan from Scandinavia and the German Blue Angel. The label addresses private and industrial end-users. Building certificates such as LEED, HQE, DGNB or BREEAM follow the description of a Type I label.
- Type II follows the ISO 14021 Environmental labels and declarations -Type II environmental labelling - Self-declared environmental claims. The label is developed for marketing in order to support fair and true ecologic information. It regulates terms to inform the end-user. (An example: the declaration 'CFC-free' in pipe insulation is prohibited as it implies a special advantage although CFC is generally forbidden in this product.) As the name says, companies can declare the products themselves.
- Type III follows the ISO 14025 Environmental labels and declarations - Type III environmental declarations -Principles and procedures and the EN 15804 Sustainability of construction works -Environmental product declarations -Product category rules and the 21930 Building construction - Sustainability in building construction – Environmental declaration of building products. The label addresses the industry and the consumer. It contains a life cycle assessment and has to be third party reviewed. For the building sector the Environmental Product Declaration is of special relevance and will be discussed in § 3.2.3.

Labels can be issued for complete buildings or on a product level. In the architectural design phase the building itself has to follow sustainable criteria. If a certification is required, parameters are to be integrated at this stage. Further on in the tendering phase the product choice takes place. Type III can be used here for comparing different ecological performances.

§ 2.3.4 Type I building certificates

In the context of this thesis the certificates Type I and Type III are relevant. Here an overview about the Type I certificates is given. Selected certificates Type III are further introduced in § 3.2.4.

Selection of building certificates			
Country	**Organization**	**Certificate (Abbriviation)**	**Certificate full name**
Canada	Canada Green Building Council	LEED CA	Leadership in Energy and Environmental Design
China	Ministry of Housing and Urban-Rural Development of the People's Republic of China	-	Green building evaluation label
Germany	German Sustainable Council	DGNB	Deutsches Gütesiegel Nachhaltiges Bauen
Great Britain	Building Research Establis-hment	BREEAM	Building Research Establish-ment Environmental
India	Indian Green Building Council	LEED India	See above
Japan	Japan GreenBuild Council/ Japan Sustainable Building Consortium	CASBEE	Comprehensive Assessment
Netherlands	MRPI	EPD	Environmental Product Declaration
	Dutch Green Building Council	BREEAM NL	See above
Australia	Green Building Council	Green Star	-
France	Association HQE	HQE	Haute Qualité Environne-mentale
USA	US Green Building Council	LEED	See above

Table 1
Selection of building certificates

The introduction of building certificates supported the awareness of the sustainability in the building sector. Their application helped to understand the different components and draw attention to the consideration of the building's complete life cycle. The building certificates include an evaluation of the materials' quality and some of them are based on life cycle analyses (§ 3). This highlights the relevance of the building substance, and supported the ecological recognition of materials. They are mentioned here to give a general introduction and explain the relationship of building certificates and life cycle assessment.

The certificates aim at the quantification of sustainability. Transferring sustainable aims into physical benchmarks is complicated and requires professional understanding of each criterion. Similar topics with different approaches and units can be found in the certificates. Each has an individual rating and weighting system with which categories can be highlighted. However, they address ecological parameters differently. While most of them consider operational energy, the energy embodied in the building substance is not always quantified. A comparison from one certificate to another is therefore difficult.

The first certificate was launched in 1990 in the UK. Today, a variety of labels is available. A range of relevant building certificates is shown in Table 1.

§ 2.3.5 Legal requirements in building industry

Even though it was not possible to come to an international agreement on emission reduction, several nations defined their climate goals. Today, several building codes are applied regulating the passive qualities of the building envelope and the active means to operate a building. During the last years, a broad catalogue of norms has become available aiming at the reduction of operational energy. For Europe, the European Parliament adopted the Energy Performance Directive (Directive 2010/31/EU) in 2010, which marks a big step toward the reduction of energy. It specifies stringent requirements for newly constructed buildings.

More transparency. The energy label currently has to be presented to possible tenants or purchasers if so required. From 2020 onward it will be mandatory to provide the energy label for tenants and purchasers. Additionally, public buildings larger than 500 sqm must put the energy label on display.

Quality protection. Every nation has to have its own third party review institution to assure the quality of the label.

Energy consumption. All new constructed buildings in the EU have to be "nearly zero energy" buildings effective 2021.

The last point will have a significant effect on the planning process. More than just the active and passive capacities have to be exploited in order to generate a building with the functional and physical qualities that are required for the current level of comfort while maintaining nearly zero energy consumption to operate the building. The directive leaves it open to national legislation to define the way of achieving this standard in order to incorporate the different climate zones.

This regulation will influence the perception of sustainable buildings. Currently, operational energy is an indicator for ecologically sensible building. If new constructions consume nearly zero energy the building substance defines the level of ecological impairment. The impact related to the material will incrementally become the core parameter influencing the optimised environmental impact.

§ 2.4 Conclusion for chapter 2

§ 2.4.1 Motivation to optimise the relation between built and natural environment and the relevance of the building substance for this

Mankind interferes with nature and changes its constitution. Both natural cycles and mankind's contribution affects the global condition on different levels. Over the last three hundred years the impairment exceeded a dimension that a significant number of scientists constitute as potentially harmful for the human species. Non-renewable resources decrease and become more difficult to access.

Having a big part in this, it is the responsibility of the building sector to optimise its share of the environmental impact. Looking at the field of architecture, potential can be found in the optimisation of performance energy and the building substance.

The EPBD limits performance energy to a minimum; from 2021 onward only nearly zero energy buildings will be allowed. The building substance is already an important factor for the impairment of nature, and will develop an even higher relevance. With this, the construction method and material choice defines the dimension of environmental impact. The consideration of ecologic parameters in the planning process contributes to conservative consumption of resources; it helps to reach political climate goals, and stimulates an efficient application aiming at the full exploitation of a material's potential.

Building certificates label the level of sustainability after planning decisions are made. They stimulate the sensitivity for sustainable buildings but do not directly affect the design process and thereby related impact. The essential stage concerning ecological impact is the architectural design phase. Here, the level of impairment can be controlled.

Knowledge is available but has not been integrated into the process decisive for the level of impact. The building products industry and research institutes prepared information that now has to find application in the architectural planning process. The complex matter of LCA for building materials has to remain valid and has to meet the requirements of the design process.

The motivation for this thesis can be summarised as follows:

- Mankind influences nature and influences climatic phenomena.
- Society is interested in environmentalism.
- The building sector has potential to reduce the impact mankind has on nature.
- The amount of resources used for the building substance could be optimised, and reduce the volume of global waste.
- Knowledge is available but is not linked to the decision making process.

§ 2.4.2 Next steps

The first part of the thesis is now concluded. The relevance to improve the environmental impact of the building substance has been outlined. The method to assess this impact follows next and introduces Part Two.

3 Method to rate ecological impact of the building fabric

Chapter 3 consists of three parts. The first part provides a basic introduction into LCA including the development of LCA followed by the explanation of the normative background. The second part contains the application of LCA in the building industry. Here the Environmental Product Declaration and the building certificates are introduced. The third part evaluates the integration of ecological parameters into the architectural planning process.

§ 3.1 Life cycle assessment basics

The architect controls the level of environmental impact embodied in the building fabric with decisions made in the planning process. Ecological information of building materials is becoming increasingly available. The designer has to be able to read and understand this information in order to choose the solution with the best qualities and the least environmental impact for the particular project.

The method to quantify environmental impact is called life cycle assessment (LCA). Its framework is regulated by ISO standards that will be explained in the following. LCA represents the skeleton procedure leaving room not only for diverse applications but also of different scientific approaches. The most relevant ones for the building sector will be introduced in the main structure of the ISO standard.

§ 3.1.1 Development of life cycle assessment

The first ideas about what we understand as the term of "life cycle assessment" today were mentioned in a simplified way by biologist and economist Geddes in 1884 (Frischknecht, 2009). In (Geddes, 1884) the Scotsman developed a method to monitor energy and material flows. The generation of energy is the basis for the assessment of materials as any production involves energy. The method of life cycle assessment evolved over the last 50 years in different places. Research activity took place in different institutes, motivated by the desire to reduce waste (glass bottles versus cans, cloth versus disposable diapers) and the efficiency enhancement of energy generation due to the oil crises in the 1970s.

A study by Midwest Research Institute (MRI) for Coca Cola in 1969 with the objective to "compare resource consumption and environmental releases associated with beverage containers" is mentioned as one of the first to be conducted in the field of LCA (Jensen, Hoffman, Møller & Schmidt, 1997; Guinée, Heijungs, Huppes, Zamagni, Masoni, Buonamici , Ekvall & Rydberg 2011). In (Boustead, 1996) the author describes how he applied a calculation method to quantify the amount of energy used to produce beverage cans in 1972, and in 1979 he published the Handbook of Industrial Energy Analysis (Boustead, 1979) in order to make the method to quantify energy on a physical basis accessible to other disciplines in the UK.

(Kümmel, 2000) quotes Fink who named The Eidgenössische Materialprüfanstalt in St. Gallen to be the institute that coined the term Life Cycle Assessment in 1978. Later, also in Switzerland, the term Grey Energy was introduced by Daniel Spreng (Spreng, 1995) referring to the quantification of the primary energy used in the context of a product or service as an indicator for the environmental impact.

In (Guinée, et al., 2011) the period from 1970 -1990 is called Decades of Conception as during this phase basic concepts were developed.

Following this, Guinée et. al. define the period from 1990- 2000 as the Decade of Standardisation.

In the Nineteen Nineties, standardisation activity for LCA took place, and several institutes were founded during this period. In 1991, Nordic Guidelines for LCA were formulated; initiated by the Nordic Council of Ministers (Nordic Council of Ministers, 1992). The Society of Environmental Toxicology and Chemistry (SETAC) held two LCA workshops during 1992 in order to coordinate the activity in the field of LCA. The results were the Guidelines for Life Cycle Assessment and the Code of Practice, which was published in 1993 (United Nations Environment Programme, 2009). This was an important step in harmonising the methods. In 1992, Heijungs et. al. published the Environmental life cycle assessment of products (Heijungs et al., 1992) which is often referred to as The Guide. Based on these activities in 1997 the first ISO 14040:1997 Environmental management -Life cycle assessment -Principles and framework was published to meet the need of standardisation.

The 1990s were also the time when various institutes were established in order to organise nature concerned activities. Institut für Kunststoffprüfung und Kunststoffkunde IKB (Betz, 2012), for example, was founded in 1989. It later developed the software program Ganzheitliche Bilanzierung (GaBi) (see § 3.2.1). The Nederlands Instituut voor Bouwbiologie en Ecologie NIBE was established in this period as well, as was the Normenausschusses Grundlagen des Umweltschutzes NAGUS (1992) (DIN, 2010). In 2002, the Life Cycle Initiative was founded by UNEP and Setac with the aim to engage in life cycle thinking by offering a network platform.

Today, LCA is applied in many disciplines (in (Guinée, et al., 2011) referred to as Decade of Elaboration). From the energy generating industry to process technology, many branches use this method to quantify ecological impact. Several labels have been introduced to certify the grade of sustainability. The Type III labels according to ISO 14025 include LCA as a compulsory component (§ 3.2.3) which helped to stimulate the application of LCA in practice.

§ 3.1.2 ISO 14040 and ISO 14044

LCA is a method to quantify all input and output flows related to an assessed item based on researched information and estimations. It has a descriptive or comparing nature and does not judge but quantifies the flows. It is an instrument to screen flows and identify optimisation potential. Since LCA is applied in different disciplines it is of an abstract nature. While the basic structure and content is regulated, different systematic approaches can be integrated. Two examples are the system borders (What is part of the assessment and what is excluded?) and the consideration of recycling (Is the actual recycled content or the recycling potential considered?). Here, the standards allow different applications. The choice of approach needs to be mentioned in order to classify the results.

The need for a scientific method to quantify the harmfulness of an interaction with the ecosystem was answered with the ISO 14040. Environmental management – Life cycle assessment - Principles and framework (ISO 14040:2009-11). The norm distinguishes the LCA terms and regulates the assessment procedure. While ISO 14040 describes the framework, more detailed information for the implementation can be found in ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines (ISO 14044:2006). ISO 14044 pools the former ISO 14041-14043. It contains the “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO, 2006).

ISO 14040 and 14044 regulate the procedure to measure the impact on the environment in four phases:

- a) Goal and scope definition
- b) Life cycle inventory analysis (LCI)
- c) Life cycle impact assessment (LCIA)
- d) Interpretation.

LCA consists of mandatory and optional parts which can be adjusted to the specific requirements. LCA can contain a), b), d) or a), b), c) and d). LCA has an iterative character which means that while conducting one phase, parts of an earlier phase have to be adjusted. These changes have to be considered and integrated in subsequent steps. In the following, each phase will be briefly introduced.

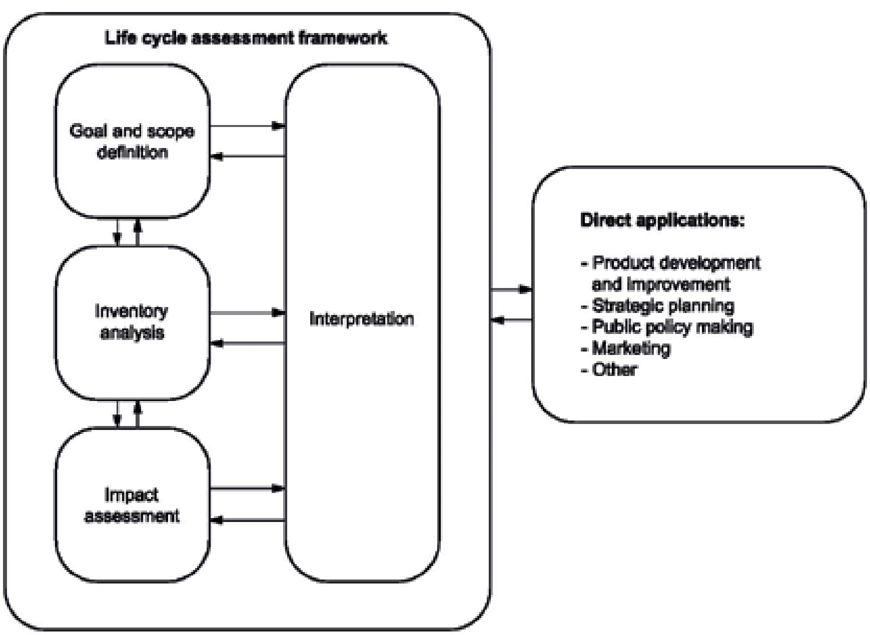


Figure 8
Scheme LCA from ISO 14040:2006

§ 3.1.2.1 Goal and scope

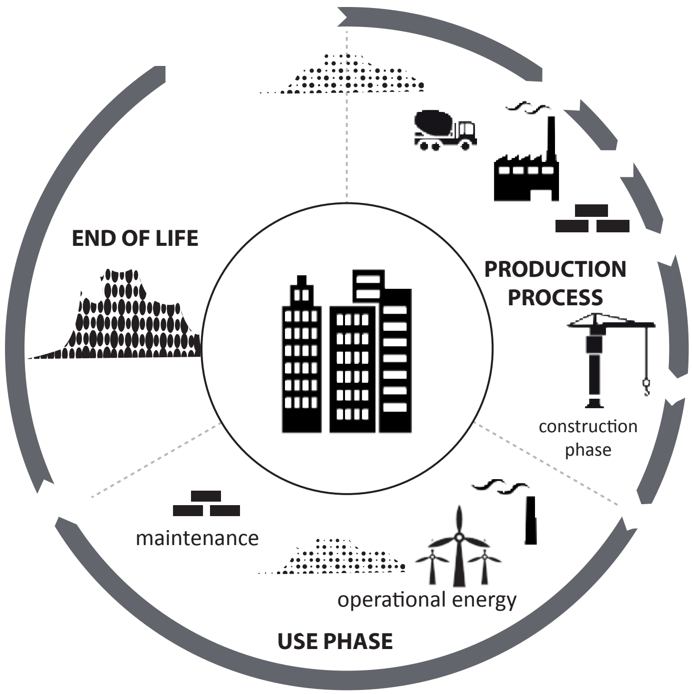


Figure 9
Life cycle stages for a building

The first step in carrying out an LCA is the definition of the goal and scope. The precise description hereof is an essential start for the LCA. The intended application is to be specified concerning the motivation, audience and context of the study. All variable parameters are specified during this phase. In Goal and Scope, the layout of the LCA is defined.

The most essential part is the description of the object of assessment which is called functional unit. The functional unit can be a product, a service or a company. The definition requires a functional description that explains the detailed performance of a product or service for which the ecological impact is measured. Functional unit is an ISO normed term which is defined in ISO 14044 by "quantified performance of a product system for use" (N. i. DIN, 2006). The more precise the description is (for example by a range of physical numbers), the fairer the comparison will be. The life cycle phases have to be defined. The life phases of a product are cradle, gate(s) and grave. An LCA can consider the phases from cradle-to-gate (upstream processes), from gate-to-gate (manufacturing processes), from gate-to-grave (downstream processes), or include all phases in a cradle-to-grave consideration. The life cycle phases of a product can be subdivided into production, usage and end of life phase. EN 15804:2012 defines these in more detail which is explained in § 3.2.3.1.

Furthermore the borders of the assessed item have to be defined. This is named the system border and it identifies included and excluded parameters. The cut-off criteria can be based on "mass, energy or environmental significance" (see DIN EN ISO 14044:2006 §4.2.3.3.3). Here, the level of itemisation is defined (e.g. 99% of the materials have to be included in the assessment).

The system border is a very essential part as subsequent comparability is influenced by it. (The comparison of two similar products with included and excluded end of life scenarios leads to misleading results.)

LCA can be either comparative or descriptive. A comparative LCA assesses different variants and delivers data to base a decision on. The descriptive LCA analyses the distribution of the different components of the assessed product or service.

Due to the LCA's iterative character, redefinition of the system borders during the process can be possible and is a legitimate procedure.

During this first phase, the applied recycling method has to be explained.

The format of the results is defined in this part as well. The impact categories depend on the goal of the LCA; they can address different topics such as specific emission groups or resource consumption (§ 3.1.2.3).

A detailed and consistent description of the scope and goals is important as this defines a subsequent application. The most important aspect of this part is the description of the procedure to generate transparency and comparability.

§ 3.1.2.2 Life cycle inventory analysis (LCI)

According to the goals defined in the first step, the life cycle inventory analysis (LCI) identifies and quantifies all processes related to a particular product. All flows are quantified and identified as input or output flows. The elementary flows are resource consumption and emission. The inputs and outputs are categorised in the following groups:

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs
- Products, co-products and waste
- Releases to air, water and soil
- Other environmental aspects

For the collection of the data, time, geographic origin and data consistency bear a special relevance.

All data needs to be well documented and be validated in terms of plausibility and comprehensiveness. This part contains the sensitivity analysis in which the system border is double-checked, and adjusted if necessary.

The LCI quantifies the material and energy flow related to a system. Within this system there can be many products (co-products). When a process delivers more than one product it is called allocation. ISO 14044 defines it as “partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems”. Whenever possible, allocation should be avoided because of its complicated nature due to the variation of the functional units (division into smaller functions or extension including all functions). If allocation cannot be avoided, the flows should be divided according to the physical proportions. The most common divisions are by weight, volume or monetary value.

LCI studies are also a common format. They assess the input and output flow, and deliver results for primary energy, both non-renewable and renewable. In comparison to the LCA studies they do not include the LCIA but scope and goal, LCI and interpretation. Typical results are expressed in primary energy.

Approaches to recycling

There are several academic issues regarding LCA that are not part of this thesis. For the scope of this research it is interesting to mention recycling.

The energy required for a recycling process can be allocated to the primary materials as part of the end of life process or to the secondary product as part of the production process. The cut-off methodology represents the first, substitution the second approach. Both will be described hereunder.

Cut-off

The cut-off approach considers scrap without the expense of treatment. It is released as scrap without any burden; so to say free of ecological charge.

Furthermore, on the input side, a share of recycled material without this burden is considered. Only the effort for collection and melting is taken into consideration. Scrap is regarded as part of the previous process. The scrap leaves the system without ecological burden; thus this called the cut-off approach.

Recycling content

The substitution approach focuses on the recycling capacities of a material. Potential future recycling is allocated for the system. The applicability is called recycling potential. Recycling potential is the share of recycled material that could fulfil the function of primary material in the next material cycle. The scrap including treatment and recycling energy is considered as input and replaces primary resources (substitution).

§ 3.1.2.3 Life cycle impact assessment (LCIA)

The life cycle impact assessment (LCIA) assigns ecological impact categories to the LCI results. The LCI results are organised by their impact on the environment and are summarised in an impact category. The LCI is a quantification of all input and output flows related to a functional unit. Emissions (impact indicators) with different levels of harmfulness are accounted for in one group by weighting. The selection of impact categories, category indicators and characterisation models is the first of three steps. Assigning impact categories to the LCI results is called classification. Totalising the category indicator results is named characterisation.

ISO 14040 defines the mandatory requirements of the LCIA as follows: "The LCIA phase shall include the following mandatory elements: selection of impact categories, category indicators and characterisation models; assignment of LCI results to the selected impact categories (classification); calculation of category indicator results (characterisation)."

An optional part of the LCIA is the normalisation in which all indicators are accumulated into one factor. This means that only one value is available, and contradictions are avoided. The process is well discussed in the scientific field as the hierarchy is complex. In (Wegener Sleeswijka, van Oersc, Guinée, Struijsd, & Huijbregtsb, 2007) the authors describe difficulties in weighting various factors into one. An overview of applied normalisation methods is presented as well. In the building industry this rarely finds application as critics emphasise the constrained traceability.

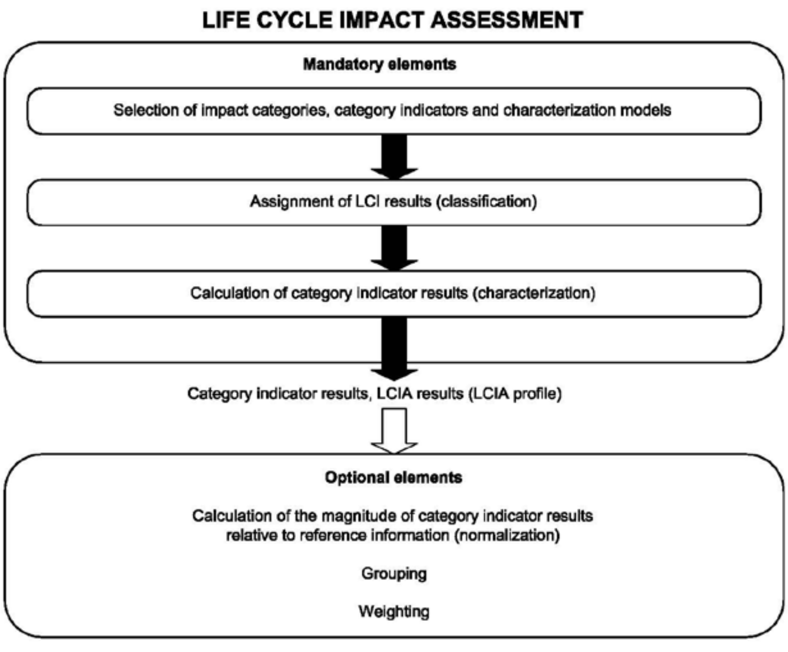


Figure 10
Scheme life cycle impact assessment from 14040:2006

§ 3.1.2.4 Interpretation

The LCI or LCIA can be followed by an interpretation, which identifies the significant results according to the goal and scope defined in the first step. Significant results can be (ISO 14044:2006 §4.5.2.2) "inventory data, such as energy, emissions, discharges, waste, impact categories, such as resource use, climate change, and significant contributions from life cycle stages to LCI or LCIA results, such as individual unit processes or groups of processes like transportation and energy production."

In this step the compliance with the defined items in goals and scope must be controlled. The significance of this is to be determined if all requirements are fulfilled.

§ 3.1.3 Indicating ecological impact

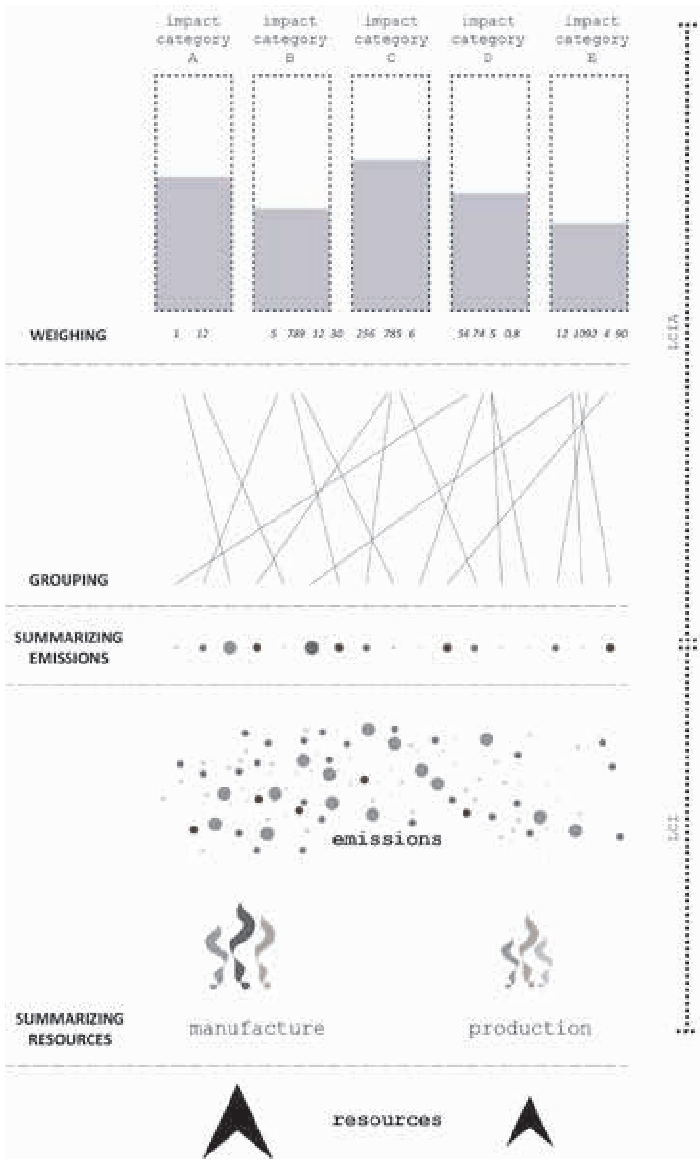


Figure 11

LCIA scheme. Resources are harvested and used within a production process. Within this, emissions are created. These are summarized and organized in groups according to the field they cause harm in. The emissions are weighted by a factor to express the level of impairment. The result is given per indicator or emission category.

In § 3.1.2 the framework of life cycle assessment is explained, and the differences in LCI and LCA have been introduced. The different models of characterisation and the indicator for environmental impact are further discussed in this chapter.

§ 3.1.3.1 Characterization models

While the emission of a process can be monitored and calculated, environmental impact is more difficult to measure. In order to estimate the harm a product has on nature, methods were developed to translate emissions into ecological impairment. These characterisation methodologies define ecological protection targets aiming at a complete picture of nature. All emissions affecting the target are listed in the target or impact category. These emissions are grouped in the impact category and weighted according to their environmental harm. For example, carbon dioxide and methane contribute to the global warming potential. Since methane has a stronger impact than carbon dioxide a factor is applied to compensate for this difference. The common denominator of the two are found, and both emissions can be identified with the same unit (in LCA terms category indicator).

Overview characterization models		
Impact Assessment Methodology	**Publisher /Institute**	**Country code**
BEES	National Institute of Standards and Technology (U.S. Department of Commerce)	USA
CML-IA	University of Leiden CML	NL
Eco-indicator 99	PRé Consultants bv	NL
EDIP 2000/ EDIP 2003	Institute for Product Development (IPU)	DK
Impact 2002+	Risk Science Center	USA
Ecological Scarcity (UBP Method)	Öbu/ FOEN	CH
ReCiPe	RIVM, CML , PRé Consultants, Radboud Universiteit Nijmegen and CE Delft.	NL
Traci 2	U.S. Environmental Protection Agency	USA
TWIN2010	NIBE/ Stichting Bouwkwaliteit	NL
USEtox	UNEP-SETAC	USA

Table 2
Diverse characterization models have been published by Universities and companies. Each model includes a suggestion for an emission- factor within a specfic emission group.

Numerous models with different approaches are available. An overview is provided in Table 2. Each of the characterisation models contains protection targets expressed by the impact categories, the category indicator, a list of emissions which belong to each impact category, and the factor by which these need to be accounted for. Impact indicators can address the target on midpoint or endpoint level. Midpoint level addresses the impact category such as ozone depletion potential; while endpoint would express the contribution to cancer.

Along with the characterisation models, most of the models offer weighing for normalisation. They describe the method to calculate one factor from several indicators.

In the following, a selection of characterisation models will be introduced. The CML-2, EcoIndicator 99 and TRACI can be frequently found in literature for application in the building industry.

CML-2 method

CML -2 Method			
Impact category name	**Impact category indicator**	**Protection target**	**Unit of characterization factor**
Ozone layer depletion	Ozone depletion potential (ODP)	Human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials	kg CFC-11 equivalent/ kg emission
Human toxicity	Human Toxicity Potentials (HTP)	Human environment	1,4-dichlorobenzene equivalents/ kg
Freshwater aquatic ecotoxicity	Ecotoxicity Potential (FAETP)	Fresh water ecosystems	1,4-dichlorobenzene equivalents/ kg
Marine aquatic ecotoxicity	See description freshwater aquatic ecotoxicity		
Terrestrial ecotoxicity	See description freshwater aquatic ecotoxicity		
Photochemical oxidation	Photochemical Ozone Creation	Human health and ecosystems	Kg ethylene equiva-lents/kg emission
Global warming (GWP100)	Global warming potential (GWP)	Ecosystem health, human health and material welfare	kg carbon dioxide/kg emission
Acidification	Acidification Potentials (AP)	Impacts on soil, groundwater, surface water, organisms,	kg SO2 equivalents/ kg
Abiotic depletion	Abiotic depletion factor (ADF)	Human welfare, human health and ecosystem health	kg antimony equivalents/kg extraction
Eutrophication	Nutrification	Air, water and soil	kg PO4 equivalents/ kg emission

Table 3
The CML-2 Method is one of the most commonly used characterization models. Most of the categories are applied in the EPD.

The CML-2 method is widely applied in the building industry. EPD according to ISO 14025 use five of the impact categories and apply the CML-2 method to assess the environmental impact. The German building certificate does the same. Criteria 1-5 display the impact categories of the CML-2 method.

Developed by the Environmental Sciences of the University of Leiden, the CML method organises the results of the LCI according to the effect in environmental protection target. The protection targets relate to environmental problems. It is therefore called a problem-oriented or midpoint approach.

Eco-Indicator 99

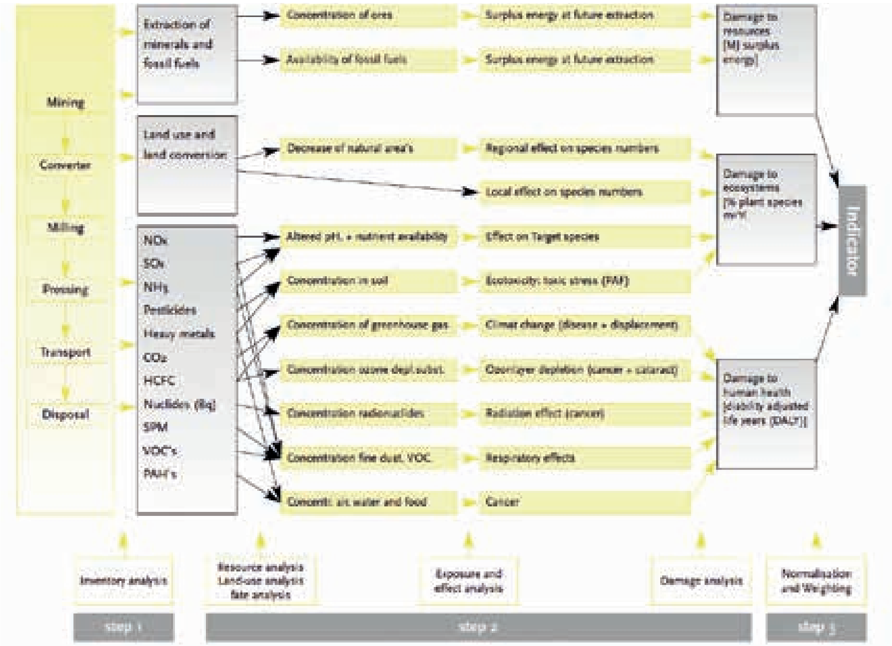


Figure 12
Scheme damage model (image: Ministry of Housing, 2000)

The Eco-Indicator 99 is a method developed for product design by the Dutch Ministry of Housing and Spatial Planning and the Environment. It weights and interprets LCA results into Eco-Indicator in order to make them easily understandable. The indicators present “the relation between the impact and the damage to human health or to the eco system.” Eco-indicator 99 approaches on endpoint level as it addresses the damage (also called damage-oriented approach).

The Eco-indicator 99 simplifies the LCI results and categorises them in three groups; damage to human health, to ecosystem quality, and to resources (Figure 12) (Ministry of Housing, 2000; Joint Research Centre, 2010).

Eco-indicator 99	
Damage category	**Damage indicator**
Human health	Factor derived from the number of years lost, numbers of years lived disabled DAILYs
Ecosystem	Loss of species over a certain area for a certain duration
Resources	Surplus energy needed for future extraction of minerals and fossil fuels

Table 4
In contrast to the midpoint approach where emissions are quantified and organized in groups the here displayed end point approach account the actual damage.

TRACI

The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts Single-issued method (TRACI) was developed by the U.S. EPA. TRACI builds up on existing categories chosen "by their level of commonality, their consistency with EPA regulations and policies, their current state of development, and their perceived societal value" (Bare, 2012). Abiotic depletion was recognised as a relevant factor but discussion on the weighting led to the depletion of fossil fuels as a category. The impact categories are shown in Table 5 TRACI's impact categories. The indicators in the environmental impact categories are calculated on endpoint and midpoint level.

TRACI's impact categories
Impact categories TRACI
Acidification
Ecotoxicity
Eutrophication
Fossil fuel depletion
Global warming
Human carcinogenic effects
Human non-carcinogenic effects
Human particulate effects
Including ozone depletion
Land use effects
Potential effects
Tropospheric ozone (smog) formation

Table 5
TRACI's impact categories which also uses a mid point approach

§ 3.1.3.2 Indicator

The result of the characterisation is organised in impact categories. These indicators quantify the environmental impact; they need to be accurate and practicable at the same time.

Impairment on nature works in two directions. Resources are withdrawn and emissions are produced, which both constitutes disturbance to the ecosystem. In the building sector two kinds of indicator are most frequently applied: Primary energy as a result of the life cycle inventory and emissions grouped in impact categories to indicate the pollution.

In the building industry, indicators are applied in the building certificates according the ISO 14024 Type I and ISO 14025 Type III declaration; in other words for the green building certificates such as DGNB and EPD. The following explains the most common indicators.

Indicating environmental impact: embodied energy

The indication of environmental impact by energy expresses the volume of effort; it does not address a certain environmental protection target. Ideally, the process involves low amounts of primary energy in order to cause low environmental impact.

Primary energy consists of primary energy from renewable and from non-renewable resources. Since primary energy from non-renewable resources has a bigger impact on nature, this indicator finds broad application. It is also called embodied energy (EE) or grey energy as the energy is not immediately noticeable. Non-renewable primary energy PE (PEnr) originates from fossil and nuclear energy sources. Renewable primary energy PE(r) contains energy generated by wind, water, solar radiation and bio mass. PE is typically measured in Megajoule (MJ), or less often kilo Watts hour (kWh).

Embodied energy is not a term defined by a standard. In literature, examples can be found in which EE expresses other emitting parameters. (In eco-devis 2g solvent account for 1 MJ primary energy.) This mixture of parameters leads to incomparable indicators. In order to counteract such complications, cumulated energy demand (CED) was developed by Kasser and elaborated by Frischknecht. CED defines the energy categories and excludes any other factors.

The cumulated energy demand is regulated in the VDI standard 4600-2012 Cumulative energy demand (CED) - Terms, definitions, methods of calculation. CED includes the expenditure of primary energy spent for the production (CEDH), use phase (CEDN) and the end of life phase (CEDE) of a product or service. VDI 4600-2012 distinguishes between primary energy from non-renewable energy sources (nuclear and fossil origins) (KNAR) and from renewable resources (KAR). Both are included in the indicator CED.

In this thesis, the term embodied energy is used to indicate the amount of primary energy from non-renewable resources. The sum of primary energy from non-renewable and renewable resources complies with the CED.

Indicating environmental impact by emission group

Global Warming Potential (GWP 100)

Without greenhouse gases, life on earth would be impossible. They form a reflective layer around the globe; contributing to a filtering effect of harmful radiation. They also keep the earth from cooling and provide moderate temperatures. The heat cannot volatilise and remains between earth and atmosphere. With the growth of the layer the temperatures rises as well. Rising temperatures affect the poles and advance the depletion of their ice volume. The additional amount of water floods regions located close to sea level and threatens the basis of existence. Carbon dioxide CO_2 as the most common greenhouse gas was chosen as reference for this impact category (CO_2 -equivalent).

Ozone Depletion Potential (ODP)

The ozone layer is located in the stratosphere 15-50 km from the earth. It filters UV radiation, which is potentially harmful for humans, animal and plants. With the ozone layer depletion, radiation is able to penetrate this filter. This has two effects on the earth: It contributes to global warming, and supports the development of diseases such as cancer. Ozone depletion started at the poles, and is now observed in middle latitudes, also affecting Europe. CFC was the main contributor to the ozone depletion. With the CFC/Halon Prohibition Ordinance the CFC emission decreased significantly. The effects will remain. R11 equivalent is chosen as the reference indicator for ODP.

Acidification Potential (AP)

The acidification of water and soil becomes visible by forest die-back. This phenomenon directly damages forest and indirectly affects to the surrounding soil. Sulphur dioxide and nitric oxides are emitted in burning processes and reduce the PH values. The conversion of emission into acid rain affects the water quality and the ecosystem. AP is indicated in sulphur dioxide equivalents (SO_2 equivalent). .

Eutrophication Potential (EP)

Eutrophication describes the ecosystem's response to an increased amount of fertilizer in bodies of water. Algae in surface water grow and block sunlight from deeper water layers. This leads to less photosynthesis and consequently less oxygen in these layers. Fish and plants loose the basis of existence and die. A well know example is the Caspian Sea. Parts of it suffer from eutrophication. The eutrophication potential is expressed in phosphate equivalent (PO_4- equivalent).

Photochemical Ozone Creation Potential (POCP)

High ozone concentration on earth (troposphere) occurs under a complicated chemical process when CO_2 emissions and SO_4 are radiated with high intensity. This toxic gas develops under high temperatures in summer, low humidity, hardly any air movement and high CO_2 concentration. A typical situation can occur in summer on a highly frequented highway in the city centre. Photochemical ozone can lead to breathing difficulties. It is suspected to be responsible for damage on vegetation and material. In higher doses it is toxic for humans. POCP is measured in ethene equivalent (C_2H_4-equivalent).

Abiotic resource depletion potential (material) (ADP element)/ Abiotic resource depletion potential (ADP energy) (fossil)

Resources can be distinguished in biotic (living) and abiotic resources. Abiotic depletion relates to the extraction of minerals and fossil fuels. It considers the amount of global reserves to express the potential. Hence the amount of abiotic resources for a process in relation to the global amount of this resource defines the abiotic depletion potential. ADP indicates the amount of resources involved in the production of a material or in the process of energy generation (1/reserves). The quantification of the existing reserves is difficult, and different models are available. In (Heijungs et al., 1992) Heijungs refers to the World Resources Institute (WRI).

EN 15804:2012 defines AD to be a part of the PCR and with this of the EPD. It is therefore a relatively young indicator in the building industry.

§ 3.2 Application of LCA

Measuring ecological impact is complex; especially in the building industry, where numerous processes and various aspects can be assessed. During the last two decades, instruments were developed offering a variety of choices in database, software and impact assessment methods. In the following a selection of LCA instruments, databases and the application is introduce in order to provide basic information.

§ 3.2.1 LCA instruments

LCA instruments consist of a calculating part and a database. The databases contain elementary flows, impact assessment and some of them weighting factors. The Joint Research Centre (JRC), a unit of the European Commission, publishes a comprehensive overview about LCA instruments (JCR, 2012). Here, an overview of the software and databases used in the construction context is given.

Overview for building related LCA software tools (JCR, 2012)				
Software	**Full name**	**Publisher /Institute**	**Country code**	**Source**
Athena		Athena Sustainable Materials Institute	CA	www.athenasmi.org
BEES	Building for Environmental and Economic Sustainability	National Institute of Standards and Technology	USA	www.nist.gov/el/economics/BEESSoftware.cfm
ECOBIS	webbasierte ökologische Baustoffinformationssystem	Bayerische Architektenkammer, BMVBS	GER	www.wecobis.de/jahia/Jahia/Home
EcoQuantum		IVAM	NL	www.ivam.uva.nl
GaBi	Ganzheitliche Bilanzierung	PE International	GER	www.lbp-gabi.de
Greencalc		Stichting Sureac	NL	www.greencalc.com
Legep Software		LEGEP Software GmbH	GER	www.legep.de
Ogip	Optimierung der Gesamtanforderungen (Kosten/Ener gie/Umwelt) in der Integralen Planung	EMPA	CH	www.ogip.ch
SBI's LCA-Tool	Danish Building Research Institute's Life Cycle Assessment Tool	Danish Building Research Institute	DEN	
SimaPro		PRé Consultants B.V.	NL	www.pre-sustainability.com
Umberto		ifu Hamburg GmbH	GER	www.ifu.com/en
VITRUVIUS		VITRUV AG	CH	www.vitruvius.ch

Table 6
This list of software tools was published by the Joint Research Centre in 2012 (JCR, 2012)

In the last 25 years, a variety of LCA software instruments were developed. They started in the packaging industry and are now available for a broad range of applications. They find increasing acceptance in the building sector. Software can address the environmental impact on a material or a building level. The parameters are shown in Table 6. Ecologic parameters can be used to categorise the part of the building that is being assessed in the software. Some software tools can be used to assess the ecological impact of a complete building; while others only consider parts of it.

Products on the building level can include the ecological aspect of the operational energy; tools on material level only consider the building substance.

Eco-quantum models a complete building including the use phase. In GreenCalc, building elements are assessed; GaBi lets the user choose which elements of the buildings are to be assessed. In (Siegenthaler, Braunschweig, Oetterli, & Furter, 2005), 28 LCA software programs were evaluated. It is stated that most of the sold software licenses originate from German and Dutch products.

Eco-Quantum

Eco-Quantum was developed by the Dutch IVAM and W/E consultants and released in 2002 (Guaita, 2012). Eco-Quantum computes a LCA, but accumulates product- based LCA information to a building level. It incorporates material, energy and water usage in order to display the environmental impact in one or several numbers. Eco-Quantum aims at easy readability and tries to establish clear comparability of different scenarios in an early design phase. The results are organised in the four categories: material, emissions, energy and waste. (Kortman,2012)

GaBi

The software GaBi (acronym for the German name Ganzheitliche Bilanzierung, English: Holistic Assessment) was developed by the University of Stuttgart, Chair of building physics and is distributed by PE International GmbH. The first version, GaBi basic was developed in 1991; initially to calculate the environmental performance of industrial products (unknown, 2012). Since then several successive versions have been introduced, leading to today's GaBi 5. Different life cycle phases as well as various impact assessment methods can be chosen. GaBi includes a database for material flows and building materials. Additionally, it is possible to include performance energy according to their ecological impact. The same is true for maintenance and refurbishment measures. They have to be modelled in detail. The software feature Built-it was developed to simplify the building LCA. The subdivision into building element level according to the DIN 276 Building costs is a core element of Built-it.

The software requires a high degree of detailed information, offers a variety of scenarios as each step is modelled individually and presents the results with a high degree of transparency and complexity. (Betz, 2012)

GreenCalc+

GreenCalc was developed in 1997 by the Dutch institute NIBE and, in2012, was replaced by GreenCalc+ by the umbrella organisation Stichting Sureac. GreenCalc+ assesses the ecological quality of a building or an urban quarter considering the three categories material, energy and water (and, on an urban level, mobility). The building area, the materials and the energy source are core information in GreenCalc+. The software distinguishes buildings according to their function and delivers one-number results, the so-called Environmental-Building-Index MIG (Dutch: Milieu-Index-Gebouw). This index is determined during the design phase, and describes a declaration of intent. In the further process this ambition via the MIG can be controlled. (Sureac, 2010)

LEGEP

LEGEP is a German product published by Holger König. It addresses the five aspects cost planning, life cycle costs, life cycle assessment, heat and electricity, and profitability. The results contain information about the production costs, the energy demand, LC cost and LCA which are displayed separately. LEGEP considers the production maintenance, refurbishment and the demolition phase. Issuing the energy pass according to the German EnEV standard is also possible with LEGEP. The database Wecobis is used as a baseline to evaluate the ecological dimension of a building, and sirAdos is applied to quantify the costs. For building elements, the user can choose from preset examples or adapt elements individually. (König, 2009)

SimaPro 7

Dutch PRé Consultants introduced SimaPro 7 in 2006. It is available in several languages, and was developed to assess products. SimaPro 7 includes inventory, characterisation, damage assessment, normalisation and weigthing. SimaPro 7 contains a wide range of databases. For the building industry, SimaPro 7 Database and ecoinvent Data are the most relevant ones. Ecological as well as economical information can be gained. (Goedkoop, De Schryver, Oele, Durksz, & De Roest, 2010)

Umberto

Umberto was developed by the German Institut für Umweltinformatik Hamburg GmbH. (The original name in 1994 was EcoNet.) Umberto was invented for process optimisation and efficient energy management. It displays steps of the production process in a net. With its generic character, different products can be modelled. Its main target are industrial processes. The database ecoinvent is used in combination with others.

§ 3.2.2 Databases

A compilation of LCA data can be found in databases. A range of databases are available, some of them freely accessible. Some databases were published in XML format, which offers the advantage of easy access without the necessity of particular software tools, and a quick and sufficient overview. Material comparison on the bases of mass and volume can easily be made based on this type of information. Some databases contain LCA information from literature, others display assessment results. For researched databases, the consistency of background information has to be checked. The German Government offers several free databases available at www.nachhaltigesbauen.de, such as Wecobis or Ökobau.dat (Kerz 2012). The EU's JRC offers a database, too. LCA data from industries are compiled into a catalogue accounting for over 300 materials. It is available free of charge at JRC's webpage.

Software	
Full name	**Publisher /Institute**
CPM LCA Database	Center for Environmental Assessment of Product and Material Systems - CPM
DEAM™	Ecobilan - PricewaterhouseCoopers
DEAM™ Impact	Ecobilan - PricewaterhouseCoopers
DIM 1.0	ENEA - Italian National Agency for New Technology, Energy and the Environment
ECODESIGN X-Pro database V1.0	EcoMundo
ecoinvent Data v1.3	ecoinvent Centre
EIME V8.0 / EIME V9.0	Bureau Veritas CODDE
erawsdf	AQUA+TECH Specialities
esu-services database v1	ESU-services Ltd.
Eurofer data sets	EUROFER
GaBi databases 2006	PE International GmbH
GEMIS 4.4	Oeko-Institut (Institute for applied Ecology), Darm-stadt Office
IO-database for Denmark 1999	2.-0 LCA consultants
IVAM LCA Data 4.04	IVAM University of Amsterdam bv
KCL EcoData	Oy Keskuslaboratorio-Centrallaboratorium Ab, KCL
LC Data	Forschungszentrum Karlsruhe
LCA Database for the Forest Wood Sector	Bundesforschungsanstalt für Forst- und Holzwirt-schaft (BFH)
LCA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)
MFA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)
Option data pack	National Institute of Advanced Industrial Science and Technology (AIST)
PlasticsEurope Eco-profiles	PlasticsEurope
ProBas	Umweltbundesamt
Sabento library 1.1	ifu Hamburg GmbH
SALCA 061	Agroscope Reckenholz-Tänikon Research Station ART
SALCA 071	Agroscope Reckenholz-Tänikon Research Station ART
SimaPro database	PRé Consultants B.V.
sirAdos 1.2.	LEGEP Software GmbH
The Boustead Model 5.0.12	Boustead Consulting Limited
Umberto library 5.5	ifu Hamburg GmbH
US Life Cycle Inventory Database	Athena Sustainable Materials Institute
Waste Technologies Data Centre	UK Environment Agency

Table 7
List of databasis containing LCA information related to the building sector.

ecoinvent

In 2003, the institutes of the ETH, (Paul Scherrer Institute, EMPA, Agroscope Reckenholz Tänikon, ART) under the direction of Frischknecht published the LCA database ecoinvent. The institutes contribute LCA information according to their discipline. The data was produced based on European and Swiss elementary flows. According to this, the transport of products includes national and European average distances. A query tool enters the basic flow information from the consumer. The information is stored in the database which serves as a resource for the calculation of processes (Frischknecht & Jungblut, 2007). The calculation from flows to processes enables the compliance to the same calculation frame, and therefore generates a level of comparability within the database. ecoinvent lets the user choose from different characterisation models. The ecoinvent database includes the common LCIA models, such as CED, EcoIndicator 99 or the CML method.

Econum

Dämmstoff	Spezifikation	Rohdichte [kg/m³]	Graue Energie [MJ/kg]
Steinwolle	Platten, Produktion CH	30–110	15.7
Glaswolle	Platten 50–70 % Altglas, Produktion CH	12–80	41
Schaumglas	Platten, 100 % Import	105–165	59
Perlit	Schüttdämmstoff, Produktion CH	ca. 100	9.3
Vermiculit	Schüttdämmstoff, Produktion CH	ca. 80	5.7
Perlit	Platten, 100 % Import	ca. 150	17.0
Polystyrol expandiert (EPS)	Platten, Produktion CH	15–40	105
Polystyrol extrudiert (XPS)	Platten, 100 % Import	20–60	109
Polyurethan (PUR)	Platten, Ortschaum, Produktion CH	ca. 30	102
Polyisocyanurat (PIR)	Rohrisolation, Produktion CH	ca. 30	102
Harnstoff-Formaldehyd (UF)	Ortschaum, Produktion CH	ca. 12	40
Zellulosefasern	Schüttdämmstoff, Produktion CH	35–80	3.6
Zellulosefasern	Schüttdämmstoff, Import	33–80	4.5
Holzfasern	Platten, Produktion CH	160–200	20
Korkplatte	Platten, 100 % Import	90–120	12.7
Baumwolle	Matten, Filze, 100 % Import	20–60	17.6
Schafschurwolle	Platten, Matten, 100 % Import	25–65	16.5

Figure 13
Datasheet Econum insulation material (image: Kasser & Pöll, 2003)

Econum GmbH published a compendium of researched LCA data in Switzerland. The first version was released in 1995, the second edition was available in 2003 (Kasser & Pöll, 2003). The compendium contains LCA data that is selected by its plausibility and transparency. The origin of the data is not further explained; only one indicator is given. Embodied energy is specified as energy from oil, gas, coil and all energy carriers and resources with the respective (calorific) value, uranium with the heat generated in a light-water reactor and water energy with the utilised mechanical energy from the turbine. The author argues that EE indicates the amount of embodied carbon and the amount of other polluting emissions. He states that EE is a holistic and simple indicator. Kasser et Pöll incorporate the dissolvent into EE with 2g of dissolvent accounting for 1 MJ.

Inventory of carbon and energy (ICE)

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY				
Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Aggregate				
General (Gravel or Crushed Rock)	0,083	0,0048	0,0052	Estimated from measured UK industrial fuel consumption data
Aluminium	Main data source: International Aluminium Institute (IAI) LCA studies (www.world-aluminium.org)			
General	155	8,24	9,16	Assumed (UK) ratio of 25.6% extrusions, 55.7% Rolled & 18.7% castings. Worldwide average recycled content of 33%.
Virgin	218	11,46	12,79	
Recycled	29,0	1,69	1,81	
Cast Products	159	8,28	9,22	Worldwide average recycled content of 33%.
Virgin	226	11,70	13,10	
Recycled	25,0	1,35	1,45	
Extruded	154	8,16	9,08	Worldwide average recycled content of 33%.
Virgin	214	11,20	12,50	
Recycled	34,0	1,98	2,12	
Rolled	155	8,26	9,18	Worldwide average recycled content of 33%.
Virgin	217	11,50	12,80	
Recycled	28	1,67	1,79	
Asphalt				
Asphalt, 4% (bitumen) binder content (by mass)	2,86	0,059	0,066	1.68 MJ/kg Feedstock Energy (Included). Modelled from the bitumen binder content. The fuel consumption of asphalt mixing operations was taken from the Mineral Products Association (MPA). It represents typical UK industrial data. Feedstock energy is from the bitumen content.
Asphalt, 5% binder content	3,39	0,064	0,071	2.10 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 6% binder content	3,93	0,068	0,076	2.52 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 7% binder content	4,46	0,072	0,081	2.94 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 8% binder content	5,00	0,076	0,086	3.36 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.

Figure 14

ICE 2.0 datasheet for steel

The Sustainable Energy Research Team (SERT) at the University of Bath developed the Inventory of Carbon& Energy (ICE) under the lead of Prof. Hammond and Jones. This database is a compilation of UK data. The origin of information is displayed in the right hand column (Figure 14). The presented indicators are embodied energy EE (MJ/kg), embodied carbon EC (kg CO_2 /kg), and embodied carbon equivalent (kg CO_2 e/kg). The datasheet presents variations of products; for example the virgin and recycled share and their effect on EE and EC.

Ökobau.dat

Ökobau.dat was compiled by LCA company PE International, and published by the German Government in 2008. It is available in xml format, in so-called ILCD format, which was defined by the JRC, and as a software configuration. The database was originally created for use by GaBi, but is also used with other software products, e.g. SimaPro. The xml and ILCD formats do not require professional software. While the database offers quick information, the ILCD file provides information on included life phases, end of life scenarios and validity.

Datensatzinformation

Kerninformation des Datensatzes

Geographische Repräsentativität	DE
Referenzjahr	2000
Name	Basisname; Technische Kennwerte/ Eigenschaften 1.3.01 Kalksandstein Mix; 2000 kg/m3
Technisches Anwendungsgebiet	Kalksandstein-Plansteine (Dichte zwischen 1600 und 2200 kg/m3)
Referenzfluss (Flussdatensatz)	Kalksandstein
Menge	1 kg (Masse)
Anwendungshinweis für Datensatz	Das vorliegende Umweltprofil beinhaltet die Aufwendungen für die Lebenszyklus-Stadien "Cradle to Gate". Es basiert hauptsächlich auf Literaturrecherchen. Der Datensatz ist bereits mit einem Sicherheitszuschlag von 10% auf die Ergebnisse versehen, da kein unabhängiges Review vorliegt.
Gliederung Produktgruppe (GaBiCategories)	Klassifizierung / Ebene / Ebene Bauindustrie / Mineralische Baustoffe / Steine und Elemente

Urheberrecht? Ja   Eigner des Datensatzes (contact data set)   PE INTERNATIONAL

Quantitative Referenz

Referenzfluss (Name und Einheit)	Kalksandstein - kg (Masse)

Zeitliche Repräsentativität

Zeitliche Gültigkeit des Datensatzes	2013
Erläuterungen zur zeitlichen Repräsentativität	Jährlicher Durchschnitt

Technische Repräsentativität

Technische Beschreibung inklusive der Hintergrundsysteme	Die Lebenszyklusanalyse von 1 kg Kalksandstein umfasst die Lebenswegabschnitte cradle to gate, d.h. die Herstellung von Roh- und Hilfsstoffen sind ebenso berücksichtigt wie die KS-Produktion inkl. Verpackung. Die Systemgrenze bildet also das versandfertige Produkt am Werkstor. Transporte vom Werk zur Baustelle sind nicht berücksichtigt und müssen bei Systembetrachtungen eingerechnet werden.

Modellierung und Validierung

Angewandte Methode und Allokation

Art des Datensatzes	EPD-XML-Format

Datenquellen und Repräsentativität

Datenquellen (source data set)	GaBi4 Software und Datenbank 2006 Ökobilanz für den Baustoff Kalksandstein und Kalksandstein-Wandkonstruktionen, 1995

Figure 15

Extract of Stylesheet for lime stone out of the Ökobau.dat

§ 3.2.3 EPD - Type III labels according to ISO 14025 and En pr 15804

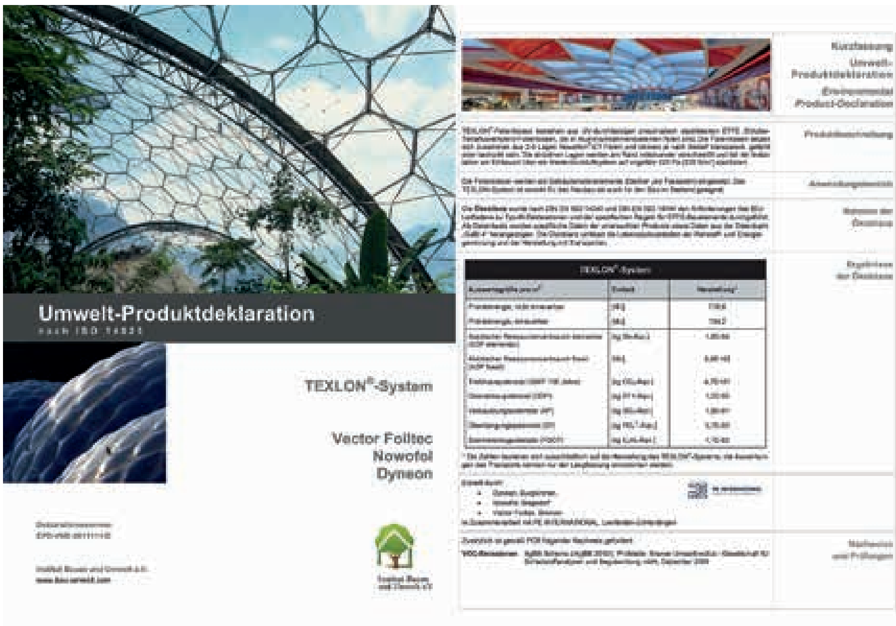


Figure 16
Environmental Product Declaration Texlon-System. Figure 16 shows the cover and the core information of the EPD: primary energy non-renewable and renewable and the emission in indicator groups for one sqm.

The Type III label Environmental Product Declaration EPD are of special relevance for the integration of life cycling into practice as they present ecological information on a reliable and readable basis. The aim of an EPD is described as follows: "present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function". (Labelling, 2006) With EPD based on ISO 14025 a format was introduced that communicates the amount of resource and energy used in the production of a product. The main element is the presentation of LCA results for products in a condensed and readable format.

LCA is designed to compare different solutions, and to identify the one with the least ecological impact. In order to do so, the investigation of the ecological impact has to have the same basis. The same phases have to be assessed, the same system borders have to be chosen, and the same processes need to be included or excluded. In order to generate a fair comparison, Product Category Rules (PCR) regulate these parameters for each product category group. The structure and content is regulated in ISO 14025. The PCR are developed by the institutes which issue the certification in cooperation with industry partners. The content of PCR is displayed in the box below (Table 7). The application of the PCR helps essentially to increase comparability, and thereby supports the acceptance of LCA data.

Product Category Rules content
1 Product definition
2 Base materials
3 Manufacturing of the product
4 Product processing
5 Condition when in use
6 Singular effects
7 End of life phase
8 Life cycle assessment
9 Evidence
10 PCR document and verification

Table 8
The PCR define mandatory components and the table of content for a EPD

EPD was introduced by Swedish environdec, after which several European institutes followed (Marino, 2012). The German Institute Construction and Environment e.V. (IBU) published EPDs in over 20 categories relating to the building sector (Peters, 2012). Companies can approach an institute such as IBU or environdec. The IBU requires an LCA conducted with the Software GaBi or SimaPro (see § 3.2.1) If a PCR is available, the LCA will be conducted according to that, if not a PCR will be developed. The institute itself does not carry out the LCA itself but is the holder of the certificate. An external reviewer is required to check compliance with ISO 14040 and the PCR. By doing so, the ISO 14025 criteria third party review is fulfilled.

A product is assessed by volume, mass or area, and therefore follows ISO 14040.

LCA results for products are displayed along with other physical properties.

The EPD has a descriptive character and neither judges the results nor translates them into a benchmark system. Over the last two decades, the demand for EPD increased significantly because EPD's deliver a relevant input for material criteria for the Type I building certificates.

§ 3.2.3.1 EN 15804:2012, EN 15643 and EN 15978:2011

PCR phases according to EN 15804:2012			Cradle to gate	Cradle to grave
Proudction stage	A1	Raw material supply	m	m
	A2	Transport	m	m
	A3	Manufacturing	m	m
Construction stage	A4	Transport	o	m
	A5	Construction/ installation process	o	m
Usage phase	B1	Use	o	m
	B2	Maintenance including transport	o	m
	B3	Repair and transport	o	m
	B4	Replacement including transport	o	m
	B5	Refurbishment including transport	o	m
	B6	Operational energy use	o	m
	B7	Operational water use	o	m
End of life stage	C1	De-construction demolition	o	m
	C2	Transport	o	m
	C3	Re-use recycling	o	m
	C4	Final disposal	o	m
Benefits and loads for the next product system	D	Re-use recovery and recycling potential	o	o

Table 9
m=mandatory, o=optional

Even more reliability is achieved with the EN 15804:2012 Sustainability of construction works-environmental product declaration- core rules for the production category rules of building products. It regulates PCR for products in the building context like the name says. It subdivides phases of a building product's life cycle production, construction, usage, end of life stage into smaller, more precise units. (Table 9).

In the same series of standards (Sustainability of construction works) the EN 15643 Sustainable assessment of buildings is located. It is subdivided in four parts. The first one describes the general framework to quantify the grade of sustainability of a building. The following three parts deal with the ecology (Part 2: Framework for the assessment of environmental performance), the social aspects (Part 3: Framework for the assessment of social performance) and economy (Part 4: Framework for the assessment of economic performance). This thesis focuses on the ecology aspect and therefore only the first and second parts relevant here. Like the PCR, the EN 15643 aims in a transparent breakdown of building feature by delivering the framework to measure this. The EN 15978 Sustainability of construction works –Assessment of environmental performance of buildings –Calculation method; builds on this and gives advice for the calculation method. E.g. it distinguishes different time term and requires the creation of usage scenarios. Further, the calculation of exchange senarios is regulated.
A very relevant part of the EN 15978 is the adaptation of the life phases from products for buildings like shown in table 8. This scheme is applicable on material and building level.

The standards limit the use of characterization models to the CML method in order to increase the comparability. Additionally the following impact categories are to be presented: global warming, ozone depletion, acidification, eutrophication, photochemical ozone creation, abiotic resources (distinguished in fossil energy and material).

§ 3.2.4 LCA in building certificates

The consideration of the ecological quality of building materials increased significantly with the popularity of the building certificates. All building certificates include materials in their evaluation but the methods vary fundamentally.

For the green building labels BREEAM, LEED and DGNB, the evaluation of the building substance is described in the following.

The certificates are similar in structure. Divided into subjects, a number of criteria describe the quality of the building. Minimum requirements (prerequisites) have to be fulfilled in order to pass and earn the label. Being better than the minimum requirements is expressed in credits. The amount of credits given for one area defines the relevance of each subject.

The certificates have an individual method to assess the sustainable qualities of a building. The weighting factors also vary. It is difficult to compare one label with another as each one can emphasise different parameters. Green building certificates can be analysed with the categories operational energy, building substance and specific qualities. Furthermore, the indicators are relevant. Here, the three parameters of sustainability help to differentiate. The labels use indicators addressing ecology, financial aspects or measure functionality and comfort. For example, while the operational energy can be expressed in power (kWh or MJ) a monetary unit can be also used. This thesis focuses on the material part and evaluates its ecological dimension.

Three green building labels with three approaches to integrate an evaluation of material are introduced here. The certificates themselves are only briefly described. The ecological consideration of the building materials is discussed in more detail.

§ 3.2.4.1 BREEAM

In the Nineteen Nineties the first building certificate was introduced in the UK. The acronym BREEAM stands for Building Research Establishment Environmental Assessment Method and was published by the British Building Research Establishment (BRE), which was founded in England in the Nineteen Eighties. Supported by the UK government, it developed a certificate to display the level of sustainability for buildings. It can be applied to different types of buildings, and is applicable to the design and construction phases. BRE Ecohomes good, a label for residential housing, became mandatory for new construction in 2003 in the UK. Internationally, over 200,000 houses are certified. (BRE, 2012)

BREEAM contains information about the operational energy which is calculated by a software tool. It specifies the ecological qualities of materials by categorisation, and considers health and management issues. BREEAM rewards innovation with credits.

Figure 17
Screenshot Breeam.org (2012)

The BRE started publishing LCA data for building related products in the Nineteen Nineties. The LCA results were provided with open access. However, the database remained closed. The evaluation of the building material incorporates the LCA data by weighting the LCA results into a rating from best A+ to F (Anderson & Shiers, 2009). A certain percentage of good materials (materials with good grades) accounts for credits. The more materials with good grades are planned to be part of the building substance, the higher the number of credits will be. The Greenguide of Specification is comparable to NIBE Milieu. Both evaluate the environmental impact of building elements and weigh the factors in order to generate a grade that defines their impact on the ecosystem in a range between very good and burdensome.

§ 3.2.4.2 LEED

Leadership in Energy and Environmental Design (LEED) is the certificate of the US representation of the U.S. Green Building Councils (WGBC). The US Green Building Council is the biggest department of the WGBC. LEED started with worksheets which could be answered quickly and easily. On one hand, it was this simplicity that helped building certificates to gain popularity. One the other, it caused criticism and the demand for more evidence. With LEED 2009, compliance with the stricter ASHRAE 2007 standards was required. Compared to BREEAM or DGNB the workload is still lower. With impressive marketing LEED helped the discussion going, and stimulated international awareness of building certificates.

Performance energy is labelled by the Energy Star, which is known with regards to electronic appliances. The name of the program is Performance of Energy Star for Homes. The indoor air comfort values follow ASHRAE standard. Innovation and the design process are also part of the evaluation. The USGBC publishes 13.633 certified projects on their homepage (August 2012).

LEED for new construction addresses materials under two aspects. In Indoor Environmental Quality, harmful emissions are limited. Here, the direct effect on human health is evaluated. In Materials & Resources, the distance from the factory to the site is specified, and the application of renewable and recycled materials is rewarded. The LCA is not yet part of the LEED system, although several announcements in the WGBC and USGBC can be followed. The USGBC homepage published a sheet showing the Beta version of LCA application in LEED. In the US, LCA data has not been available as long as it has in Europe. Considering LCA in building certificates, a LCA database is required.

The Reference Guide 2009 is currently valid. It includes only a limited number of ecological aspects for materials.

§ 3.2.4.3 DGNB

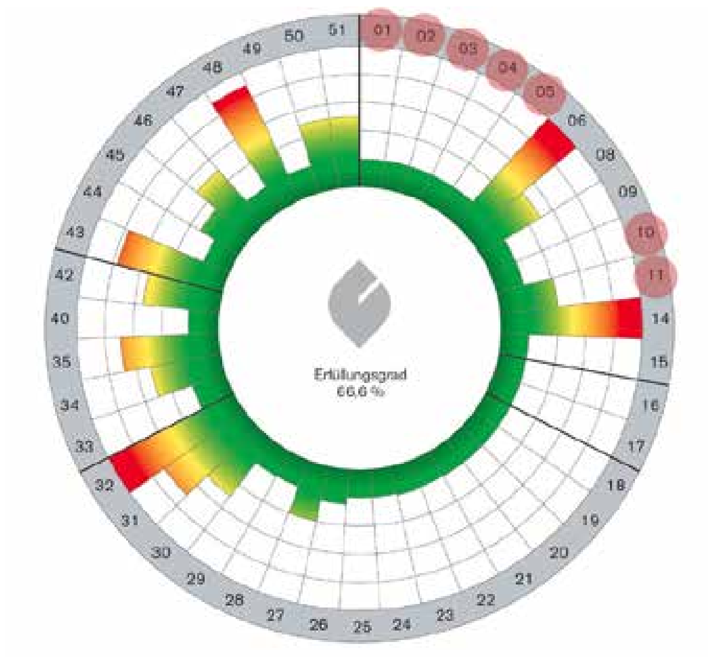


Figure 18

DGNB flower expressing the performance of a building. The marked criteria (red dots) relate to the ecological performance of the building substance.

In 2007, representatives of the building industry institutes founded the German Sustainable Building Council. The main intent was to use the broad national norm catalogue and establish a certification system that would meet the requirements for reliable evidence in Germany. The certificate is called Deutsches Gütesiegel Nachhaltiges Bauen (DGNB) and is characterised by comprehensive evaluation of each criterion. It contains over 60 criteria and integrates material assessment for seven of them. The criteria are based on a normative catalogue. Each indicator is represented in one criterion. The certificate contains the lawful energy pass; a LCA for the building material. It demands a certain level of indoor comfort, and evaluates the process along other criteria. In August 2012, over 320 projects are certified (DGNB, 2012).

LCA results are represented by criteria 1-5 and 10-11. The indicators of CML impact assessment method are part of the category Ecological Quality. The seven criteria include a description of the impact indicator and explain the procedure to calculate the specific indicator. A marginal, a reference and a target valued are defined (Braune, Kreißig, & WIttstock, 2009). The building information has to be organised according to DIN 276. The duration of the building is estimated at 50 years.

§ 3.2.5 Interactive databases

Interactive databases consist of a database and a simple web-based calculation tool (with no software installation required). The ecological impact of, for example, 1sq m façade can be calculated by the thickness of each layer. Different materials for the layers are provided. With very little effort, different solutions can be compared to each other. The simple user interface of these interactive databases makes them interesting for a quick material comparison but the background information (data quality) needs to be transparent. The TU Darmstadt used to openly publish buildingmaterial.db which is no longer available.

§ 3.2.6 Building information model BIM

An interface between 3D modelling and information management was developed over the last 15 years. The software feature Building information modelling (BIM) organises physical or financial information and relates them to the 3D model. With BIM, mass and volume can be easily assessed. Theoretically, costs and other information (such as LCA data) can be connected to these and the parameters can be easily evaluated. With the application of BIM, changes in the cubature of the building would no longer entail new calculations; but could be exported form the 3D model. CAD developers such as Autodesk included BIM in software product Revit as well as Computerworks for Vectorworks.

BIM is a relatively young product to the building industry, and it has to overcome some beginner's obstacles such as allocation of building elements, for example.

A similar concept can be found in the planning software for façade construction. For example Wicona and Schüco use tools with integrated LCA of a façade product. Theses software solutions offer an embedded mass calculation and connect this to ecological information. Hence, the export for the complete profile is relatively simple.

§ 3.2.7 Guidelines

Guidelines for building construction in general try to simplify complex knowledge by formulating generalized guidance. The given information is abstract, as it does not relate to a particular project. Several formats are available, differing in the balance between the degree of complexity and level of comprehensibility. For the EE field, guidelines do not exist. The Swiss Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt SNARC (engl.: methodology for the evaluation of sustainability in architectural projects in an environmental context) is a methodology developed as a tool for the architectural competition in order to compare and judge the ecological impairments of the different designs (SIA, 2004). It addresses building components by 10 parameters (see table below). The SNARC format comes close to a guideline for EE by addressing the resource consumption of design by the parameters construction, shape, windows and refurbishment.

Table of content for SNARC	
Chapter	**Subchapter**
Site	Green space
	Water balance
Resources	Excavation
	Resources for shell construction - construction - shape - windows - refurbishment
	Resources for operation
Functionality	Structure
	Building service
	Building envelope
	Summer thermal insulation
	Sound insulation

Table 10

SNARC organizes its ten criteria in three chapters Site, Resources and Functionality. With these ten criteria a building in the early design phase is judged according to its ecological qualities.

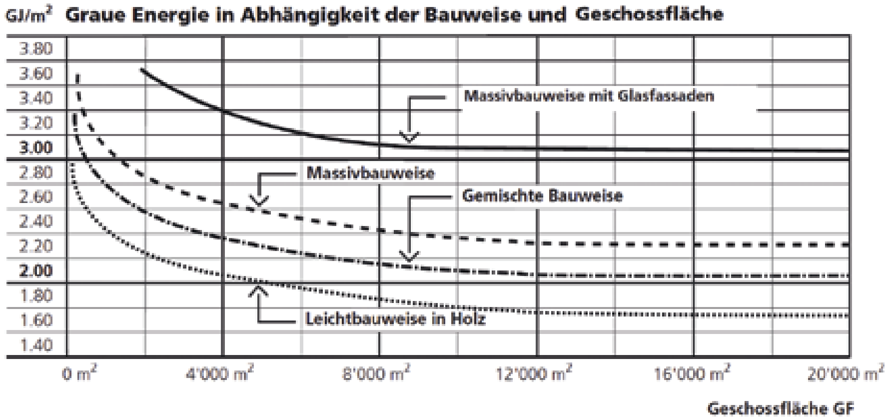


Figure 19
Indication according to the SNARC method

By showing the impact of planning decisions on the ecosystem conclusions for the design can be drawn.

§ 3.3 Integration of ecological impact in the architectural planning process

The ecological quality of the building substance can be assessed by a life cycle assessment LCA. ISO 14040 delivers the framework and IS0 14044, ISO 14025 and EN 15804 offer a good basis to generate comparability. Environmental impact can be indicated with life cycle inventory analysis LCI results by embodied energy. Different applications of this term require specification. VDI 4600 defines the cumulated energy demand CED. The life cycle impact assessment LCIA is conducted under the consideration of a characterisation method. The dimension of pollution allocated to a product can be expressed by different impact categories.

The most common indicators are primary energy, renewable and non-renewable, global warming potential, ozone depletion potential, acidification potential, eutrophication potential, photochemical ozone creation potential and abiotic resource depletion. The aggregation into one factor is called normalisation. The weighing of one impact against another is scientifically thoroughly substantiated. Normalisation causes a decrease in traceability and hence comparability. Identifying one indicator would help to render a judgement. This issue is not yet entirely solved; so the common practice is to display primary energy and global warming potential.

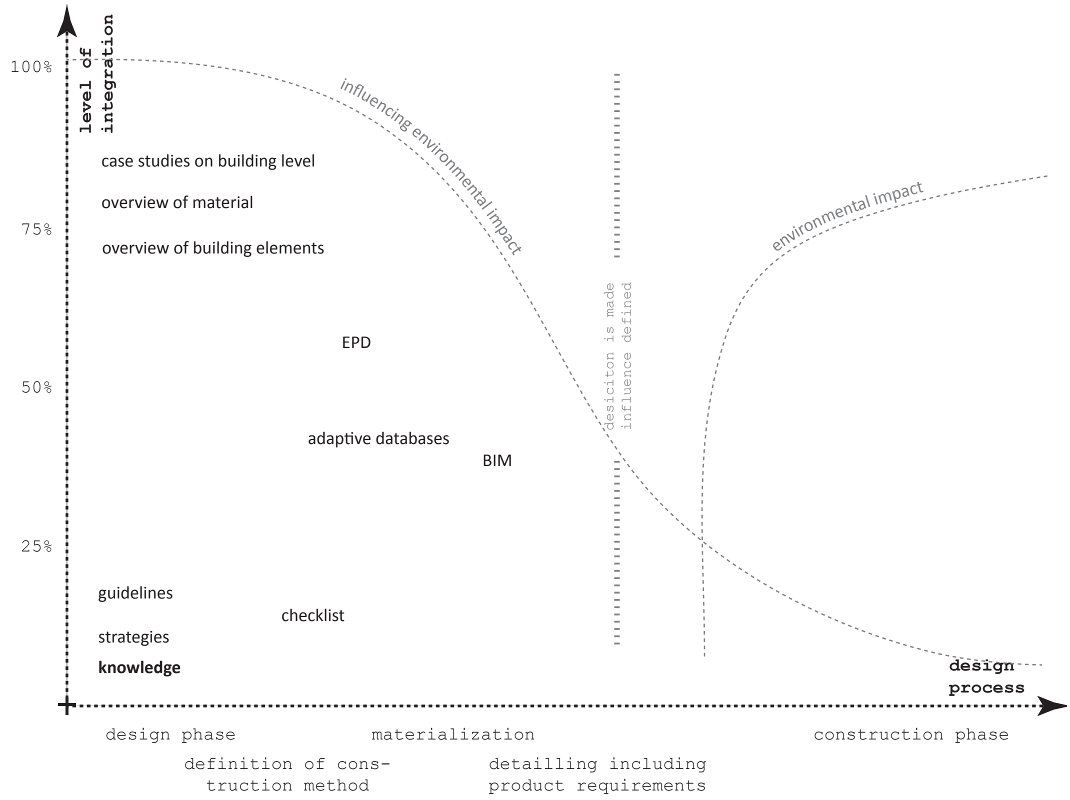


Figure 20
Ecological aspects in the planning process

It is evident that several political and scientific activities to stimulate sensitivity for nature took place over the last three decades, in particular. From the architect's perspective ecological information about building material is accessible but quite complex. A tight deadline lies in the nature of the planning process. Added processes need to be very efficient in order to be integrated in the planning routine. The available information for non LCA professionals appears in different forms. They can be described in three groups.

a Publication on LCA methodology and case studies

b Adaptive databases and individual information

c Guidelines and strategies

They vary in their level of integration into the architectural planning process. For example, case studies and building material information embody complex knowledge but do not address a particular planning situation.

The following evaluates the three groups mentioned above. An outlook on the subsequent steps completes this chapter (and also Part One).

§ 3.3.1 LCA methodology and case studies

Publications on LCA methodology discuss abstract calculation methods relevant for conducting a LCA. These publications are accessible, for example via the JRC, but they require education and profound knowledge in this field in order to understand the coherences and derive information that is useful for a specific planning situation.

Case studies on LCA in the building sector are somewhat easier to understand. Case studies consider different parts of the building; some compare entire buildings including operational and embodied energy, others compare and evaluate building elements with the same function.

Here, the knowledge is easier to access, and the case studies questions might be similar to what an architect is confronted with in practice. The goal is to find a case study as perfectly fitting to the project in question as possible; differences, for example in use or duration might change the result. This is also true for the green building certificates. General knowledge can be derived but it takes time and effort to organise and apply it correctly.

§ 3.3.2 Individual information, adaptive and not- adaptive databases

Individual information in this context means information about the embodied energy of a material communicated in an EPD or a database. The nature of singularly information is its simplicity. The decision for one construction method or material over another is related to the desired function. The database can help to decide between two materials if their functionality is absolutely clear. The same is true for EPD's. Here, the LCA data will be more precise because it relates to a certain product rather than to average values.

In the construction or material decision phase, interactive databases help to quickly evaluate variations. In the databases and EPD's, material values are mostly presented by mass or volume; the adaptive databases calculate from the thickness. The calculating part is not necessary, and potentially mistakes can be avoided. If an ecology integrated planning process would only require the definition of the material with the least EE, the web based databases would offer the complete solution.

The fact is that materialisation is an essential part of ecological optimisation. The databases are limited to layering; they do not consider the material joint or the possible scenarios at the end of life, and address only one part of the building.

§ 3.3.3 Guidelines and strategies

Guidelines offer coherence and give advice for the decision planning process. In contrast to a general description of methodology, they address this planning situation.

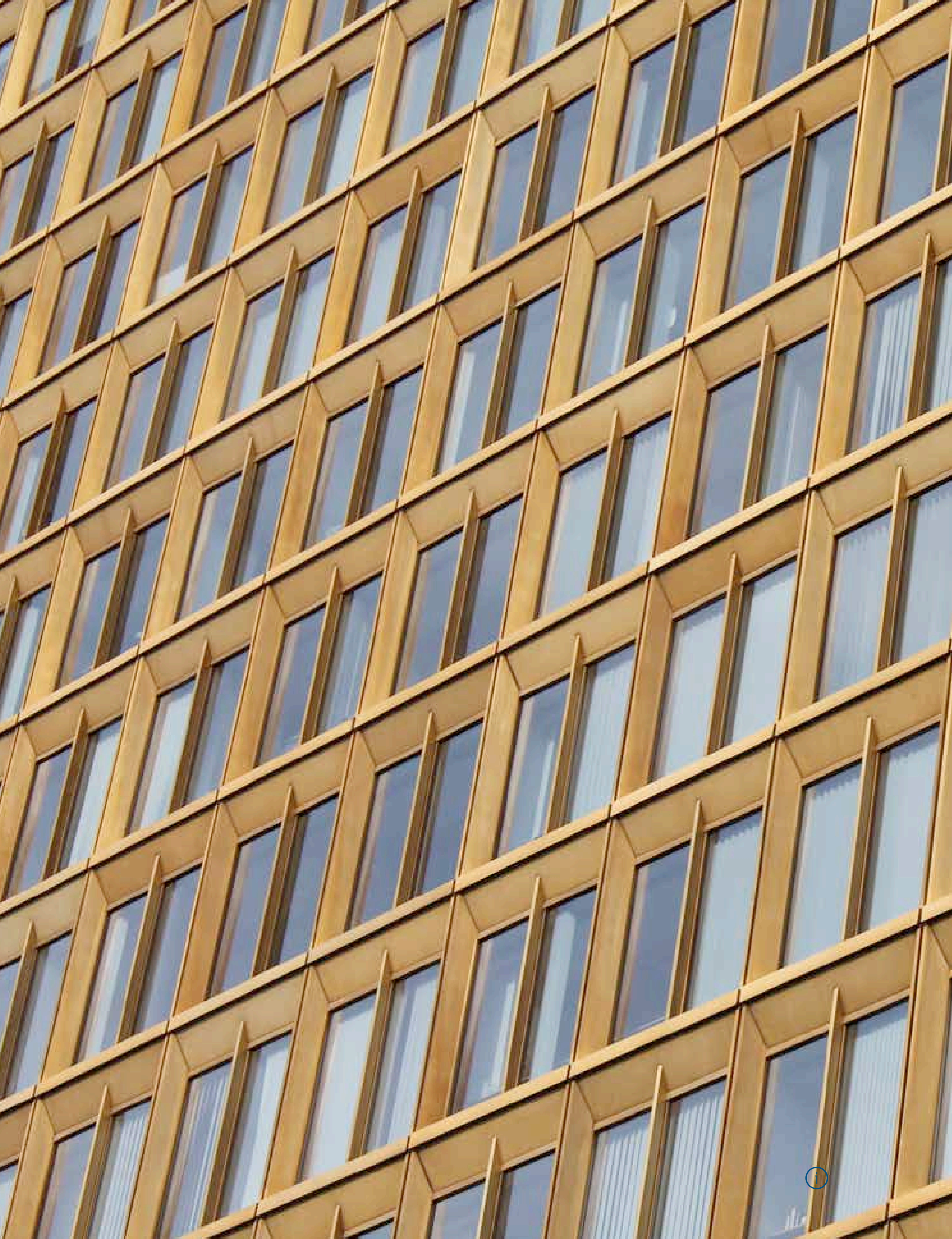
Guidelines can be given for different planning levels. Depending on the content, they are applicable during the very early design phase, for the choice of construction, or during the materialisation phase.

Strategies are more compact. In contrast to guidelines they do not explain but rather present information in a condensed form. Knowledge is organised in the most concentrated form. Guidelines are able to address the complexity of the building by approaching several aspects. Essentially, strategies do the same: they organise the parameters and interdependencies in a visual and direct manner.

§ 3.4 Conclusion for chapter 3

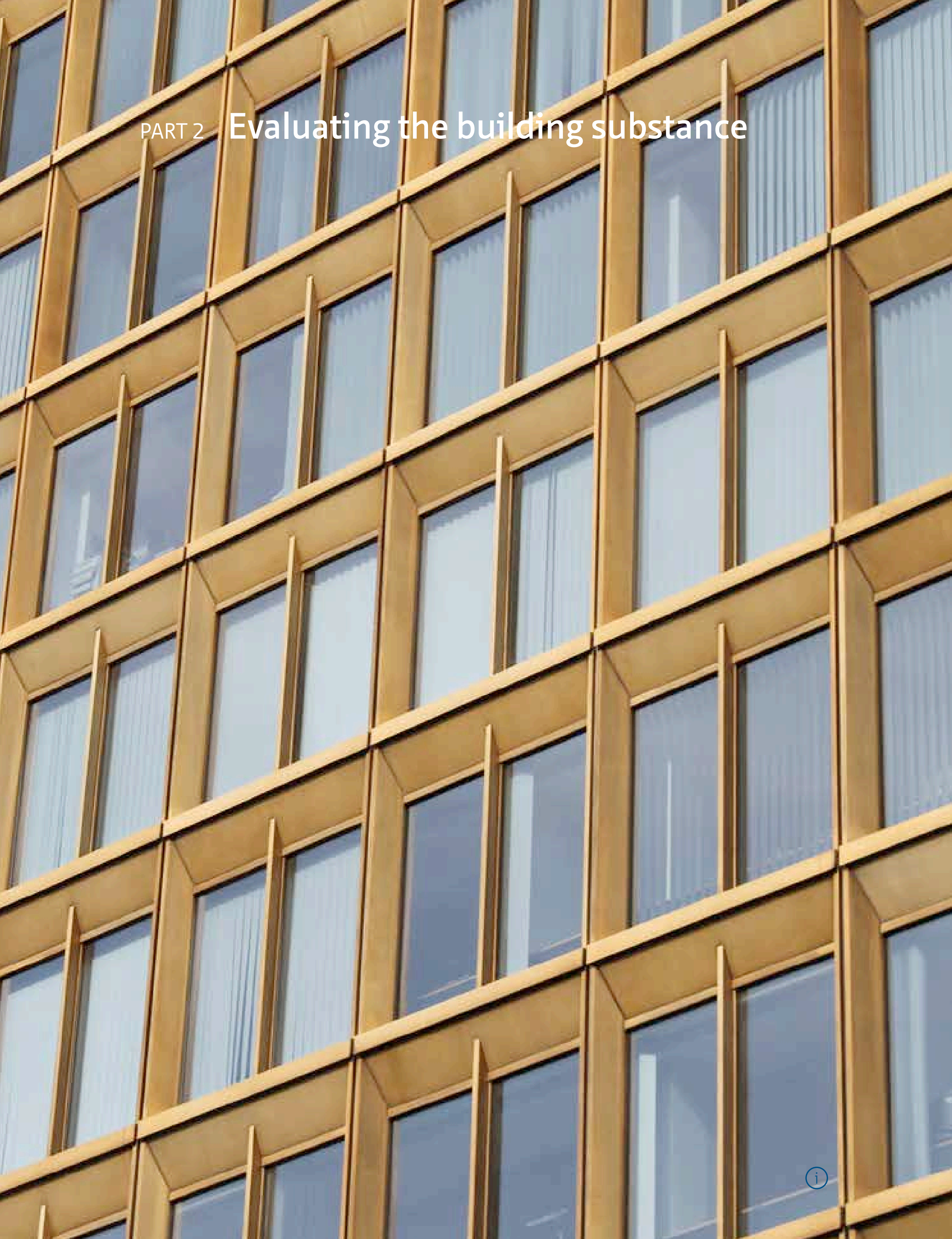
The complex nature of ecological information has to be simplified in order to be integrated into the architectural planning process. In the building context, three levels can be distinguished; material, building element and building. The complexity increases with size of the investigated element. All three levels are important in order to gain a general understanding of the functionality, and furthermore to be able to identify the relevant parameters in the building context.

In order to understand the interdependencies between material and ecological impairment, the next step should be examining the smallest unit. Chapter 4 introduces the parameters of an ecological material evaluation in order to provide fundamental comprehension.



PART 2

Evaluating the building substance



4 Framework for an ecological evaluation of building material

Building materials have been assessed with LCA methodology for the last 20 years, and today the information for individual materials can be accessed through different portals. The ecological evaluation of building materials is the first approach to gain a general understanding of the impact the building fabric has on nature as it examines the smallest module of a building.

This chapter discusses an adequate method to evaluate building material in terms of its ecological impact. The ecological evaluation follows in chapter 5. This chapter introduces evaluation parameters that help to identify the character and scope of ecological information. These parameters will reappear in the framework for buildings (§ 6) and also for façades (§ 8), modified when necessary.

§ 4.1 Categories for the ecological evaluation profile of building material

LCA information on a material level can be evaluated by comparing data that refers to the same reference unit (mass, volume, area and/or function) and the same life cycle stages with the same indicator. These parameters (reference unit, life cycle stages and indicator) are most relevant to characterise the scope of a LCA result and to control comparability if more than one LCA are considered. LCA results cannot be compared if different parameters are included. (E.g. a LCA result for the production cannot be compared to a result for production and end of life.)

The following introduces a framework of ten categories, which contains information with which LCA evaluation can be characterised. It is based on the categories given in ISO 14025 and pr 15804. In each category different criteria can be chosen to illustrate the content and the scope of the LCA evaluation. This profile is applicable for building material, building elements and complete buildings, and will be used in the following evaluations to communicate the LCA information.

In the following each category will be introduced individually. Background information is given and references to standards are made. These categories are later used to characterise building information in chapter 6 to and façades information in chapter 8. The categories remain the same but their content adapt to the specifics for buildings and façades. Some aspects within the categories might be true for all (building material, building and façade) level. They will be explained in this chapter. Later paragraphs will refer to it.

The categories form a profile that expresses the parameters of the ecological evaluation and hence is named Ecological Evaluation Profile (EEP). The EEP consists of the following categories

- Evaluation goal
- Data source
- Generic and specific LCA data and its validity
- Relevant data
- System borders
- Reference unit
- Calculation method and tool
- Life cycle phases
- Considered time span
- Indicator

§ 4.1.1 Evaluation goal

The execution of a LCA starts with the definition of the LCA goal. A goal can be the presentation of the environmental impact of a product, a service or function if only one item is assessed. (This is further specified in § 4.1.6 Reference unit.) The evaluation of ecological qualities is the consideration of more than one item. Evaluation (minimum two items) and LCA goal (one item) both have a quantitative nature. They express the ecological dimension of a product, service or function in numbers. An evaluation aims at the comparison and, most commonly, at identifying the solution with the least environmental impact. The evaluation can be made more specific by identifying detailed (research) questions. Possible evaluation goals could be the comparison of generic and specific data or the variation with regard to different durations

§ 4.1.2 Data source

Three aspects are relevant for the data source:

- The LCA data needs to be traceable. All categories which will be explained in the following have to be accessible.
- The standards ISO 14040/14044 are prerequisite.
- The choice of data should be documented and be appropriate to the scope and goal of the evaluation. Its consistency is key. More than one database can only be applied when they are subject to the same framework.

§ 4.1.3 Generic and specific LCA data and its validity

Generic data is generated by averaging values from research and literature. For some building materials only generic information is available. Specific (or product) data is preferred over generic data if the planning is developed to product level. Additionally, the specification is relevant for the validity of the data. According to EN 15978, generic data has to originate from the last 10 years, as it is assumed that the general line of processing will remain the same (and a change in the production chain regarding the average will not have a big impact). Specific data has to be less than 5 years old; as a change in the manufacturing process might impact energy reduction; causing recognisable changes that warrant more frequent updates. This applies to all building levels.

Example for generic and specific information			
	EE (MJ/kg)	GWP (CO_2 eq./ kg)	Ökobau.dat source
OSB	5.79	-1.06	3.2.04 OSB (average); 619 kg/cbm
OSB EGGER	6.20	-1.24	3.2.04 OSB Eurostrand - Egger; 615 kg/cbm

Table 11

Example for a generic and a specific LCA data.. (The flows are taken from the Ökobau.dat as one of the databases. A range of databases is introduced in § 3.2.2.)

§ 4.1.4 Relevant data

LCA data is preselected from the available data sources and sorted by relevance for the evaluation goal.

For general assessment, the organisation into material groups can be helpful. Each group should consist of a significant amount of materials. At least ten materials should be evaluated in order to reach an informative result depending on the evaluation goal.

§ 4.1.5 System borders

The category system borders relate to the LCA data and contain all information outside the categories life cycle phases and life span. In the EPD format, system borders were used to describe the life cycle phases. (This is especially true before the introduction of the pr 15804 which now defines the Life cycle phases).

System borders express the boundaries of actual flows to those reflected in the assessment. The relevance (and complexity) of the assessment increases with the number of the included flows.

If certain data is left out this needs to be documented by means of the LCA conductor. A more elaborate description was given in § 3.1.2.1. In this category all relevant parameters that are not covered in other categories should be named.

The definition of system borders is especially relevant for the building and building element evaluation.

§ 4.1.6 Reference unit

The reference unit for building material can relate to a mass, volume or area unit such as 1 kg, 1 cbm or 1 sqm. This is true for a general comparison with a comparably simple approach since the functionality is excluded. A more complex evaluation goal could include physical capabilities such as load-bearing capacity or heat transmission. The reference unit essentially defines the scope of application and needs to be stated clearly.

Material data is seldom related to a function as one material is typically combined with another material to form a building element. Comparing material LCA's against one another will not offer an assessment of the sensibility of an application in the building as the functionality is excluded and therefore the scope is very limited.

Since the goal of the material evaluation is the understanding of the spectrum of one material group and how it compares to other materials, it prepares for further assessment on building and building element level. It can be used to understand the effect of manufacturing processes on the ecological impact of a material and is a first step to understanding the ecological dimension of building materials.

§ 4.1.7 Calculation method and tool

The calculation for building materials is rather simple. Compliance with the introduced categories is assumed. The LCA data for building material is available in XML and PDF format. The given values refer to mass or volume. If only one mass related LCA information is given, volume related information is calculated by use of the material's density. The calculation part is limited to converting into different units. The tool here for can be Excel or any other simple data processing software.

§ 4.1.8 Life cycle phases

The life cycle phases generally include production, usage and end of life phase. pr EN 15804:2012 subdivides these into more specific phases as explained in § 3.2.3.1. This cycle refers to building materials as well as to buildings. It is very crucial to differentiate the subject of investigation. The cycle of a building material or a building itself differs; especially in the usage phase. While the usage phase of a complete building accounts for a significant amount of energy, the usage phase only includes possible effort for maintenance, repair and exchange.

The most common parts of a LCA are production (mandatory) and end of life.

The following describes the main steps of a LCA according to pr 15804.

Production stage (A1-A3)

The basic content of an LCA is the depletion of resources, the transportation to the treatment facilities and treatment itself. Distance, vehicle and utilisation influence the ecological impact by transport. Power consumption and the necessity to produce heat are the main environmental burdens during the production process of building material. Depending on the primary resource, the amount of emission varies. For example, 1MJ from a brown coal power station releases significantly more emission than a power station for natural gas. This phase entails the highest energy consumption and the highest production rate of emissions. It fundamentally impacts the EE and GWP.

Construction stage (A4-A5)

For a material evaluation the construction context has yet to be defined. Therefore, the construction stage is not included and not relevant for the EE and GWP.

Usage stage (B1-B7)

The usage phase is not included in the material evaluation. As explained in the introduction, buildings and building products have a different nature when comparing life phases. Effort has only to be spent on repair and maintenance. It highly depends on the building context and is therefore not considered in the ecological evaluation of materials. Building materials and building elements consume the major part for their production and only require small amounts for maintenance, repair and at the end of life. (Energy supply for building elements is very rare but would be true for e.g. permanently inflated foil cushions). This phase is of minor relevance for EE and GWP.

End of life stage (C1-C4) and benefits and loads for the next product system (D)

The LCA method models hypothetical situations. In order to balance the complexity and comprehensiveness, end of life scenarios are simplified. Generic scenarios are offered for most building material groups. End of life scenarios for specific building products are less common but increasingly available.

- The generic end of life scenarios are as follows.
- Building rubble procession
- Recycling
- Energetic recycling
- Landfill

Generic end of life flows			
	EE (MJ/kg)	GWP (CO_2 eq./ kg)	Ökobau.dat source
Building rubble procession	0.04751	0.0348	9.5.01 Bauschuttaufbereitung
Recycling (Aluminium)	-121	-9.74	4.8.01 Recyclingpotential - Aluminium (Blech und Profile)
Energetic recy-cling (Plastic)	-27.7	1.65	6.8.01 Verbrennung PS in MVA incl. Gutschrift
Landfill	0.1602	0.02024	9.5.02 Bauschutt-Deponierung

Table 12
The most common end of life flows are here shown. The do not relate to a specific product but account for a group of materials.

For the evaluation of building materials, the end of life scenarios are described in the General Ecological Information.

The phase contributes to the amount of EE and EC. The extent depends on the scenario.

A Building rubble processing

Building rubble processing is particularly applicable for mineral materials. It includes demolition on the building site, crushing with mobile or stationary crushing machinery, a sorting process and preparation for further use as building rubble.

B Recycling and energetic recycling

The consideration of recycling can be conducted with the two methods introduced in § 3.1.2.2. The Recycling Content Approach is used for the material, building and façade evaluation.

The share of potential material for recycling depends on the collection rate from the previous functional context. This does not apply to building materials and is not taken into consideration.

Recycling processes vary for different material groups and are particularly used for metals and plastics. Here the consideration of the end of life scenario determines the overall result.

Recycling can potentially decrease the overall amount of EE and EC. The numbers shift essentially; especially for metals such as aluminium and steel when considering recycling at the end of one life cycle.

C Landfill

The process of landfill describes the deposition of non-functional material for permanent storage. Unlike the other generic end of life processes, no energy can be accredited, as this scenario requires energy and does not deliver a surplus.

Conclusion

The production phase has a fundamental influence on the amount of EE and EC. During this phase, the extent of ecological impact is defined. The end of life phase also contributes impact. Recycling can potentially lower the amount of EE and EC and is especially relevant for metals.

The production steps (for the production and end of life phases) explain the differences in ecological impact and need to be displayed clearly to provide comprehension.

§ 4.1.9 Considered time span

The ecological evaluation uses the time dimension in three different ways. They are introduced here to give an overview and to differentiate the aspects from one another. Various terms are used to describe aspects of time. *Life span* is a limited period of time (also called duration).It can express the time an indicator contributes to ecological effect . A life span is often used to describe scenarios and to express the expected amount of years related to a function. The *life time* describes the actual time a persons lives or the time of existence for an object.

1 Time span emissions contribute to a certain effect.
In Chapter 3 the different characterization models were introduced. On page 61 Figure 11 shows the origin of emissions, their quantification and the weighing in emission groups. A time span is defined per indicator group in which the effect of one emission is accounted. For example, the effect of CO_2 in the atmosphere is assessed for the period of a hundred years as it is believed that the effects are traceable within this time span.

2 The life span that is related to performance.

The life span can be related to a certain performance like technical and economic life span. The technical life span describes the time an object performs in its expected technical function. The economical life span contains the time in which the investment costs are amortized. In the same manner, an environmental performance could be defined. The term *service life* also belongs to the category of performance-related life span. Service life describes the life span an object performs in its expected function.

3 The life span the building is considered.
Each building material, building element or building is subject to a certain duration in the building context. When the technical life span of a material ends, it is exchanged if the building is further used. The *considered time span* is a window out of the buildings life span. It describes a defined amount of years and impacts the exchange cycles; Is the considered time span higher than the building material or element's life span, it is accounted for multiple times.

The ISO standard 15978:2011 § 7.3 differentiates the following phases: The required service life (Required Service Life ReqSL) , reference service life (Reference Service Life RSL) and the reference study period (Reference Study Period RSP).They serve to describe different usage scenarios. The here called considered time span is equivalent to the RSP. The ISO term is not used in this context as the ISO standard includes the exchanged material differently than described here. (Example: A building element has a technical life span of 20 years and the RSP is 30 years. The ISO standard accounts the building element 1,5 times while in the subsequent evaluation the element would be included two times. This method is chosen because it reflects the building practise better.)

This description is especially relevant for the evaluation of buildings and building elements. As the term is also used for the material evaluation it is introduced here. The material evaluation excludes the building context and, with this, possible exchange cycles. The considered time span for material is most commonly one year (hence, the material is only evaluated once).

§ 4.1.10 Indicator

Ecological indicator have been introduced in § 3.1.3.2. The indicator should reflect the goal. For the sake of comparability, an indicator according to 14025 is strongly recommended.

§ 4.2 Communicating LCA information on material level

The categories given in the last paragraph aim at defining the LCA evaluation's content and scope. The evaluation itself needs to be specified, as well as the evaluated item. The introduced categories form a profile that characterises the complete evaluation or necessary information on a case study level. For building material it is sensible to subdivide them into material groups. This introduces a mid-level between evaluation and case study level, the group level.

Two types of communication are distinguished in the following: the first kind is presentable in a table; the second requires a descriptive text. Together they deliver a format that characterises the evaluation of various ecological evaluations and can be applied to building material, building elements and complete buildings.

Overview for the framework parameters (T - table, D - description)		
Parameter for LCA	**Evaluation level**	**(Grouped) case study level**
Evaluation goal	T / D	
Data Source	T / D	
Generic or specific data	T	
Validity	T	
Relevant data	D	D
System border	T / D	
Reference unit	T	
Calculation method and tool	D	
Life cycle phases	T	
Considered life span	T	
Indicator	T	

Table 13
The table shows the information that will be given in the EEP and the description part. It distinguishes between material and material group level. The form (table or description) are recommendations.

§ 4.2.1 Evaluation Level - EEP table

On the basis of the categories introduced in § 4.1 Table 14 shows the Ecological Evaluation Profile (EEP). It contains only the parameter and is later filled with information from the evaluation in Table 15.

Parameter for the ecological evaluation of building material		
Evaluation goal		
Data source		
Generic or specific data		
Validity		
Reference unit		
Calculation tool		
Life cycle phases	A1	Raw material supply
	A2	Transport
	A3	Manufacturing
	A4	Transport
	A5	Construction/ installation process
	B1	Use
	B2	Maintenance including transport
	B3	Repair and transport
	B4	Replacement including transport
	B5	Refurbishment including transport
	B6	Operational energy use
	B7	Operational water use
	C1	De-construction demolition
	C2	Transport
	C3	Re-use recycling
	C4	Final disposal
	D	Re-use recovery and recycling potential
Considered time span		
Indicator		

Table 14
EEP categories that can be displayed in a table

Aiming at a comprehensive means of communication, most of the information can be displayed in the form of a chart. This delivers a comprehensive overview as shown in Table 13. It displays categories to characterise one or more LCA results. It can be applied to a complete evaluation.

§ 4.2.2 Case study level- EEP description

The background of the information in each category is not included in the table, and should be accessible in form of a description (as shown in Table 12). In general, it is interesting to have this kind of information available for all categories. The following parameters are especially relevant for comprehensiveness and control of comparability. Their most significant content is mentioned.

- Evaluation goal

Research question expressing the evaluation's specific goal help to specify the results and to provide profound results..

- Data source

The choice of data should be explained by mentioning relevant criteria. The result can be shown in the table.

- Calculation method and tool

The name of the calculation tool should be mentioned. The underlying argumentation needs to be explained in a more elaborate form. This feature is quite complex, while extremely crucial for the process. The calculation needs to be traceable and therefore carefully documented. This is true for self- programmed sheets as well as for the use of common software programs. Here, the pre-settings have to comply with the evaluation goal. For example, the consideration of exchange cycles cannot easily be reflected in all software programs. This needs to be considered and documented.

§ 4.3 Conclusion Chapter 4

The ecological evaluation of building material can be done within a framework of eight parameters. These can be expressed by a table, as well as a descriptive part. The two different angles of this evaluation are assessing the information on material and on material group level.

On the material level, evaluation Goal, data source and system border are presented in both forms; table and description. The information is displayed in the EEP, while the background is explained in a descriptive part. The type of data, the reference unit, the life cycle phases, the duration and the indicator are expressed within the table. The relevant data, the calculation method and tool and the evaluation goal require more background information and are explained in a separate descriptive part.

5 Evaluation of building material

In this chapter, the previous categories are applied as framework for the ecological evaluation of 163 materials, which are subdivided into five material groups. The number of materials is defined by the information needed to provide students of the Detmolder Schule für Architektur und Innenarchitektur, a part of Hochschule OWL, with material flows for the ecological evaluation of buildings and façades between the years 2008 and 2012.

First, the specifics of this evaluation will be introduced according to the categories previously explained. The evaluation will follow in § 5.2.

§ 5.1 Framework for the subsequent evaluation

Beyond the categories discussed in chapter 4, four topics are mentioned that should be explained with a description in each material group.

- Ecological description
- End of life description
- Data description
- Evaluation summary

These and the item Relevant data form the descriptive part on material group level.

The content of these descriptions is further discussed in § 5.1.2.

In addition to the summary in each material group, an overview for the complete evaluation should be given for all building material at the end of the chapter. All information on material level is discussed in the next paragraph § 5.1.1.

The EEP for the here conducted material evaluation is shown in Table 14.

Parameter for the ecological evaluation of building material			
Evaluation goal		Material comparison	
Data source		Ökobau.dat, EPD	
Reference unit		1 kg/ 1 cbm	
Generic or specific data		Both, average values are marked	
Validity		varies 2011-2013	
Calculation tool		**Excel**	
Life cycle phases	A1	Raw material supply	x
	A2	Transport	x
	A3	Manufacturing	x
	A4	Transport	
	A5	Construction/ installation process	
	B1	Use	
	B2	Maintenance including transport	
	B3	Repair and transport	
	B4	Replacement including transport	
	B5	Refurbishment including transport	
	B6	Operational energy use	
	B7	Operational water use	
	C1	De-construction demolition	
	C2	Transport	
	C3	Re-use recycling	
	C4	Final disposal	
	D	Re-use recovery and recycling potential	
Considered time span		1 year	
Indicator		EE (GWP)	

Table 15
EEP for the material evaluation

§ 5.1.1 Evaluation goal

The aim of the ecological evaluation is a comparison of materials in material groups. The evaluation is conducted in order to answer the following questions:

Do the materials have similar ecological footprints within the material group?

What components account for high, which for low values? What potential does recycling have?

§ 5.1.2 Data source

The data is chosen according to the following criteria:

1. Transparency and traceability
   The data has to be conducted according to ISO 14040 and 14044. This has to be traceable.

2. Free access
   Financial limitation encourages the use of free accessible information.

3. Data operation without any software
   To integrate students into the process, the data operation should be as simple as possible. Therefore the use of software products was limited. Criteria for the choice of source were transparency and reliability of the data as well as its free availability. The last criterion limited the search to the format of databases and singular ecological information.

The databases introduced in § 3.1.5 were examined under the criteria described above.

Ecoinvent complies with criteria 1 and 3 but is excluded by 2.

Econum, the Swiss database, accumulates dissolvent and EE, which leads to incomparable results and has to be excluded under the premises of criterion 1.

Bath's ICE consists of researched results from different sources. The description of the background is incomplete and has to be excluded under criterion 1.

The German Ökobau.dat fulfils all criteria and was available in ILCD format, where all necessary framework information was displayed, and also as xml export. (The xml-export is no longer available from the government webpage and is used in the version of 2008 under the consideration of the updates published in the same source.)

LCA information for single materials can be accessed with the EPD. They comply with all 3 criteria and in chapter 5 they are used to fill gaps of the Ökobau.dat.

EPD are available as PDF files; the information has to be copied to a simple digital spreadsheet in order to become part of the ecological evaluation.

The main source for this evaluation is Ökobau.dat. (A general description can be found in Ökobau.dat op pagina 78 .) The evaluation of buildings at the Detmolder Schule started in 2008. Therefore, the version of 2008 is the basis of evaluation. Meanwhile, a new version has been released in 2011 which included changes. These changes were incorporated in all evaluations.

EPDs are discussed in § 3.1.6. The EPDs used herein are obtained from the German IBU.

§ 5.1.3 Relevant building material

Material group					
M1 Mineral material	**M2 Wood based products**	**Cbm Metals**	**M4 Synthetics**	**F5 Insulation materials**	**F6 Window frames and glass**
Concrete	Massive wood	Steel products	Boards	Wood products	Aluminium profiles
Reinforced concrete	OSB	Aluminium products	Sealing	Mineral material	PVC profiles
Aerated concrete	Fibre boards	Copper products	Foils	Synthetic insu-lation	Wood profiles
Lightweight concrete	Floor surface	Zinc	Profiles	Renewable ma-terial (without wood products) incl. cellulose	
Mortar and plaster		Other	Floor covering		
Cement and aggregates					
Brick / clinker					
Hollow brick					
Limestone					
Natural stone					

Table 16
Six material groups will be evaluated in the following. The table lists the material within each group.

The relevance of the building materials is defined by the application in the design process. Since 2008, each semester, approximately 50 Sustainable Construction students of the Detmolder Schule für Architektur und Innenarchitektur design two office buildings and façades. The list of materials the students receive at the beginning of the project is adjusted for materials needed for the building and façade design. The materials that the students include in the design are divided in 5 material groups:

M1.Mineral material

M2.Wood based products

M3.Metals

M4.Synthetics

F5.Insulation materials

F6.Window frames and glass

The groups are organised according to their material composition with the exception of group 5 Insulation materials and 6 Windows frames and glass as shown in Table 16. They are organised by function and particularly described with regards to their ecological relevance by their passive contribution to operational energy. The material groups are identified by the letter M, the function groups by the letter F.

§ 5.1.4 System borders

The material evaluation includes the modulation of LCA results to one denominator. Due to the calculation, no lost data is considered. Consequently, the results do not include an uncertainty factor.

The allocation is excluded from the evaluation as the information provided is not complete. EPDs mostly explain this parameter but the Ökobau.dat style sheet does not present information on allocation. (It names this category but does not describe the procedure.)

§ 5.1.5 Calculation method and tool

EPD and Ökobau.dat data is gathered in an Excel sheet. The material is subdivided into material groups; each in a separate file. The files consist of the data and the figure sheet. Each data sheet contains two rows for each material. The first row contains information based on 1 kg material, the second for 1 cbm. When only one number is available, the other can be calculated by the material's density. The columns from left to right show the name, the density, the information whether it is mass or volume, primary energy non-renewable, primary energy renewable and the global warming potential. These parameters are reflected in the bar chart on the figure sheet.

§ 5.1.6 Evaluation summary

The chapter will be rounded of with a summary of the evaluation results. It will interpret the evaluation result for each material group and discuss the functional unit for building material. Finally, it will answer the questions formulated in the evaluation goal.

§ 5.1.7 Material evaluation per group

§ 5.1.7.1 Relevant data

Relevant data within the material group highlights materials of special relevance. Relevance is defined by application in the building industry. Highlighted materials are e.g. cement products, massive wood products, aluminium, poly ethylene foil and mineral wool. The background information is given in the categories described below.

§ 5.1.7.2 Ecological description

Each material group will be briefly introduced in the Ecological description. Different parameters influencing the degree of ecological impairment will be described. The material's origin will be named because it defines the availability of the resources and the effort for its generation, and gives a better understanding of the composition of the data. The application indicates the duration, which informs about the exchange cycles and defines the amount of resources used for one function. Furthermore, it provides information about the maintenance during the time of use.

§ 5.1.7.3 End of life description

The actual process after the material looses its function in the building context will be described. The possible end of life flows will be named as well.

§ 5.1.7.4 Data description

The main information of this part is embodied energy and embodied GWP of 1 kilogram material (reference unit). The data description contains an easy to read graph, and reveals the information EE, GWP, the density and, if existent, EE renewable of the material mass or volume related. For clarity purposes, only production processes are shown. The evaluation for each material group is explained in the text. The dark grey bars indicate the EE in primary energy non-renewable (MJ). The light grey bar indicates the primary energy renewable (MJ). The sum of both accounts can also be considered as CED. EE relates to the upper x-axes. GWP is shown by the green hash which is displayed in kg/CO_2 equivalent per 1 kilogram. GWP relates to the lower x-axis. The black stripes show the density of the material. For the readability of the graph, density is displayed divided by a factor (1,000 or 100). The evaluation of EE and GWP referring to volume use the same way of presenting. MJ and kg CO_2 eq. here refers to 1 cbm. The scale varies in order to display the differences in the material group.

Individual materials are further discussed in the following segment. For the discussion of the results, literature is consulted, in particular (Corradini, Hutter & Köhler, 1999; Kasser & Pöll, 2003; Kümmel, 2000).

§ 5.1.7.5 Summary

The findings of each paragraph are summarised in the box at the end of each material group. It answers the question of how the environmental impairment can be optimised. The content of the summary box is the basis for the material input of the strategies in chapter 10.

§ 5.2 M1 Mineral material

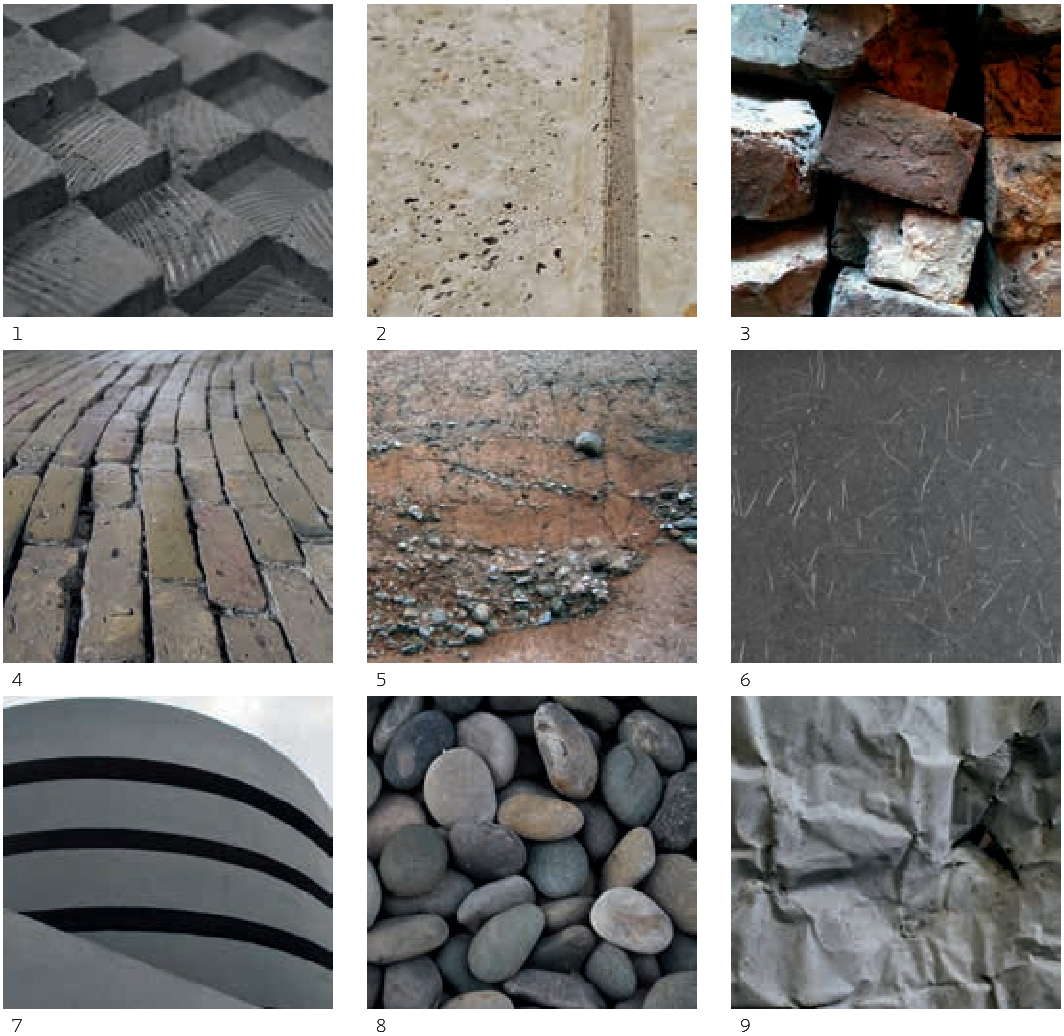


Figure 21

Illustrations: (1) concrete pixel, (2) concrete detail, (3) loose bricks), (4) bricks as floor material, (5) earth layers, (6) firbre reinforced concrete, (7) Guggenheim NYC, (8) gravel, (9) concrete shaped by a metal formwork

§ 5.2.1 Relevant data

Data for 01 mineral material		
	Ökobau.dat	EPD
Concrete	3	
Reinforced concrete	5	
Aerated concrete	3	4
Lightweight concrete		3
Mortar and plaster	7	7
Cement and aggregates	6	
Brick / Clinker	1	
Hollow brick	1	3
Limestone	3	3
Natural stone	1	

Table 17
The data source for the material evaluation of mineral material is listed here. This table will be given for each material group.

The evaluation of mineral material contains 50 materials. They are subdivided in 10 groups that are displayed in Table 17.

§ 5.2.2 Ecological description

Mineral materials are named after their (mineral) origin and are part of the inorganic materials. This classification functions as an orientation. Added materials such as reinforcement for concrete, for example, technically do not belong to this group. However, as the main material is concrete, reinforced concrete is considered part of the group of mineral materials.

In nature, mineral materials occur in stones, clay or sand, for example. After the treatment phase these materials become building material. Applications in the building context are various: load-bearing building elements, façades, interior walls, floor coverings or ceilings.

Mineral materials account for the highest share of building materials in Europe. As opposed to construction methods in North America, exterior walls and floors are built as massive systems. Thus, mineral materials can account for up to 85% of a building (Rudolphi, 2008).

Construction elements with mineral origin have a very long duration. Their high weight provides a robustness that resists weather conditions for a long period of time.

Interior and exterior surfaces are clad with plaster and render to seal them and define their outward appearance. This functional layer has a shorter life cycle depending on the material condition and changing fashion. A high level of conflation limits the disconnection of materials; hence the end of life scenarios are limited. Reusing mineral materials is rarely possible, and most mineral building elements cannot re-enter their life cycle.

§ 5.2.3 End of life scenarios

The bonding of mineral material is usually permanent and irreversible, which limits its flexibility and recyclability. Walls made from brick rarely have reuse potential. Material recycling can be conducted so that the rubble can become filler materials for roads.

Steel reinforced concrete can be separated. For this process, the metals are sorted out. Kümmel (2000) deals with the ecological dimension of recycled concrete. The figures presented here relate to his research. For recycling, concrete gravel or expanded clay is replaced with demolished concrete parts. 70% of 1cbm demolished concrete can become part of a further material cycle in a concrete product. Recycled concrete bonds 0.084 MJ/kg, gravel and sand 0.034 MJ/kg, and expanded clay 3.12 MJ/kg. Considering only the EE, the recycled content has no ecological advantage. For the comparison of recycled and primary content, transport is a relevant parameter. Recycling treatment plants can be installed on the demolition site, on the new construction site or be part of a permanent treatment plant in a factory. If the distance of the gravel is 30 km longer than for the recycled concrete, the EE is equal. Furthermore, use of recycled concrete contributes to the protection of resources and helps to minimise landfill.

Prefabricated concrete elements can be deconstructed and become part of new building if technical requirements are met.

In general, gypsum can be reused but the share of other materials has to be very low; so that high effort is required to clean the board. Landfill is less expensive and hence very common (Kasser & Pöll, 2003). Gypsum is a humidity barrier and has therefore to be sorted separately from regular construction rubble.

(Glass is depicted in Figure 23 and 24. This is shown here and not in the F6 Windows frames and glass due to the graphs reference unit. The graph in § 5.7 relates to 1 m which is impractical for glass. Thus, the ecological description for glass can be found in the later.)

§ 5.2.4 Data description

Figure 23 shows the EE, GWP and the density of 1 kg material. It includes concrete products (1-10), aerated concrete (11-17), lightweight concrete (18-20) aggregate and cement products (21-23, 27, 28), mortar and plaster (24-26, 29-38) including gypsum products, brickwork (39-43), limestone (44-49) and natural stone (50).

Mineral materials embody 0.5 to 9 MJ per kilogram and 37 to 22.737 MJ per cubic meter. Aggregates have the lowest values with 0.5 MJ/kg (gypsum stone, position 38). The maximum values for EE are bound in natural stone, position 50.

1	Insitu concrete	18	Light concrete, exterior wall, for association	35	Gypsum lime coat
2	Concrete block	19	Light concrete, interior wall, for association	36	Gypsum lime interior coat
3	Insitu concrete	20	Light concrete, partition wall, for association	37	Gypsum plaster board
4	Prefabricated concrete ceiling 20 cm	21	Expanded clay	38	Gypsum stone
5	Prefabricated concrete ceiling 40 cm	22	Pumice	39	Clinker
6	Prefabricated concrete stairs	23	Perlite	40	Hollow brick
7	Prefabricated concrete wall 12 cm	24	Mortar (Baumit)	41	Brick
8	Prefabricated concrete wall 40 cm	25	Mortar (Ökobau.dat)	42	Hollow brick, for association
9	Fibrated concrete	26	Mortar (Schwenk)	43	Hollow brick with mineral filling
10	Eternit Faserzement	27	Cement screed	44	Limestone (Xella)
11	Aerated concrete P2	28	Cement (average)	45	Limestone lintel (Xella)
12	Aerated concrete P4, reinforced	29	Basecoat mortar (Schwenk)	46	Limestone Silka Therm Kimm (Xella)
13	Aerated concrete P4	30	Finishing coat (Baumit)	47	Limestone, for association
14	Aerated concrete P2 (H+H)	31	Light mortar (Schwenk)	48	Limestone
15	Aerated concrete P4 (H+H)	32	Cement coat (Baumit)	49	Eco-Limestone
16	Aerated concrete PPW 2 (Xella)	33	Gypsum	50	Granite boards
17	Aerated concrete PPW 4 (Xella)	34	Gypsum coat	51	Glass

Figure 22
Key for fig. 23 and 24

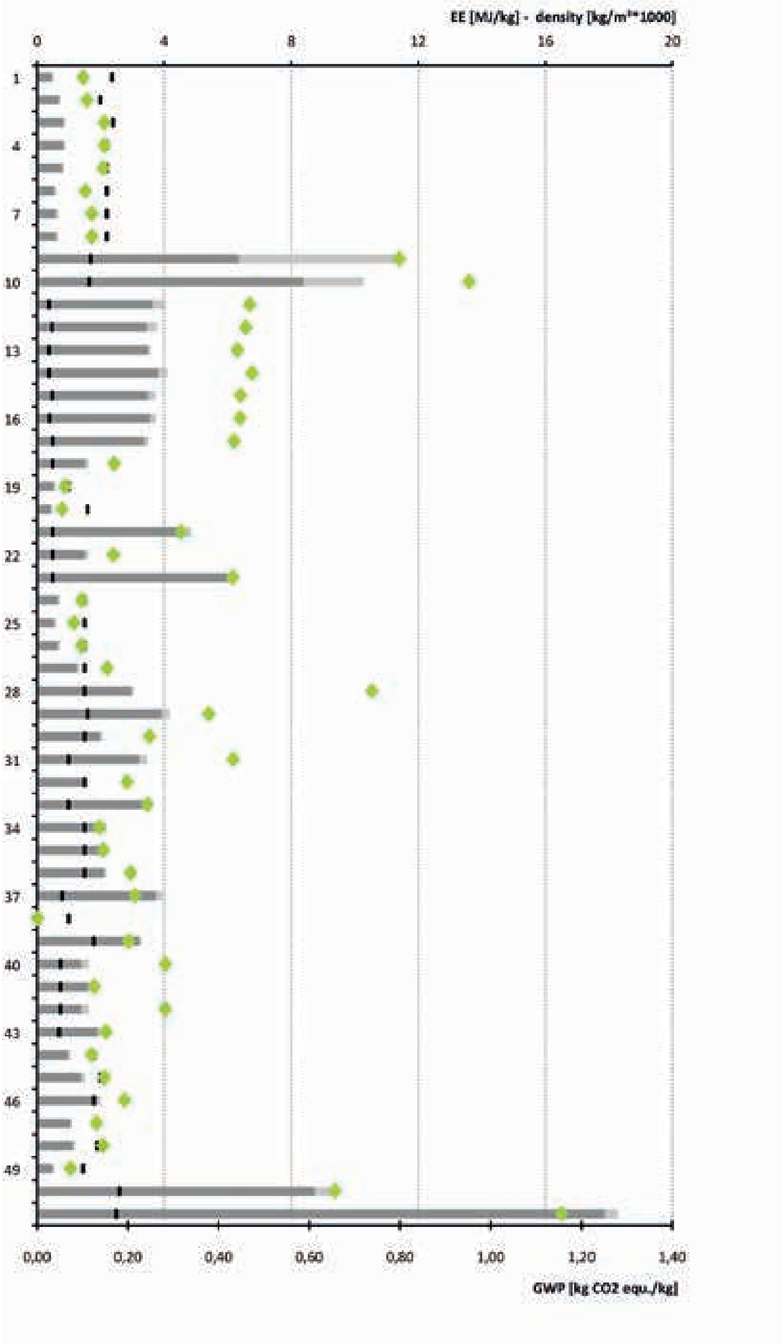


Figure 23

LCA data for 1 kg mineral material

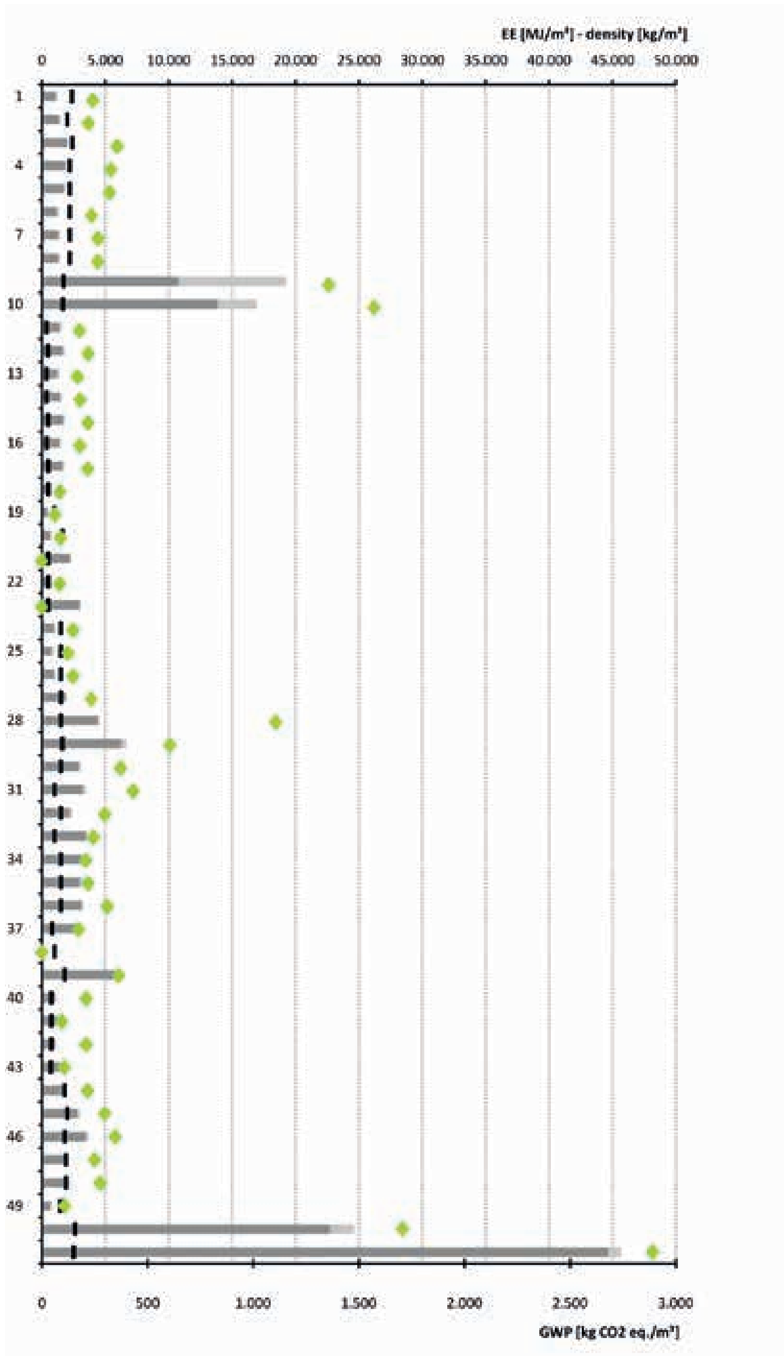


Figure 24
LCA data for 1cbm mineral material

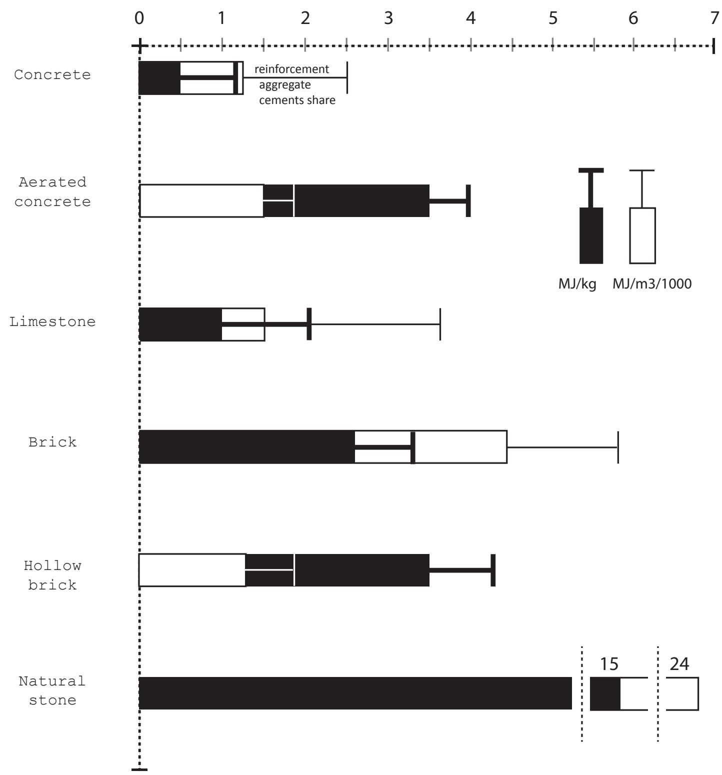


Figure 25
Mineral material evaluation overview.

In the following, cement products, sand lime stone and brickwork are explained in greater detail.

§ 5.2.4.1 Cement products

The main resources for cement production are limestone and marl. They are mined and crushed, then pre-dried at 800°C. The main burning process follows with a temperature of 1,450°C, in which the material sinters. The addition of slag sand and gypsum defines the cement type. Slag sand is a waste product from the steel industry and embodies only transportation energy. The clinker, the gypsum and the sand are ground up again and packed. The burning process is the most energy and emission intensive.

Cement products vary in their share of cement clinker, sand and gypsum. Two of the most common products are Portland cement (CEM I) and blast furnace slag cement (CEM III). The percentage for Portland cement is 95% clinker and 5% gypsum, for blast furnace slag cement it is 15-65% clinker, 35-85% sand and 5% gypsum. The indicator shown in Figure 25 displays an average value for cement. It states that cement embodies 3 MJ/kg. Corradini et al. (1999) presents a CED of cement sinter of 4.06 MJ/kg, 4.29 MJ/kg for Portland cement, and 1.70 MJ/kg for blast furnace slag cement. This difference is due to the high share of cement clinker. The cement sintering process accounts for the main share of embodied energy and emissions. Up to 75% of the Portland cement's CO_2 emissions result from this process. Products with higher cement content will have more impact on the environment than products with a higher share of aggregate.

Concrete products consist of cement and a varying share and type of aggregates. Aggregates can be distinguished in fine and rough. Fine aggregates are most commonly sand, while loose gravel is used for the rougher aggregate. This is true for normal concrete. For lightweight concrete (i.e. of a density less than 2000 kg/cbm) rough aggregates such as pumice, expanded clay or polystyrene is added. The lower the cement concentration, the lower the EE.

The reinforcement can be supplied with steel or with fibres. Steel reinforcement is the most common application. The share of steel depends on static loads and can vary from 0.8-2 vol.%. The amount of EE correlates with the steel reinforcement. The more steel is used, the higher the EE.

For aerated concrete the conventional aggregates (gypsum, sand and gravel) are supplemented by lime, anhydrite and aluminium. The aluminium powder is made from recycled aluminium and accounts for only a small share. During the hardening process pores develop and water is released, which leads to a low density of 380-600 kg/cbm. Aerated concrete embodies 3,5-4,1 MJ/kg and 1.500-1800 MJ/cbm.

§ 5.2.4.2 Sand limestone

Lime, quartz sand and water are the resources limestone is made of. The lime is degraded, burnt at temperatures of 1,000 to 1,200º C and ground into dust. It is transported to limestone factories where it is mixed with sand at a ratio of 1:12. The resulting bricks are formed and hardened at 160-220º C for 4-8 hours. Limestone embodies 0.9 – 1.9 MJ/kg and 1,790 – 3,435 MJ/cbm.

Item 49 is a special case. The product name is limestone but technically it belongs to lightweight concrete. (Ingredients according to the EPD Meier Öko-Kalksteine: 94-90% mineral aggregates (2/8) and limestone crushed sand (0/4), 4-6% natural hydraulic lime, 2-4% Portland limestone cement.

§ 5.2.4.3 Brickwork

Clay is the resource for brick. Approximately 1cbm clay is used for 1t of bricks. For the different products, aeration agents such as sawdust or ground polystyrene are added to enhance the porosity of the brick. During the burning process these agents generate holes and thereby decrease the density. In contrast to a massive brick, hollow brick has holes which can account for 50% of the horizontal surface. The clay is formed and dried for 24 hours at temperatures from 50-120º C upward. The burning process requires higher temperatures. The brick is burnt for 6 hours at 950º C. Massive bricks are burnt at even higher temperatures of around 1,110º C.

Hollow brick accounts for 1.4-1.6 MJ/kg, considering a density of 740 kg/cbm for 1,030-1,180 MJ/cbm. The aeration agents are waste products which are not allocated to the brick cycle. The higher burning temperatures for massive brick result in higher values for EE. 3.0-3.6 MJ/kg is shown for the mass based evaluation and 5,400-5,850 MJ/cbm for the evaluation per volume.

§ 5.2.4.4 Summary

- EE increases with the rising percentage of steel reinforcement.
- With cement sinter the EE increases. Blast furnace slag and aggregates cement help to decrease EE.
- EE correlates to weight. Lightweight material embodies low amounts of EE.
- For a concrete construction, recycled content offers a potential depending on the location of the site, treatment plants and the gravel pit.

§ 5.3 M2 Wood based material

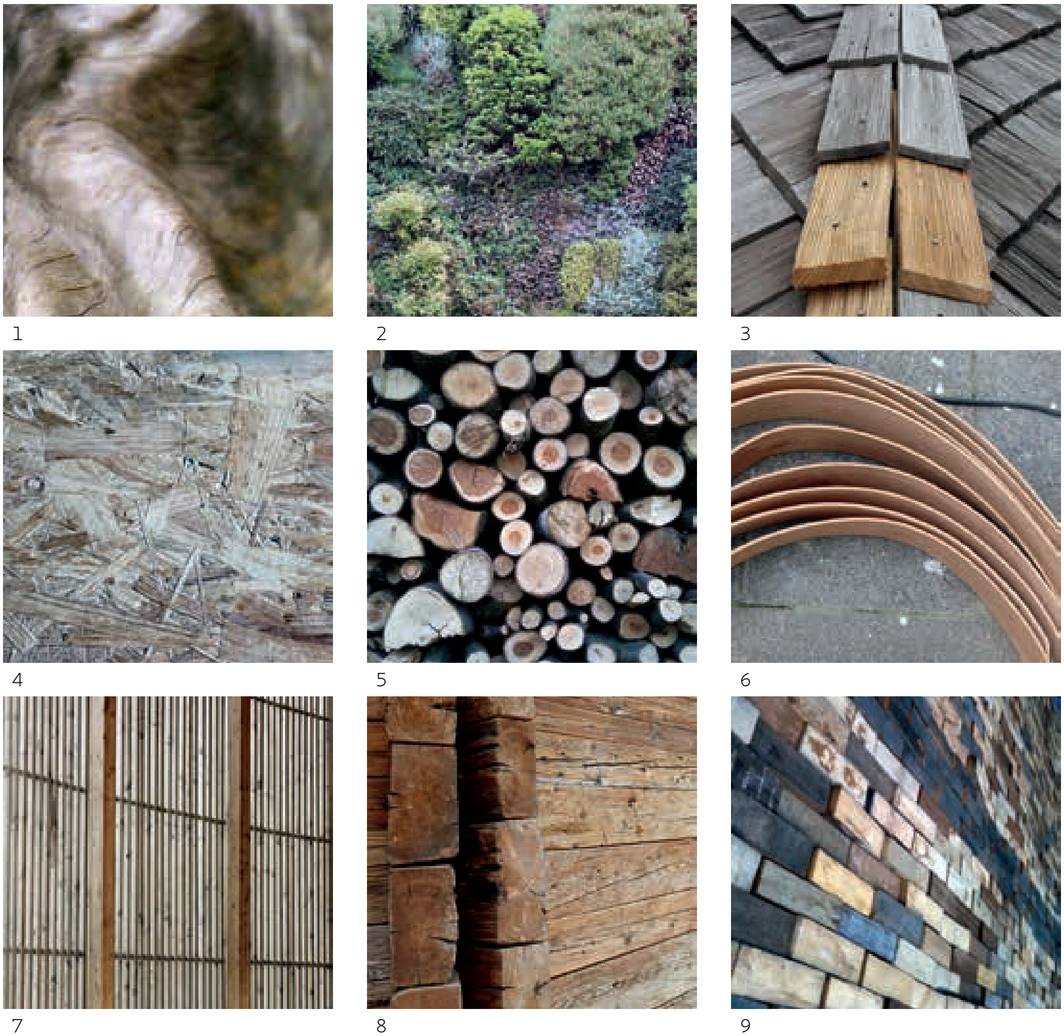


Figure 26

Illustrations: (1) wood root, (2) vertical garden, (3) old and new wood shindles, (4) OSB (5) logs (6) bended beech sheets, (7) facade of the Chapel of Reconciliation, Berlin (8) solid timber construciton, (9) timber bricks

§ 5.3.1 Relevant data

Data for M2 wood based material		
	Ökobau.dat	EPD
Boards	4	
Foils	13	
Sealing	7	
Profiles	2	
Floor covering	3	

Table 18

In the category M2 wood based material, 25 materials are evaluated. They are subdivided in massive wood products, laminated wood, wooden composites and surface according to Table 18.

§ 5.3.2 Ecological description

Impact on environmental processes is more harmful the longer time it takes nature to reproduce the withdrawn resource. Wood products are made from renewable resources. Renewability refers to the time in which nature is able to recover the loss. As defined by the German Bundesministerium für Ernaehrung, Landwirtschaft und Verbraucherschutz (Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), renewable materials are agricultural and silvicultural products that are not used for food and fodders. (Petersen, 2011)

Renewable materials in the building industry include products from wood and plants. They find application in various functions, e.g. as part of a building structure, interior and exterior surfaces and in insulation. Most renewable products in the building industry consist of wood.

Its ability to absorb and store CO_2 has a positive impact on the global greenhouse effect, as CO_2 is one of the most relevant greenhouse gases. In order to fulfil the politically defined obligation to reduce the amount of CO_2 emissions, a nation can account the national forest in its national GWP balance. Hence, forest cultivation is a global strategy to fight climate change. Carbon capture functions as a carbon sink, which helps to reduce the global greenhouse balance. (Bafu, 2009)

Renewable materials generate stability for local ecosystems and do not only have an impact on a universal but also on a direct level. For example, roots keep the soil soft and stable and, as a result, prevent erosion and flooding. Furthermore, forests are home to various animal and plant species.

The ecological quality of wood is defined by the characteristics of the forest. International certificates such as the Forest Stewardship Council FSC propose standards concerning human, ecologic and economic parameters.

The ecological footprint of a building can be influenced positively by installing renewable materials.

In photosynthesis, carbon dioxide is captured in the growing cells. The LCA method regards this period as the production phase. The binding of carbon leads to positive GWP numbers for the production phase of wood. Vast areas of Europe are covered with forests so wood is easily accessible. It only takes a few steps from harvest to the end product. Additional energy intensive processing steps such as processing at high temperatures are rarely required.

Wood captures CO_2 its growing phase and releases it when it rotts or is burnt. The longer the carbon is stored in the renewable material, the later it can function as GHG. Installing a wood product in a building as compared to letting it rot in the forest, helps extend the storage period and postpones the moment of release. See (Walz, Taverna & Stöckli, 2010).

Wood embodies energy due to the steps of fabrication necessary for the process from tree to wood product. These steps include forestation, felling and logging. Ideally, nearly zero energy and resources are used for the fabrication of a product. The consumption of renewable resources is to be favoured over non-renewable resources because nature is more capable of filling the gap the withdrawal caused.

- The use of wood for building elements has three material group specific advantages:
- The withdrawn material can be reproduced in a relatively short period of time.
- Using renewable materials prevents the consumption of fossil resources.
- The installation of wood products extends the phase of CO_2 capturing.

§ 5.3.3 End of life scenarios

When losing their function, products from renewable materials can be processed in different end of life scenarios: reuse, material and energetic recycling and landfill.

Wooden building elements with a certain size and functional condition, such as beams as part of the building structure, can be reused and installed in a new construction. Wood that has been part of wood production and does not fulfil a functional purpose is called matured wood. Matured wood is often subject to national regulation aiming at exploiting the quality of this type of wood. The regulations define a hierarchy of end of life processes and determine wood categories for specific scenarios. The most relevant differentiation for matured wood is the one into pulpwood and used wood. Pulpwood is a by-product of the wood based materials while used wood has been installed in a building. Pulpwood is a resource for derived timber products or other industries such as paper or wood chips production. Whether a matured material is approved to the specific production is regulated and depends on the grade of pollution.

When a product of matured wood has come to its end of function it can be further used for energetic recycling. The usage of matured material as a secondary resource protects primary material sources. Therefore, material recycling has priority over energetic recycling.

Burning wood at the end of life releases the formerly bound carbon. For untreated wood the carbon balance is then neutral. Based on the LCA approach, burning should be delayed as long as possible. On the other hand, the gained energy from renewable sources helps preventing the usage of fossil resources.

§ 5.3.4 Data description

Figures 27 and 28 show wood based products regarding their EE and GWP subdivided in the groups: massive wood products (1-7), laminated wood (8-12), chipboards (13-23) and floor surface (24-25). Wood based products embody 5- 21 MJ/kg and 2,700-27,800 MJ/cbm. Primary energy renewable is even higher; values vary from 8 MJ/kg (item 23 cement board) to 53 MJ/kg.

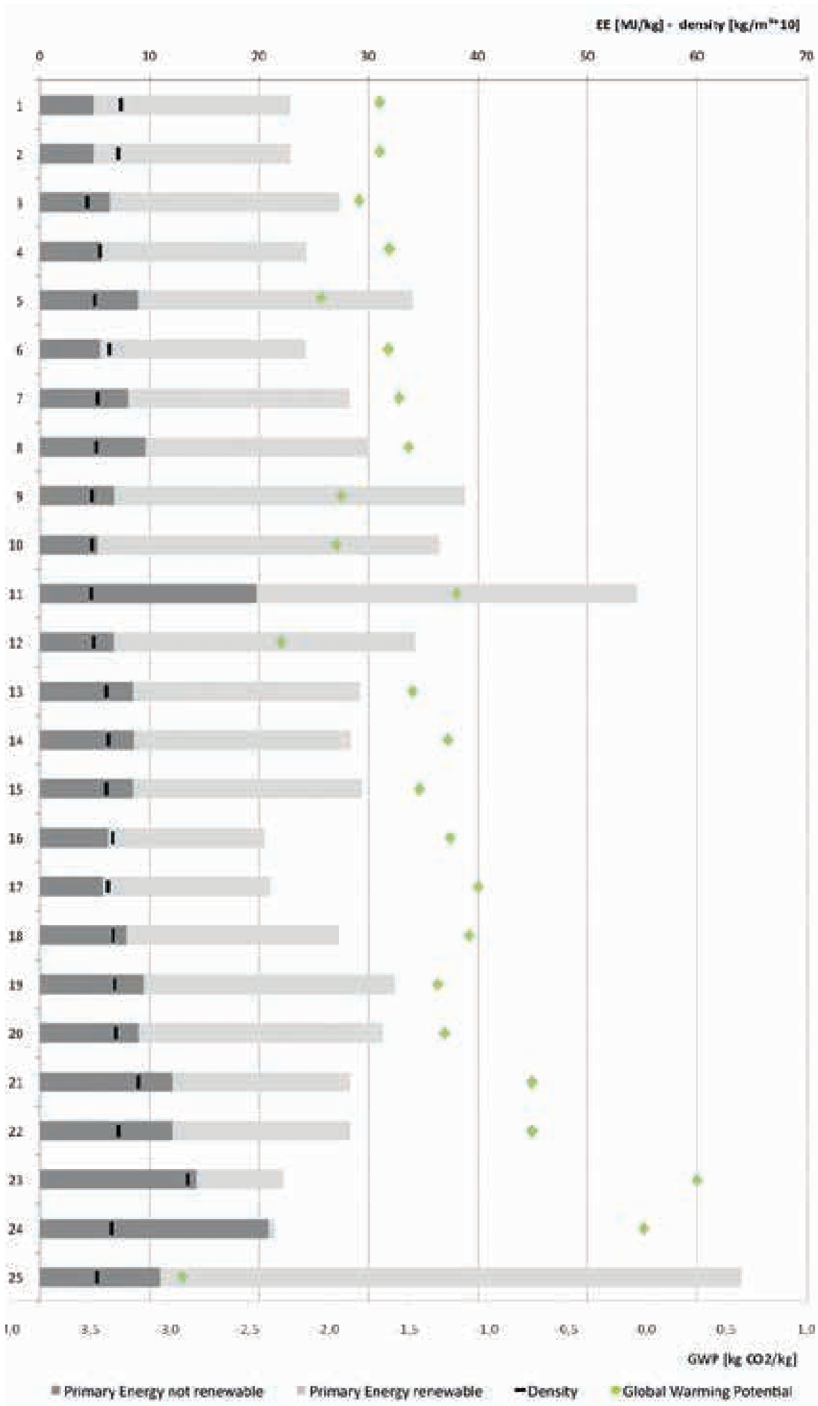


Figure 27

LCA data for 1 kg wood based material

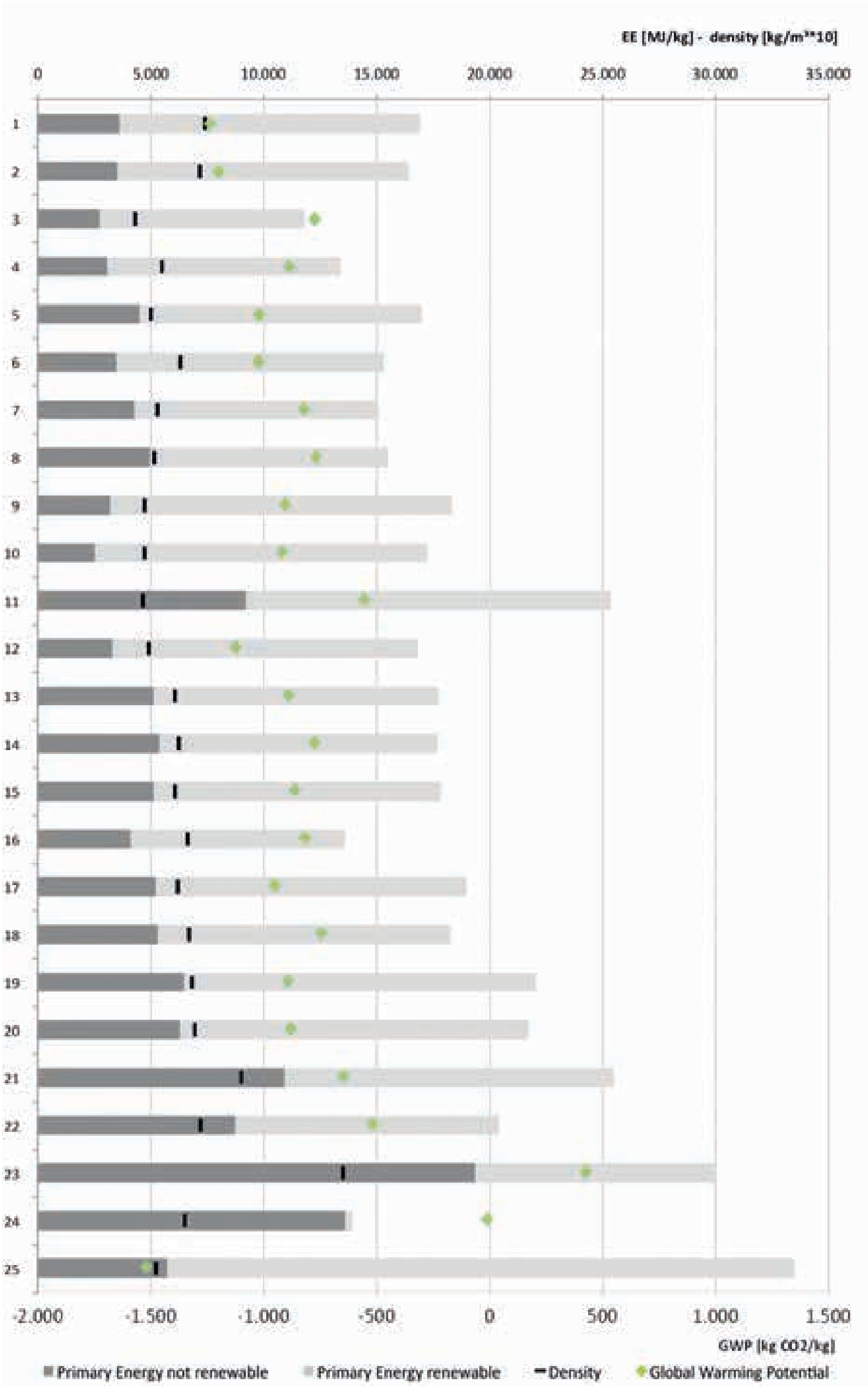


Figure 28

LCA data for 1 cbm wood based material

1	Sawn beech	10	Five layer laminated wood	19	Plywood board
2	Sawn oak tree	11	Laminated veneer lumber	20	Plywood board (Pfleiderer)
3	Sawn spruce wood	12	Plywood board	21	High density fibreboard HDF (EGGER)
4	Sawn pine	13	Oriented straw board (Agepan/Greenline)	22	Medium density fibreboard (EGGER)
5	Sawn larch	14	Oriented straw board (Kronoply)	23	Wood cement board (Eternit)
6	Sawn cedar wood	15	Oriented straw board (Agepan)	24	Multilayer hardwood flooring
7	KVH conifer wood (spruce, fir, pine, larch)	16	Oriented straw board (average)	25	Block parquet
8	Laminated beam pine wood	17	Oriented straw board		
9	Three layer laminated wood	18	Plywood board (EUROSPAN)		

Figure 29
Key for fig. 27 and 28

§ 5.3.4.1 Solid wood products

Solid wood products include products from beech, oak tree, spruce wood, pine, larch and cedar wood. The production contains the tree's growing period including the arboriculture, the harvesting, transport and the sawing. The average distance form forest to factory was 70km in Germany in 1997. (Wegener, 1997) Kolb, (2013a) presents these numbers to be true for today. According to that, 50km account for 1.2% and 300km for 7% of the total energy. Most of the energy is required to regulate the level of moisture. After the sawing, wood contains up to 200% water which is sometimes dealt with by air drying or processing in drying plants. Drying plants apply 100 C° hot air in closed chambers.

The energy amount used for this process is linked to the material's density. The density of deciduous wood is higher than that of coniferous wood. Thus, coniferous wood requires less energy to be dried. For the drying process waste wood is used for heat generation (Corradini et al., 1999). This results in high values for the primary energy renewable. Accounting for both renewable and non-renewable energy, solid wood products range between 23-27 kg/kg/MJ. Only the non-renewable energy states EE 5-7 MJ/kg.

§ 5.3.4.2 Wood fibre boards

The production of sawn wood creates small pieces and shavings as by-products. These are used for wooden fibre boards. Depending on the size of the wood pieces, different products can be made. For the production of OSB, the shavings have to have a length of 75mm. Chipboards require smaller pieces of 1.3 -1.8mm. MDF boards use lengths of 0.036-1mm. These small wood parts are gathered and bound into wooden composites by resins. The boards are formed under pressure either with synthetic or natural adhesives. OSB's are bound with 2-10% resin. Chipboards need 5-10% resin and MDF 12% (Kolb, 2013b). Synthetic adhesives are more robust than natural products and are most commonly used. The synthetic adhesives or resins are plastic based which bind higher amounts of EE compared to natural products because more processing steps are required.

The process of the wood shavings production and the resin determine the amount of EE. The drying process and the application of pressure consume the highest share of energy. OSB bind 6-8 MJ/kg, chipboards 8-10 MJ/kg and fibre boards 12 MJ/ kg. The cement bound fibre board binds the highest amount of EE due to the cement share.

§ 5.3.5 Summary

- EE rises with treatment. Solid wood products bind the least, laminated products a little more, and wood fibre products the highest amount of EE.
- Finer wood fibre boards require more EE than rougher.
- The longer wood is part of a building, the longer it keeps the carbon from being released.
- At the end of life of a wood product energy can be harvested which has a positive impact on its EE.

§ 5.4 M3 Metals

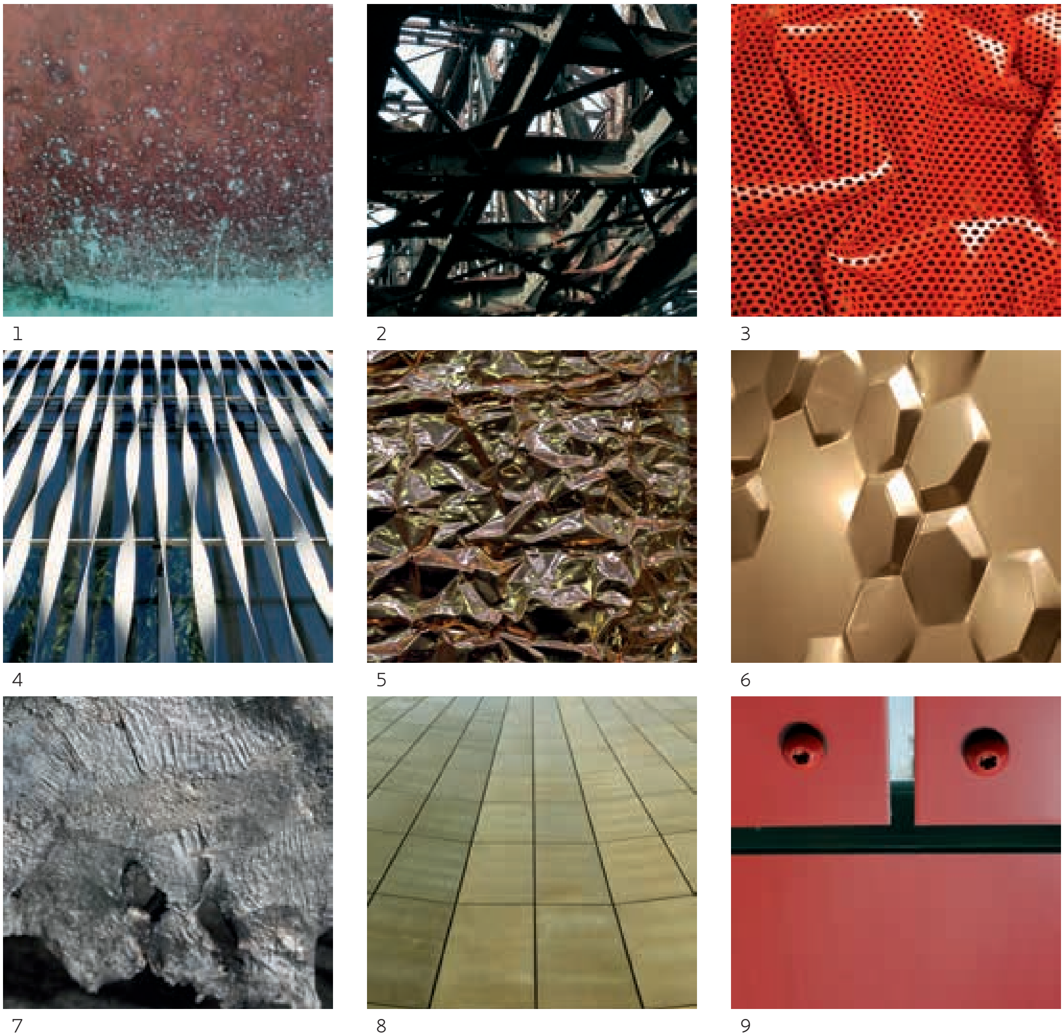


Figure 30

Illustrations: (1) copper facade, (2) steel bridge, (3) couated, perforated metal sheet,(4) twisted metal as sunshading device (5) creased metal sheet (6) shapes applied on a steel sheet, coated (7) melted aluminium (8) metal facade of the Axel Springer Haus, Berlin, (9) Alucobond detail

§ 5.4.1 Relevant data

20 materials are evaluated in the group Cbm Metals. They are subdivided in steel products, aluminium products, copper products, and other.

Data for Cbm metal		
	Ökobau.dat	EPD
Steel products	7	
Aluminium products	4	
Copper products	1	5
Other	2	1

Table 19

§ 5.4.2 Ecological description

Metals occur in the earth crust as raw material and can be harvested from different depths. Depending on the material, the production chains involve a series of steps to convert stone into metals. Metals belong to the hardest products in the building industry and are able to carry heavy loads. They have a very high density and are malleable at the same time. Metals are generally quite resistant and have a long life span. For these reasons metals find their application in skyscrapers and huge halls. The most commonly used metals in the building industry are steel and aluminium. Steel and, more commonly, aluminium are used for façades. Steel frameworks are mostly used for interior walls.

§ 5.4.3 End of life scenarios

Metals have the highest potential to become part of the same functional unit compared to the other material groups. Theoretically, metals can be recycled over and over again without a high loss of quality. The material cycle includes the phases production (installation, repair), demolition or collection, sorting, treatment and production. For a well-functioning cycle. the gaps between the different phases need to be bridged.

The demolition process is well established due to the secondmetals' price. For example, a concrete ceiling is fractured by a bulldozer and the steel reinforcement is quarried out. The remaining concrete bits are either separated on site or in a treatment plant.

The collection of metals from façades requires decommissioning and separating glass and plastics. The glass is destroyed on site. The plastics are either separated by hand or burnt in a melting process. A study by Delft University examined the total aluminium weight in buildings and found that the sum accounts for less than 1% of the total weight, but the collection rate is 92-98%. This material amount can be ablated and used for recycling processes (Boin, 2004).

The sorting process organises different metal products for further treatment. The material needs to be of single origin in order to generate a high level of material purity. Leaving materials mixed would result in lower quality. This is of particular importance in aluminium façades, as many small parts are made from steel or zinc. These need to be cut off in order to guarantee the single origin. The coating (which is also a material mix) is a lesser problem as most of these materials are isolated in the melting process.

The chemical composition is another relevant parameter; especially for aluminium recycling. In most cases, installation and demolition of a façade are separated by decades. The product information is no longer available, and examinations into the composition lower the profit.

Considering the end of life changes the overall EE assessment. The end of life of steel products is accounted for with -14 to – 6 MJ/kg depending on the steel product. Hence, including the end of life helps to reduce the overall EE for steel by half.

Accounting the end of life for aluminium has an even higher impact; 99MJ/kg can be accounted for an aluminium sheet, which reduces the overall result to two thirds.

§ 5.4.4 Data description

Figures 31 and 32 show EE for metals, subdivided in the groups: steel (1-7), aluminium (8-11), copper (14-19), a brass profile (12), a lead sheet (13), and titanium zinc (20).

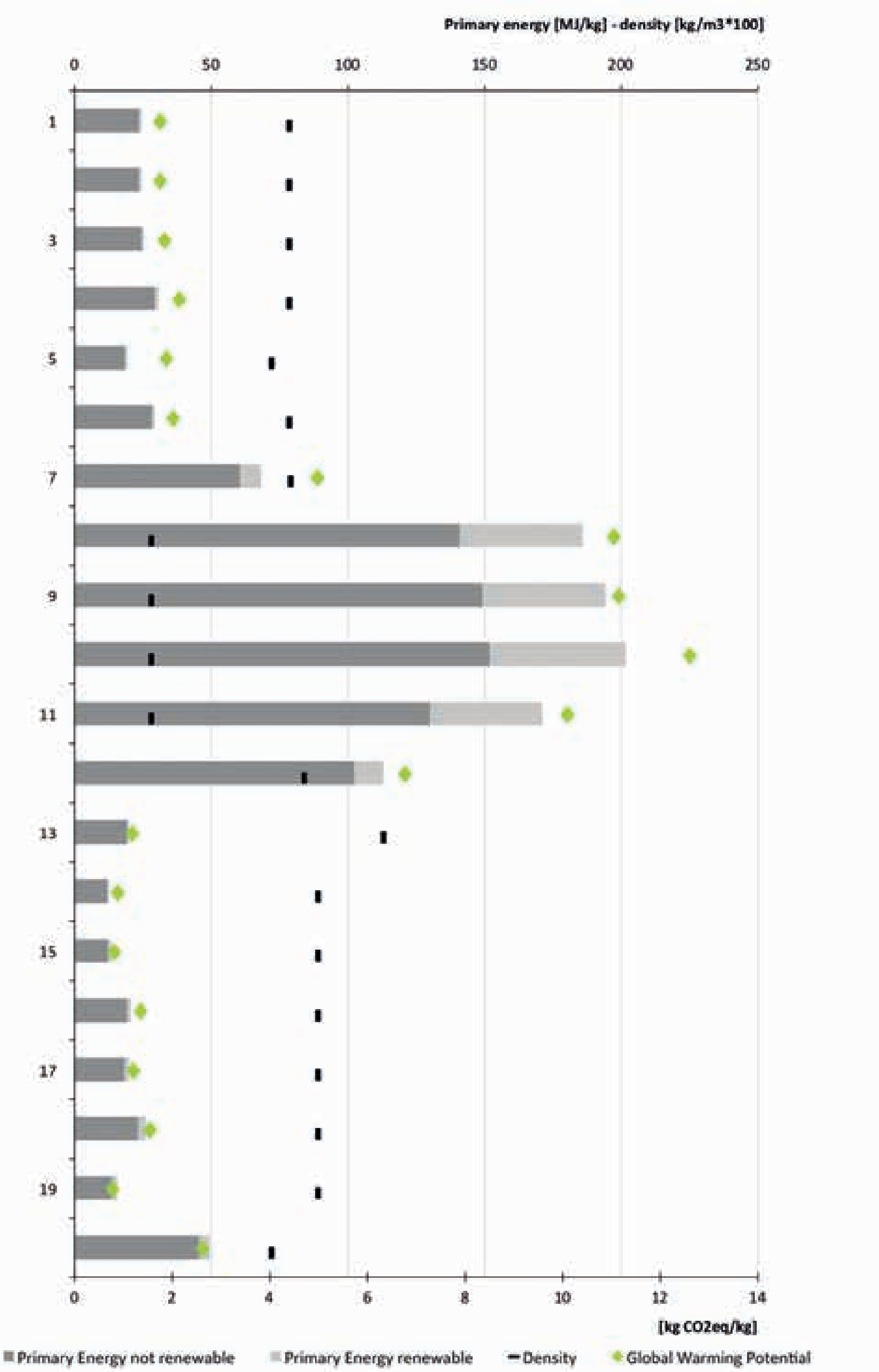


Figure 31
LCA data for 1 kg metal

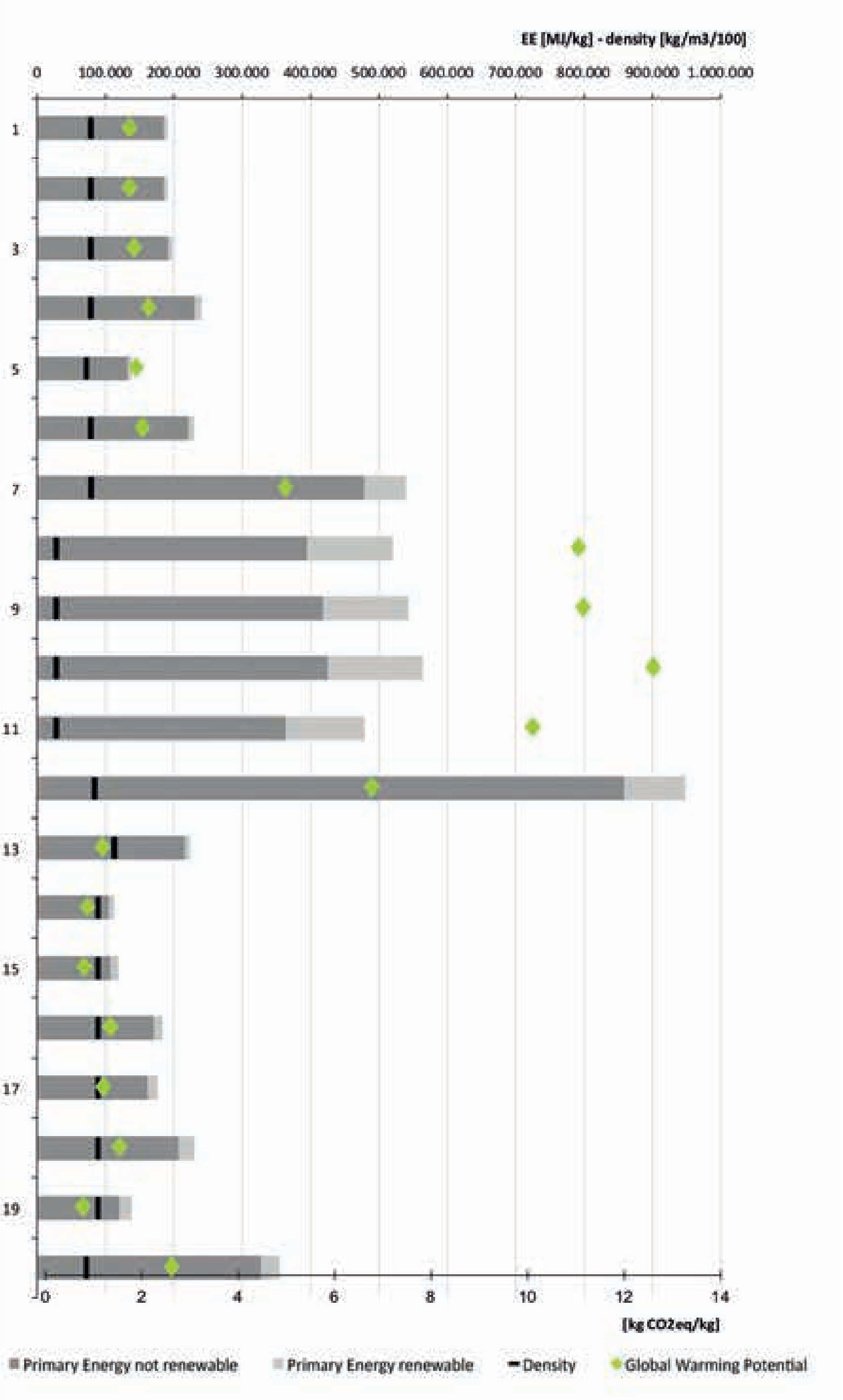


Figure 32

LCA data for 1 cbm metal

1	Steel hot rolled profile (I/U/T/H/L)	8	Aluminium sheet	15	Copper reel-Classic (TECU)
2	Steel hot rolled sheets (2-20mm)	9	Aluminium casting	16	Copper oxide (TECU)
3	Steel thin sheet (0,3-3,0mm)	10	Aluminium sheet	17	Copper Patina (TECU)
4	Steel thin sheets (20µm zinc-coated)	11	Aluminium extrusions profile	18	Copper Gold (TECU)
5	Gray iron	12	Brass profile	19	Copper Bronze (TECU)
6	Wrought iron steel	13	Lead sheet	20	Titanium zinc sheet
7	Stainless steel	14	Copper sheet		

Figure 33
Key for fig. 31 and 32

The values vary from 14 MJ/kg for copper (bronze) to 149 kg/MJ for aluminium casting. The volume assessment identifies the copper sheet (14) to embody the smallest amount of EE with 105,000 MJ/cbm. The brass profile binds the highest amount (12) with 859,000 MJ/cbm due to its high density (8,400 kg/cbm).

Both graphs look similar. Steel products vary from 20-30 MJ/kg and 180,000-220,000 MJ/cbm; only the stainless steel is higher: 61 MJ/kg and 479,000 MJ/cbm.

Aluminium marks the highest points in both graphs. 130-150 MJ/kg and 390,000-420,000MJ/kg are shown here for production.

Copper's values are close to those of steel. The variety starts at 12 MJ/kg and 100.000 MJ/cbm and ends with 25 MJ/kg and 210.000 MJ/cbm.

§ 5.4.4.1 Steel

Iron ore is the resource for iron. Alloys made from iron with a carbon share of 0.01-2.06% are called steel. After the iron ore is mined, it is separated from non-iron containing rocks on-site. The iron ore is crushed and divided according to size. For the smallest parts, binding agents are added and, under heat, the iron ore is processed into pellets. The energy used in this process results in a CED twice as high compared to ore in pieces. (According to (Corradini, et al., 1999) pellets bind 2.468 MJ/t and ore in pieces binds 1.044 MJ/t.)

The iron ore is transported to the blast furnace where it is converted into pig iron. Coke is filled in the blast furnace to generate heat and reduce the carbon content. This process releases high amounts of carbon dioxide and is the biggest factor impacting the EE.

Raw steel can be produced by two ways of treatment. In oxygen steelworks oxygen is blown onto the iron from either the top (LD process), the bottom or both. The electric arc furnace uses electricity to melt metal scrap to produce raw steel. The conversion in the electric arc consumes less than the half of the energy in the oxygen steelwork. Most commonly, raw steel is produced from primary materials in the LD process. The share of this is 70% according to (Worldsteel, 2010).

Less than two thirds of the energy required to produce the finished product. Further treatment, such as coating and shaping into profiles binds roughly the remaining third.

§ 5.4.4.2 Aluminium

Bauxite is the natural resource for aluminium. It is harvested and converted into alumina. The purification of the pure aluminium is an electrical process, in which the actual temperature of 2050° C of the metal with the addition of cryolite is lowered to 950° C with the addition of cryolite. The pure aluminium gathers at the bottom of the pool and is transported out. Electrolysis requires a high amount of electrical energy, which is bound in the product. The use of electricity includes the conversion loss from primary resource to the final product electricity. This influences the EE fundamentally.

Aluminium binds approximately 150 MJ for the production of 1 kg. This applies to the production from primary commodities. The expenditure is drastically reduced when secondary material (building elements that have been part of a building and lost their functional context) can be used. The alumina and fused-salt electrolysis are omitted because the product is already of pure aluminium. This is reflected in EE values. 1kg secondary aluminium binds 16 MJ (BIR, 2010). (Values for secondary aluminium do not occur on the graph due to the recycled content approach § 3.1.2.2)

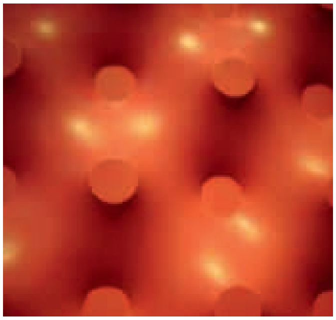
Most façade builders recycle the aluminium scrap that occurs during the production. (New scrap recycling or pre-consumer recycling.)

Recycling material that has been part of a building before is fraught with more obstacles. Aluminium façades were installed in the 1980s and later. Demolition and subsequent recycling processes are yet to come. Some façades are repaired and remain in the building which results in limited harvesting possibilities.

The façades that are exchanged and constitute a secondary resource often do not deliver information about the specific material composition. The use of these requires investigation, thus limiting the profit.

§ 5.4.5 Summary

- The long duration of metals allows for several usage cycles.
- The purity of variety influences the end of life scenario.
- Secondary material can have the same physical capabilities with only a fraction of the EE for the product from primary resources.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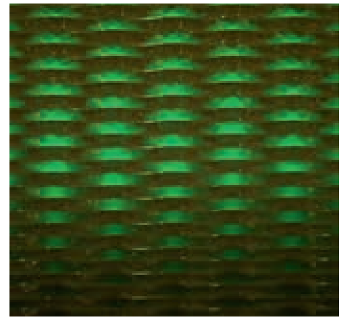
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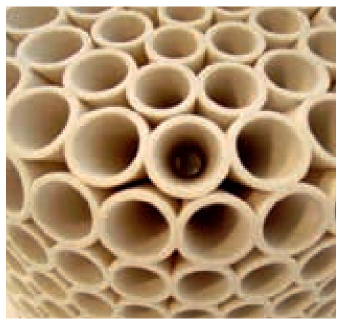
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Figure 34
Illustrations: (1) stiff plastic board, piece of scenery (2) old bike inner tubes, (3) colour changing board, (4)latransluscent textil (5) 3D printed sculpture (6) plastic bottle waste, (7) rubber ceiling (8) secondary skin, Unilever Tower, Hamburg, (9) foil facade for a temporary pavillon

§ 5.5.1 Relevant data

The evaluation in M4 Plastics includes 29 materials. They are subdivided by their function in the five groups: boards, foils, profiles, sealing and floor covering.

Data for M4 Plastics		
	Ökobau.dat	EPD
Boards	4	
Foils	13	
Sealing	7	
Profiles	2	
Floor covering	3	

Table 20

§ 5.5.2 Ecological description

Synthetics are the youngest material group in the building industry. As early as 350 years before the beginning of industrialisation Columbus watched Indians playing with an elastic ball. The indigenous people of South America recognised very early, how to use caoutchouc from rubber trees to produce balls, shoes or tanks. Only in the late 18th century natural rubber was introduced in Europe. Its water repellent properties contributed to its popularity. Heating natural rubber gives it a mechanically stability which is called vulcanisation or polymerisation. This is the chain development of short fibred chemical elements. The length of the chain defines the material's qualities. Strength increases with length. In the early 20th century the synthetic production of rubber was developed based on oil. They are named polymers according to their chemical composition. According to their chemical production, polymers can be subdivided into the three groups polymerisates, poly adduct and polycondensate.

For all of these products oil is the raw material. The next process includes the steamcracker, which prepares the material for the polymerisation. The synthetic is now granulate and can be processed into various products. Table 15 shows the different treatments, material groups and respective products.

Polyethylene (PE) is the most frequently used thermoplastic in Germany, followed by polyvinyl chloride (PVC) and polypropylene (PP).

Polymers			
	Poly adduct	Polycondensate	Polymerizates
Group	Duroplastic	Elastomer	Thermoplastic
Product	PUR, EP	Silikone, PUR	PE, PVC, PS, PMMA

Table 21
Polymers can be distinguished in Poly adduct, Polycondensate and Polymerizates. Only if they are not mixed they can be recycled.

§ 5.5.3 End of life scenarios

Plastics can be divided in elastomer, thermoplastics and duroplastics. While duroplastics are more durable, thermoplastics can be heated and mixed with other materials or separated from them. Duroplastics, on the other hand, can only be repurposed with a lot of energy input. In most cases these products will get burnt. Thermoplastics can be recycled much easier. Mixing of both materials results in a degradation of the material.

For the recycling of plastics, often products with different origin are mixed. Colour is hard to influence. The only homogeneous colour available is black. Products with 100% recycled material can be produced having a 1.5 to 15 mm thickness with the same physical properties as primary products.

Purity of variety is decisive for the end of life scenario. Unlike metals, plastics are harder to identify and therefore the sorting process is more challenging. If the material is sorted according to its group, the recycling rate is very high.

Incorporating the end of life into the holistic energy assessment can have positive effects on synthetic materials if they are kept pure. Burning them can add to its performance.

§ 5.5.4 Data description

Figures 35 and 36 show synthetic materials subdivided into the groups: boards (1-4), foils (5-17), sealing (18-25), profiles (26) and floor covering (27-29). Synthetic materials range from 30 to 150 MJ/kg. Linoleum embodies the lowest amounts while the more transparent materials embody the highest amounts. These values are comparable with values for primary aluminium. The volume based evaluation displays a range of 7,000 – 186,250 MJ/cbm.

The building industry has use for diverse plastic products. The most common ones are:

- PE and PA foils
- PVC window frames
- Synthetic insulation: EPS, PS, PU
- EPDM, silicone sealings
- PA insulation bar
- ABS in internal glass gap

PE foil is introduced in the following abstract. PVC window frames are explained in 5.6.

§ 5.5.4.1 Polyethylene foil

PE products can be differentiated according to their density in low density PE (LDPE), linear low density PE (LLDPE) and high density PE (HDPE). The density defines the physical properties; strength and temperature resistance grow with increasing mass per volume. LDPE and LLDPE are used for foils and HDPE is most commonly used for profiles, injection mould profiles and pipes.

Most commonly, gasoline is the raw material for polyethylene. This is filled in the steam cracker, which applies high temperatures and steam, and generates ethylene and propylene. The process in the steam cracker is responsible for the majority of bound energy. Subsequently the ethylene needs to be polymerised. This can be accomplished with different methods of treatment and relates to the future application. Either temperature and pressure are applied or a solvent is added. The polyethylene is available as granulate. For PE foils, the granulate is filled into an extruder which delivers semi-liquid PE in tube -like form. It can then be shaped into the desired foil thickness by applying air pressure.

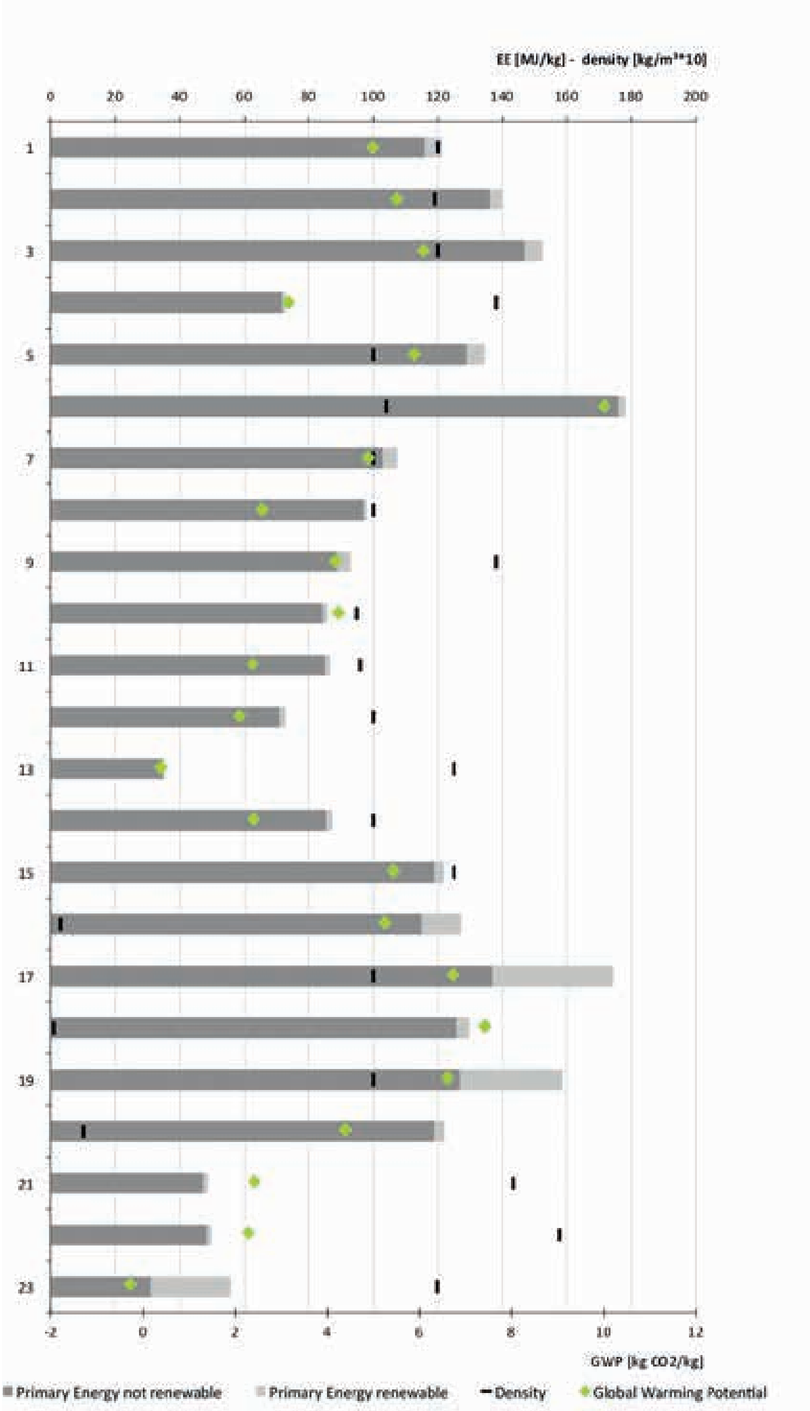


Figure 35

LCA data for 1 kg synthetic

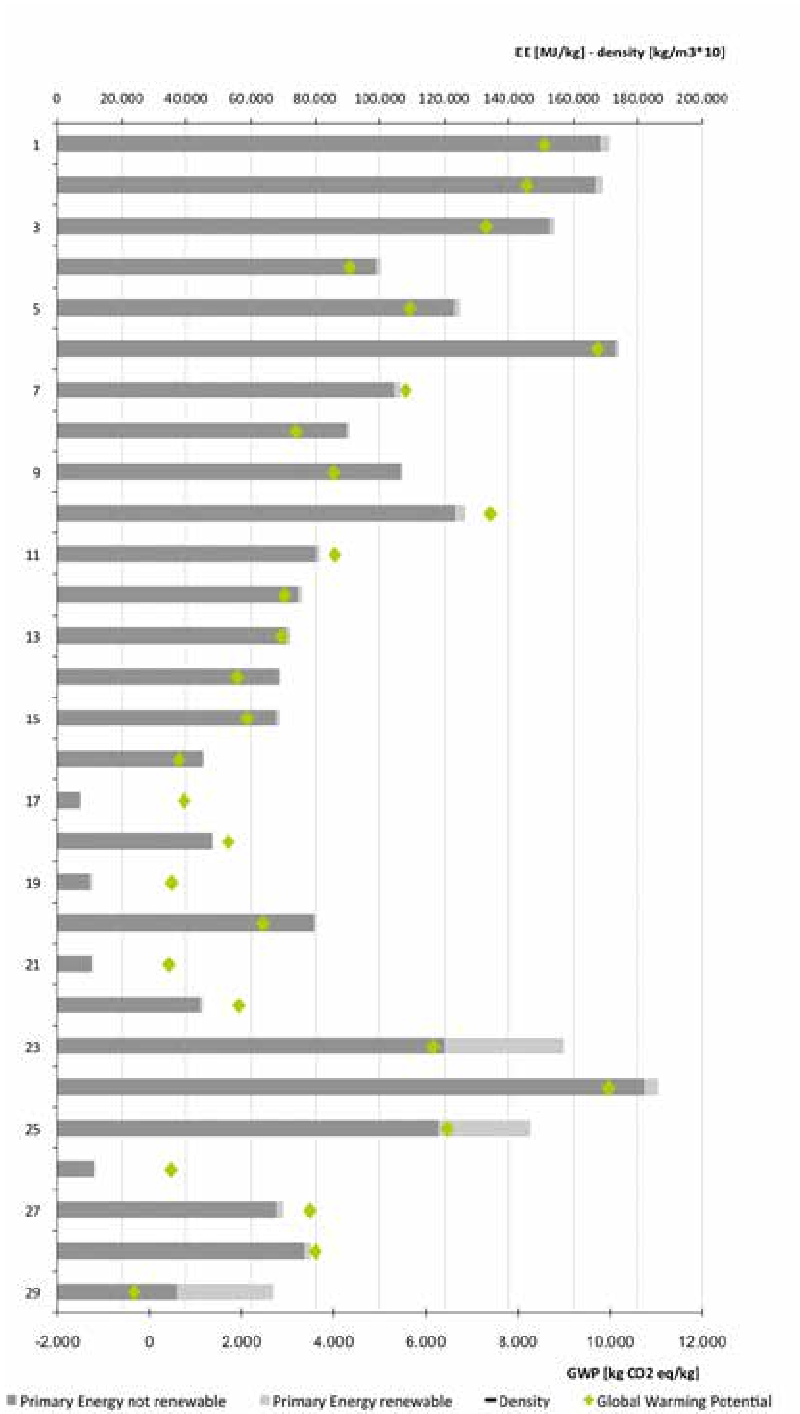


Figure 36

LCA data for 1 cbm metal

1	Transparent board PC	11	Sarking membrane PE (fibre reinforced)	21	Acrylate sealing agent
2	Transparent board PMMA	12	Sarking membrane	22	PVC-plastisol-sealing agent
3	Transparent board PMMA	13	Vapour barrier green roof	23	Silikon sealing agent
4	Transparent board PVC	14	Vapour barrier (PE HD)	24	melamin resin foam
5	Vapour barrier PET	15	Vapour barrier	25	Plasitc profile silicone
6	Vapour barrier PA	16	Bituminous sheeting	26	EPDM extrusion profile
7	Sarking membrane (PUR on PET-fleece)	17	Glass fibre fleece	27	PVC heterogeneous
8	Roof membrane EVA	18	Styrene butadiene rubber (SBR)	28	PCV homogeneous
9	Elastomer roof membrane	19	PUR sealing agent	29	Linoleum
10	Roof membrande PVC	20	Sealing agent PE with PP fibres		

Figure 37
Key for fig. 35 and 36

§ 5.5.5 Summary

- The production chain from raw material to product contains many steps which lead to quite high EE values.
- Thermoplastics can be recycled more easily than duroplastics.
- Material mix corrupts recyclability.

§ 5.6 F5 insulation material

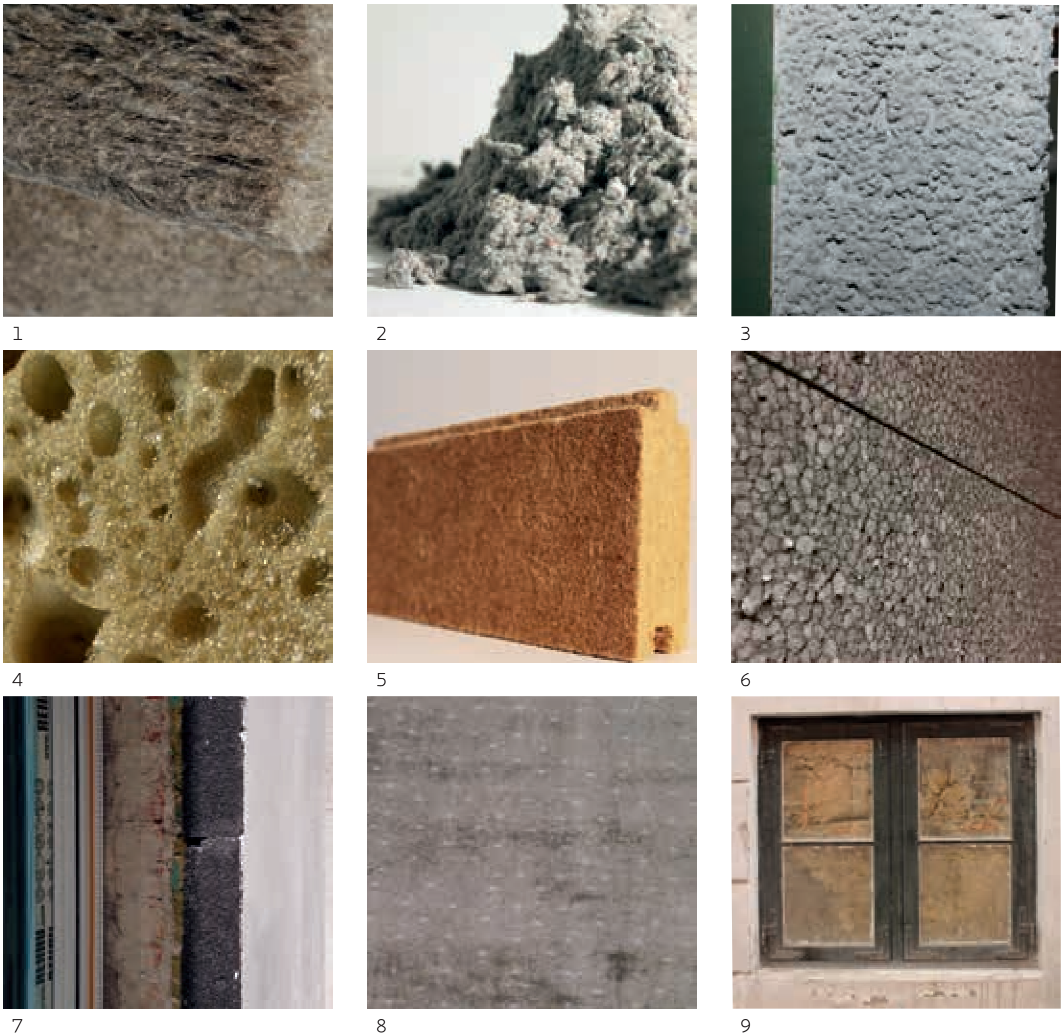


Figure 38

Illustrations: (1) wood fibre insulation, (2) celluloses, (3) EIFS, (4) mineral wool (5) high densitiy wood fibre board (6) EPS (7) wall layers with window frame (8) EIFS with humidity damage, (9) insulation behind a window

§ 5.6.1 Relevant data

The evaluation in F5 Insulation material includes 33 materials. They are subdivided by their material origin in the seven groups: wood fibre boards, foam glass and perlite, mineral wool, aerated concrete, cellulose, other organic insulation and synthetic insulation.

Data for 05 Insulation material		
	Ökobau.dat	EPD
Wood fibre boards	3	3
Foam glass, perlite	2	2
Mineral wool	5	1
Aerated concrete	2	
Cellulose	2	
Other organic insulation	4	
Synthetic insulation	6	

Table 22

§ 5.6.2 Ecological description

If a material's thermal transmission is less than 0.1 W/(mK), it is considered an insulation material. A variety of products is available with mineral wool and expanded polystyrene (EPS) being the most common ones. These are followed by extruded polystyrene (XPS) and poly urethane (PUR). In the last decades, alternative products were introduced. Wood fibre boards or cellulose are relatively young materials.

Insulation materials can be divided by their material origin. The two main groups are mineral and synthetic products. Mineral insulation materials contain rock and glass wools. Technically, aerated concrete and foam glass belong to this group, too. Synthetic products include all oil-based insulation. The third group contains organic materials. Wood fibre boards, cellulose and other organic insulation materials are included here.

§ 5.6.3 End of life scenarios

The end of life scenario for insulation product depends on the following parameters:

- Material group
- Time of installation
- Level of connectivity in the building context

The three parameters interact and determine if an insulation material can become part of a further material cycle. Insulation material is hardly ever reused. The material would still have to be fully functional (no damage caused by use phase or demolition, no humidity) and be installed loosely in order to enable a scenario for reuse.

Considering the three material groups for insulation material (introduced in the previous abstract) individually, some general findings can be stated.

Generally, mineral wool is deposited as landfill. Theoretically, rock wool can be treated and included in a new life cycle but in practise this is more of an exception. (Institut für Bau und Umwelt, 2012). Mineral wool from the early 1970s might contain arcinogenic content and has to be treated with special care. An identified, demounted product has to be stored in hazardous waste landfills.

Synthetic insulation material embodies a relevant energetic potential for incineration. The same is true for organic insulation material. The energetic value varies according to the specific calorific value. Each insulation material individually embodies potential for energetic or material recycling.

The level of connectivity has a significant impact on the end of life scenario. Insulation material is mostly installed on the exterior. Hence, the type of façade influences the level of connectivity. In a ventilated façade, the weather barrier is installed at a distance in order to enable the ventilation. The level of connectivity is low. An Exterior Insulation Façade System (EIFS) uses adhesives to attach the layers to each other, which results in a high level of connectivity. The usage phase requires this strong interconnection of materials because with non-compliance weaknesses occur, like. damages through humidity or decreased fire safety. With today’s technology EIFS has only one possible end of life scenario; it is deposited in a hazardous waste landfill.

§ 5.6.4 Data description

Figure 39 and 40 show the insulation material subdivided into wood fibre boards (1-6), foam glass and perlite (7-10), mineral wool (11-17), aerated concrete (18-19), cellulose (20-21), other organic insulation (22-25) and synthetic insulation (26-33). Their EE varies for mass from 0.1 MJ for aerated concrete granulate to 109 MJ for caoutchouc. The extreme value for mass and volume are the same. The smallest value for volume based evaluation is 39.9 MJ/cbm, the highest is 5,995 MJ/cbm.

§ 5.6.4.1 Woodfibre insulation

The raw material for wood fibre insulation is mostly pine wood. Wood fibre insulation products have a minimum wood share of 85%. Residual timber and small waste wood particles are chopped to a homogeneous size. Adding water softens the wood chips and prepares them for defibration. Grinding disks rotate while applying pressure. Subsequent process steps include either wet or dry treatment. For the wet treatment water is added to support the wood's own adhesion. The lignin does not provide enough binding capacity so that very hard external adhesives like resins have to be added. For the alternative treatment the viscous mass is dried and adhesives such as PUR resin are added. The board form is made by pouring the mass into a mould and applying pressure and heat. Mineral wool is the generic term for insulation material from stone and glass fibre. Basalt, diabas and concrete form stones are resources for stone wool. They are harvested from surface mines. The stones are transported to the furnace and melted at 1600°C. The stones liquefy and the fibres can be harvested by rotating rolls. Water with phenol-urea-formaldehyde resin is added in order to quickly cool down the fibres. They immediately stiffen and become water repellent through the oil mixed into the mass. The fibre mass is backed in the oven until the specific density is reached.

In contrast to stone wool, glass wool has many ingredients. The two main resources are sand and used glass. This share can account for up to 70%, presuming the used glass is collected as mono material. According to Corradini et al. (1999) this is a theoretical number. A share of 30% used glass is more common. The materials are gathered and heated, followed by a fibre generating process. Depending on the product, the stiffening process usually works similar to that of stone wool. The resources used for glass wool are more energy intensive compared to stone wool. This is reflected in the EE evaluation. Items 13 and 14 show glass wool; slightly higher than 15, 16, 17 which represent rock wool products.

§ 5.6.4.2 Synthetic insulation material

Synthetic insulation material includes similar process steps to the ones described in 5.4 for plastics. Polyurethane and expanded polystyrene are the most common synthetic insulation materials.

Polyurethane is produced by polyadditon and is part of the group of duroplastics. Two oil based liquids are combined with leavenings. They foam up and generate a volume that is fed into the mould for the cooling process. It can be produced to become soft or hard foam. For insulation material only hard foams are used. The generation of the ingredients consumes the highest amount of energy and results in EE values of 101-103 MJ/kg and more. This is the highest value for this material group.

The basic production process for expanded polystyrene works similar. Ethylene is basic material and a leavening (pentane) is added to expand the material. The EE evaluation shows 83-85 MJ/kg.

PU and EPS boards can be reused if they are undamaged. The industrial association of polyurethane rigid foam suggests to uses these for refurbishment, e.g. in ceiling of the top floor or as pressed boards (IVPU, 2002). Burning this type of board delivers a considerable amount of energy.

Plastering synthetic insulation generates a permanent connection of materials. The calorific values are blocked and the material has to be deposited in a landfill.

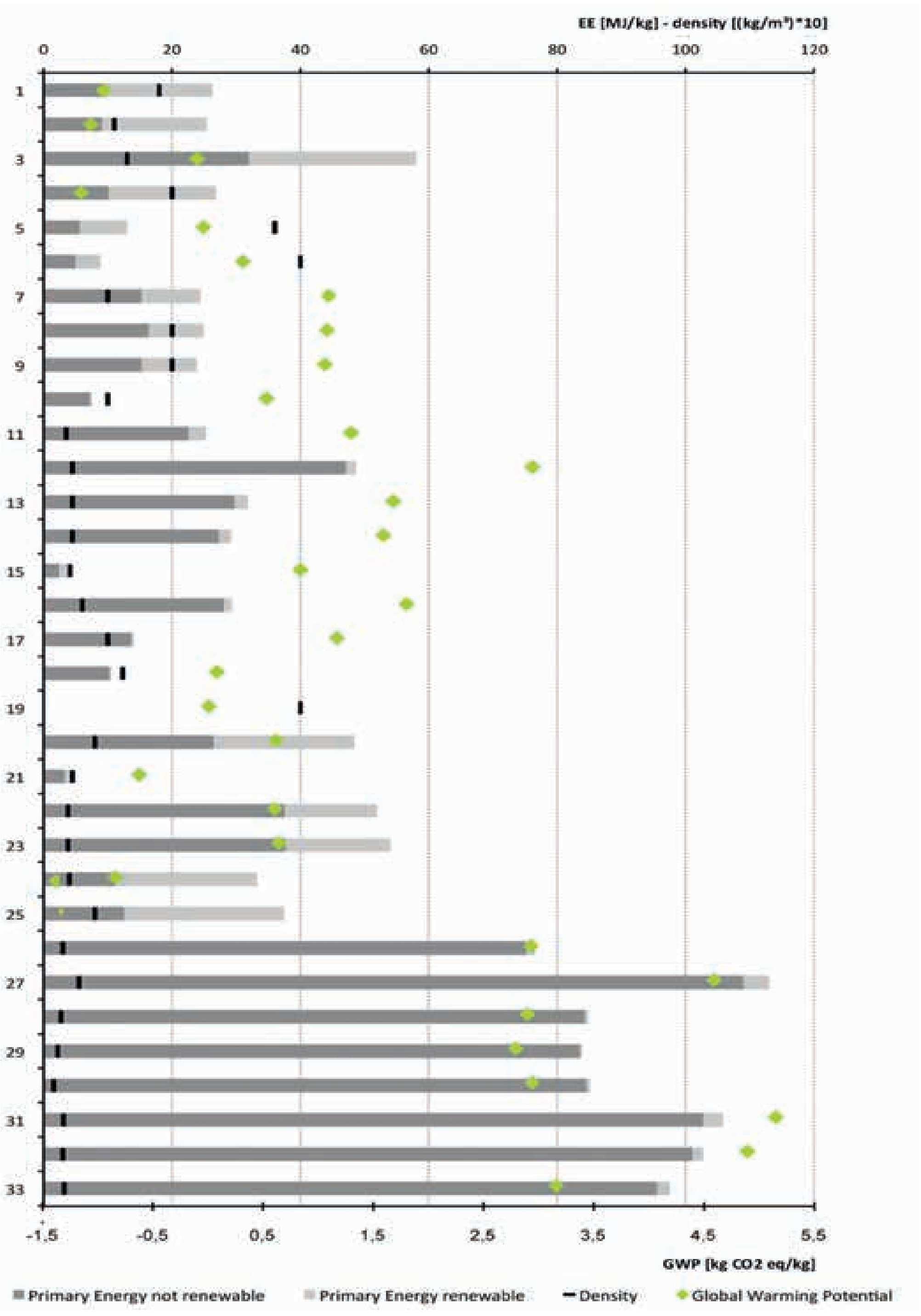


Figure 39

LCA results for 1 kg insulation material

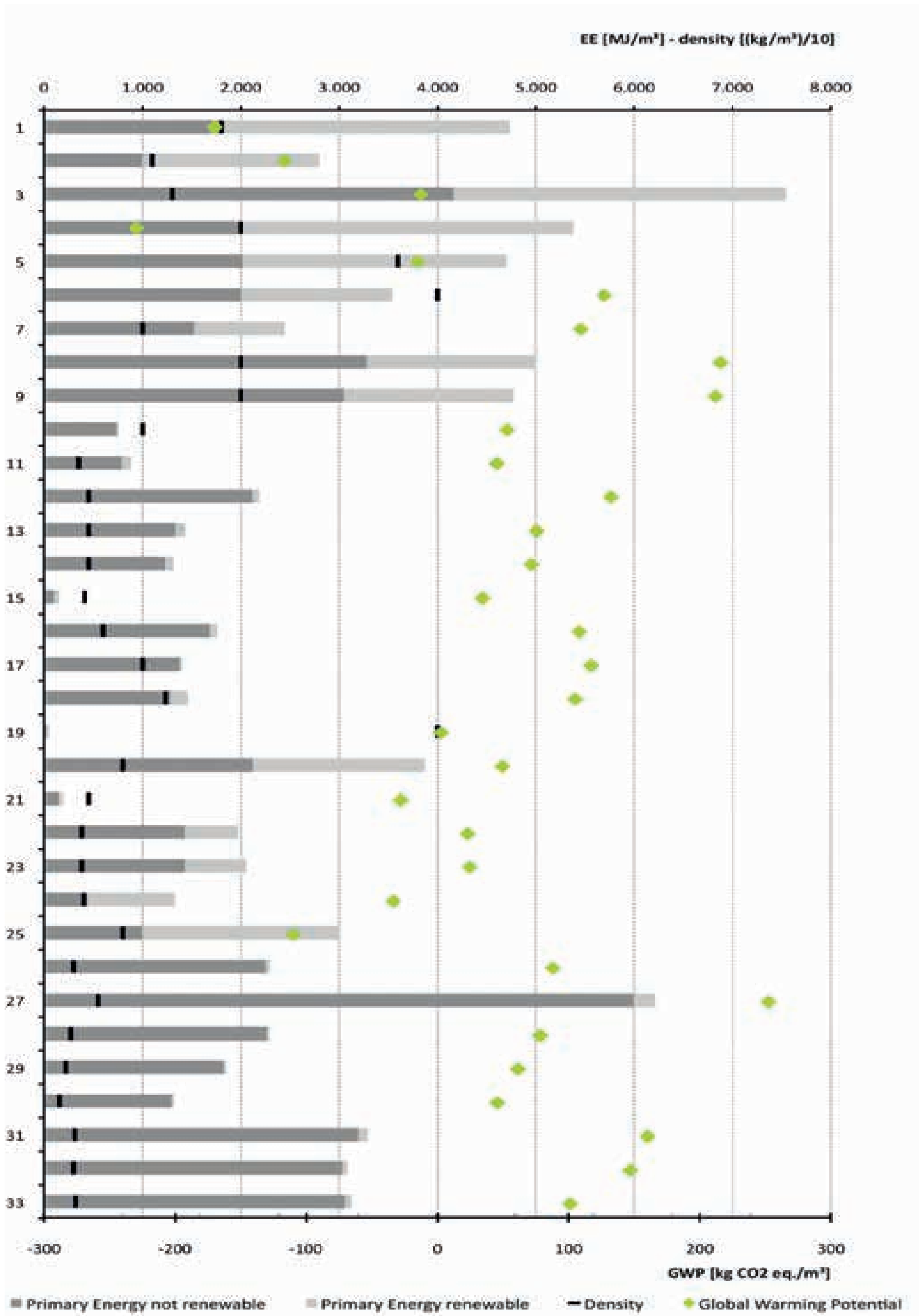


Figure 40

LCA results for 1 cbm insulation material

1	Wood fibre board (Gutex)	12	Mineral wool (Ultimate)	23	Hanffaser Vlies
2	Wood fibre board (Gutex Thermosafe)	13	Glass fibre insulation	24	Cotton insulation
3	Wood fibre insulation board	14	Glass fibre insulation	25	Expanded cork
4	Wood fibre board (soft)	15	Rockwool insulation (Rockwool)	26	PE foam
5	Wood fibre board (light)	16	Rockwool insulation (Isover)	27	Caoutchouc foam
6	Heraklith BM Heraklith EPV	17	Rockwool insulation (Rockwool)	28	EPS
7	Foamglass insulation W+F	18	Aerated concrete insulation panel	29	EPS
8	Foam glass (Perinsul)	19	Aerated concrete loose	30	EPS
9	Foam glass Perinsul SL	20	Cellulose board	31	Polyurethan-hard foam
10	Perlite (expanded)	21	Cellulose fibre	32	Polyurethan-hard foam
11	Mineral wool (Ecose)	22	Flax insulation	33	XPS Extruded Polystyrene foam

Figure 41
Key for Figure 39 and 40

§ 5.6.5 Summary

- Mineral wool will most likely end as landfill.
- Insulation material in ventilated façades has a higher potential for recycling than in EIFS
- Glass wool embodied slightly more EE than rock wool.

§ 5.7 F6 Window frames and glass

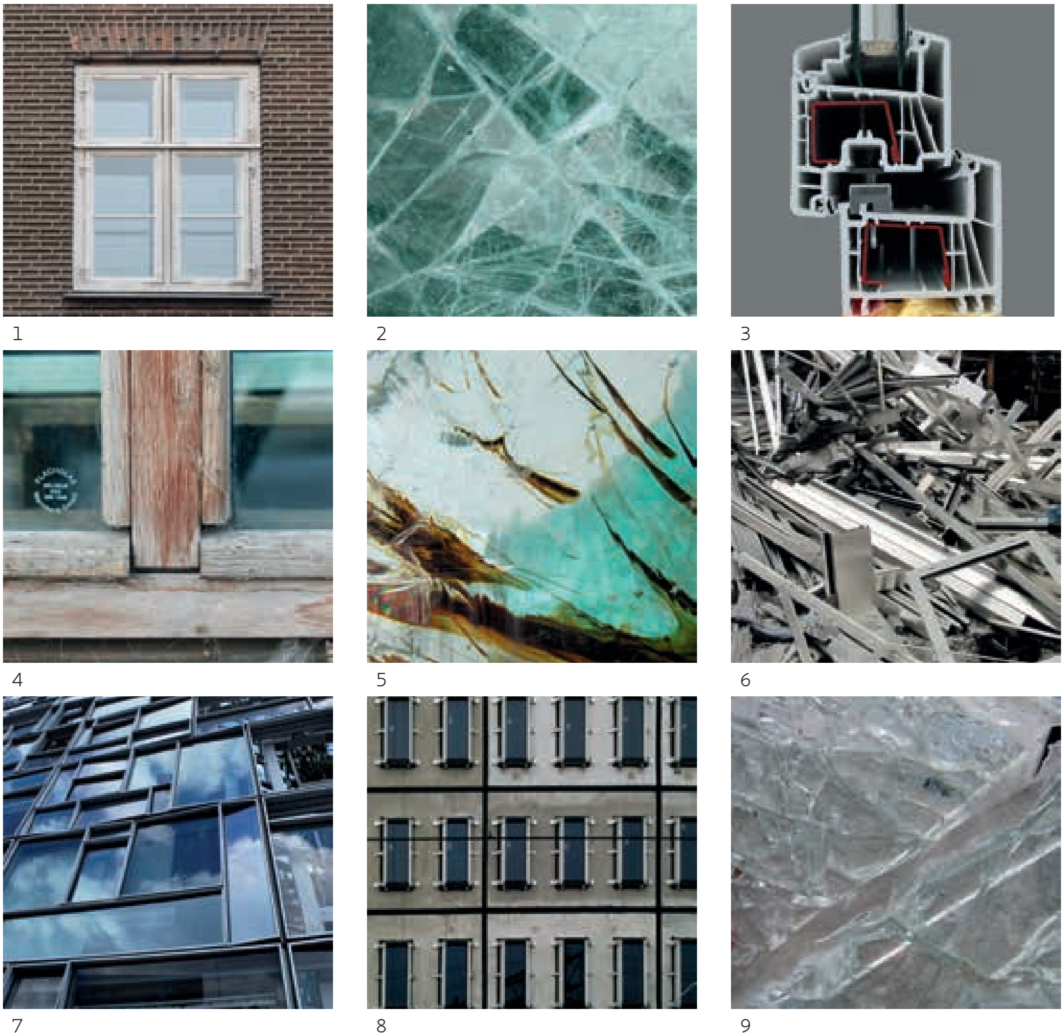


Figure 42 .

Illustrations: (1) box type window (2) glass cracks, (3) PVC window profile, (4) wood window detail (5) intermedeiate step in glass production (6) aluminium frames, (7)window facade of the Waterfront house, NYC (8) windows on concrete wall, (9) broken glass

§ 5.7.1 Relevant data

The evaluation in F6 Openings contains eight window profiles. They are subdivided by material into aluminium window profile, wood window profile and PVC window profile. The LCA data relate to 1m length.

Data for F6 window		
	Ökobau.dat	EPD
Aluminium window profile	2	
Wood window profile	2	
PVC window profile	2	

Table 23

§ 5.7.2 Ecological description

Windows are installed in the building for a comparably short period. The exchange cycles are caused by increasing energy standards, technological development and changing fashion.

The relevance of windows will be explained in the following chapters. The description here serves as a basis for this.

§ 5.7.3 End of life scenarios

The recycling processes for glass and frame material need to be considered separately. First a description of glass recycling will be given, followed by recycling possibilities for PVC, wood and aluminium frames.

In Europe, an entire industry developed for the recycling of PVC windows. The opening vents are detached and the glass is removed. Machines similar to excavators remove the window frame from the façade. Both the opening vents and the frame are transported to a treatment plant where they are chopped. A sorting machine separates metals, PVC and other plastic materials. PVC belongs to the group of thermoplastics and can be thermoformed after this process. This substance flow works quite well due to the experience gained in working with PVC (it is a commonly used product since 1930) although the ecologically unfriendly image due to the harmful effect of chlorine.

§ 5.7.4 Data description

Figure 43 shows the EE and GWP for 1m frame length. The graph is subdivided in aluminium window frame (1-4), wood window frame (5-6) and PVC window frame (7-8). With 111 MJ/m, the wood frame profile (8) embodies the lowest amount of EE. The lowest value for GWP is shown by the wood wing frame profile. The thermally separated aluminium wing frame profile embodies the highest amount of EE with 272 MJ/m and GWP with 21 kg CO_2 equivalent.

Thermally separated aluminium profiles embody the highest amount of EE, followed by profiles not thermally separated. PVC binds slightly lower values. Wood windows embody the lowest amount of EE and GWP.

The difference between profiles thermally and not thermally separated is significant. For the frame profile the difference accounts for 50 MJ/m and for the wing profile even 77MJ/m. The insulation bar and the sealing are responsible for the increased values. PVC window frames consist of PVC, a steel profile and several other plastic materials (Figure 43). They are called PVC windows because PVC is the visible material.

The raw materials for PVC are oil and salt. PVC belongs to the material group plastics. The basic processes explained in § 5.4 apply here as well. The raw material is steam cracked into ethylene. Chlorine is obtained from salt, and both are further processed under high temperatures to make granulate. Catalysts are added to the intermediate product vinyl chloride which is then intensively stirred. The end product is pure PVC.

Under pressure and high temperature, PVC profiles are extruded in a multi-chamber system. Sealing materials like rubber are attached to the profile. PVC is a rather soft material that needs to be supported. This is accomplished by a steel profile that is pushed into the chamber.

§ 5.7.4.1 Aluminium frame

The production of aluminium from raw material is described in 5.3.4.2. The production of an aluminium profile works similar to this. Massive aluminium blocks are heated up to 500 C. The aluminium is still solid but shapeable. It is pressed through a die. The openings in the die define the profile, which is usually mitre cut. Then corner connectors and fittings are added. Structurally relevant connections are made from metals such as zinc or steel. Gaskets are inserted to create air and water tightness. These are made from synthetic material and account for a relevant share of EE as described earlier.

Some aspects of aluminium recycling have been mentioned in § 5.2.The last item will now be discussed more extensively. After the use phase of an aluminium profile, it is dismantled from the building and sorted according to its material. Different alloys and impurities are not visible or determinable by quick-tests and thus hard to identify. Façade profiles have to meet high mechanical quality requirements, which can only be met by high quality wrought alloys. Secondary aluminium can only partly be added to the main primary material in order to replace primary resources.

Scrap metal merchants distinguish five categories of aluminium scrap:

1. Bare profiles
2. Shavings
3. Powder coated profiles
4. Profiles with insulation bars or foil covered profiles
5. Aluminium ware

Table 24 shows the content and further treatment.

Recycling scenarios for aluminium		
Aluminium fraction	**Content**	**Further treatment**
Bare profiles	Low anodized profiles (maximum portion 5%) with nearly no impurities	Melting without any further process -> Secondary aluminium
Shavings	Shavings that accumulate during machining processes like milling, drilling, turning or sawing	Cleaning from oil or similar -> Secondary aluminium

Table 24
The recycling of aluminium depends on material composition. Five main fraction can be differentiated which differ in content and treatment.

Recycling scenarios for aluminium		
Powder coated profiles	Powder coated profiles without insulation bars	Melting process where the coating is burnt. (Furnace has to have certain filters) -> Secondary aluminium
Profiles with insulation bars / foil covered profiles	Profiles with insulation bars or with plastic foils	Melting process where the aluminium is recovered (material recovery) while the plastic is used as fuel surrogate for the burning process (thermal recovery). -> Casting alloys with lower quality requirements
Aluminium ware	Aluminium with different impurities	Shreddered, sorted and aluminium is melted. The impurities are recovered or burnt. -> Aluminium with lower quality requirements

Table 24
The recycling of aluminium depends on material composition. Five main fraction can be differentiated which differ in content and treatment.

The surface of aluminium profiles does not influence the recycling scenario, even though the insulation bar does.

(Further discussion on aluminium façade recycling can be found in (BIR, 2010; Boin, 2004; Classen & Althaus, 2004; GARC, 2009). Additionally, the Master thesis of D. Artmann submitted in 2010 to the Detmolder Schule evaluates the recyclability of an aluminium stick building system (Artmann, 2010). The recycling categories shown in Table 24 originate from a visit at a German scrap metal merchant.

§ 5.7.4.2 Glass

Glass is categorised as flat and container glass. Here, flat glass is discussed.

The main raw material for glass is sand, which is depleted and transported to the place of treatment. There it is mixed with calcium carbonate and soda, and then pulverised. Temperatures of 1,600° C are applied. The components melt and are cooled down to 1,000° C. The glass melt is now shapeable and introduced into the tin bath (float glass process). The glass cools down on the flat tin surface and solidifies.

The glass can be further processed by applying heat and adding layers. For toughened safety glass the glass is heated and immediately cooled down. This leads to smaller broken fragments in case of destruction and thus a decreased risk of injury.

Laminated safety glass is produced by adding polyvinyl foil in between two glass layers and laminating them. Broken fragments are attached to one another, thus controlling the breakage behaviour.

Coatings can influence the transmission of sun radiation or the glass colour. The good thermal conductivity of glass requires the use of spacers when thermal insulation is necessary. Two or three glass layers are positioned with a spacer at the glass edge. The spacer is made from metal or plastic and is filled with butyl, a humidity balancing substance. The spacer is sealed with e.g. silicone.

The glass pane itself could theoretically be completely recycled endlessly. Here, contamination bears obstacle to this cycle. The table below shows the different scenarios. It shows that glass with coatings and lamination can be reintroduced in the glass cycle if they are homogeneous. The potential of a controlled deconstruction becomes evident by comparing the different end of life scenarios..

Recycling scenarios for glass according to Reiling (Pohl, 2010)		
Origin	**Content**	**Further treatment**
Glass producer, glass processor (pre consumer)	Clean float glass / Laminated safety glass	Glass recycling treatment plant ->Flat glass industry, special applications, decorative applications
Car producers, car wrecks	Mixed flat glass car window-screen glass	Due to the organic and metal impurities -> Container glass industry / Foam glass industry
Glass processors (pre consumer), municipal collecting points (post consumer)	Flat glass with higher contamination or contamination that can not be separated	Due to the impurities: metals, ceramics, organics -> Roadworks, glass for abrasive blasting, landfill

Table 25
Theoretically glass could be recycled endlessly if correctly sorted.

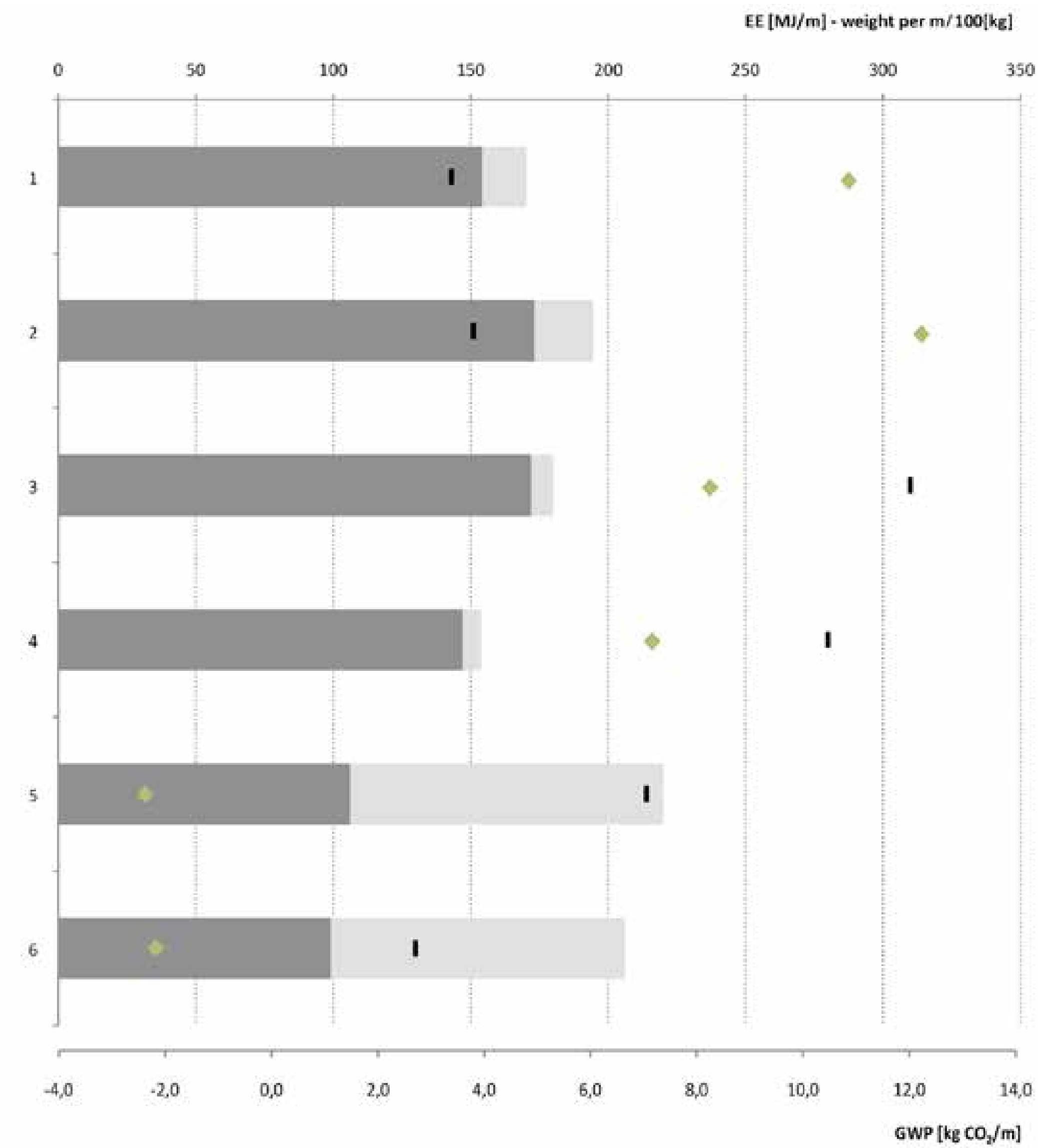


Figure 43
LCA data for 1 m profile

1 Aluminium frame profile, thermally separated
2 Aluminium wing frame, thermally separated
3 PVC wing frame
4 PVC frame profile
5 Wood wing frame
6 Wood frame profile

Figure 44
Key for fig. 43.

§ 5.7.5 Summary

- Wood profiles embody the lowest amount of EE, followed by PVC profiles. Aluminium profiles bind the highest amount of EE.
- Anodised or powder coated aluminium profiles can be processed and used for secondary aluminium for secondary aluminium.
- Glass can be recycled if separated correctly and it can become part of a new flat glass cycle.

§ 5.8 Material evaluation analysis

In the previous chapters, building material was evaluated according to its ecological qualities, which in turn where indicated by a descriptive and a quantitative part expressing EE and GWP.

The content was lead by two main questions:

Do the materials have similar ecological footprints within the material group? What components account for high, which for low values? What potential has recycling?

§ 5.8.1 Analysis main part

§ 5.8.1.1 Ecological footprint according to a material group

The overall comparison reveals that the amount of EE ranges from 0 to 200 MJ for 1 kg and from 0 to 900,000 MJ for 1 cbm. Looking at the weight and volume classification, the data distribution seems similar. The volume evaluation emphasises the extreme values but supports the general picture presented by the mass evaluation. Figure 45 shows EE for 1 kg material in all material groups in one graph (except window profiles due to the reference unit). Figure 46 displays the assessment for 1 cbm and the GWP for 1 kg. (Blue shows mineral material, green indicates wood based products, grey shows metals, red shows plastics and yellow represents insulation materials.)

Figure 45 and 46 show three evaluations. They differ in reference unit and indicator. All three demonstrate a similar picture. Mineral materials and wood based products represent relatively low values. Metals and synthetic material bear the maximum values; either as low as mineral material and wood based products, or split into a lower and a higher grouping.

In Figure 45, mineral material and wood based products have the lowest ecological impact. The EE for 1 kg mineral material ranges from 0.5 to 10 MJ with the exception of glass (18 MJ). Fibrated concrete, granite and glass represent the maximum values for this group. Wood products have only a slightly higher range of 5-15 MJ/kg with lumber (20 MJ/kg) and multilayer hardwood flooring (24 MJ/kg) being the exception in group 02. The values for GWP are the lowest compared to the other material groups..

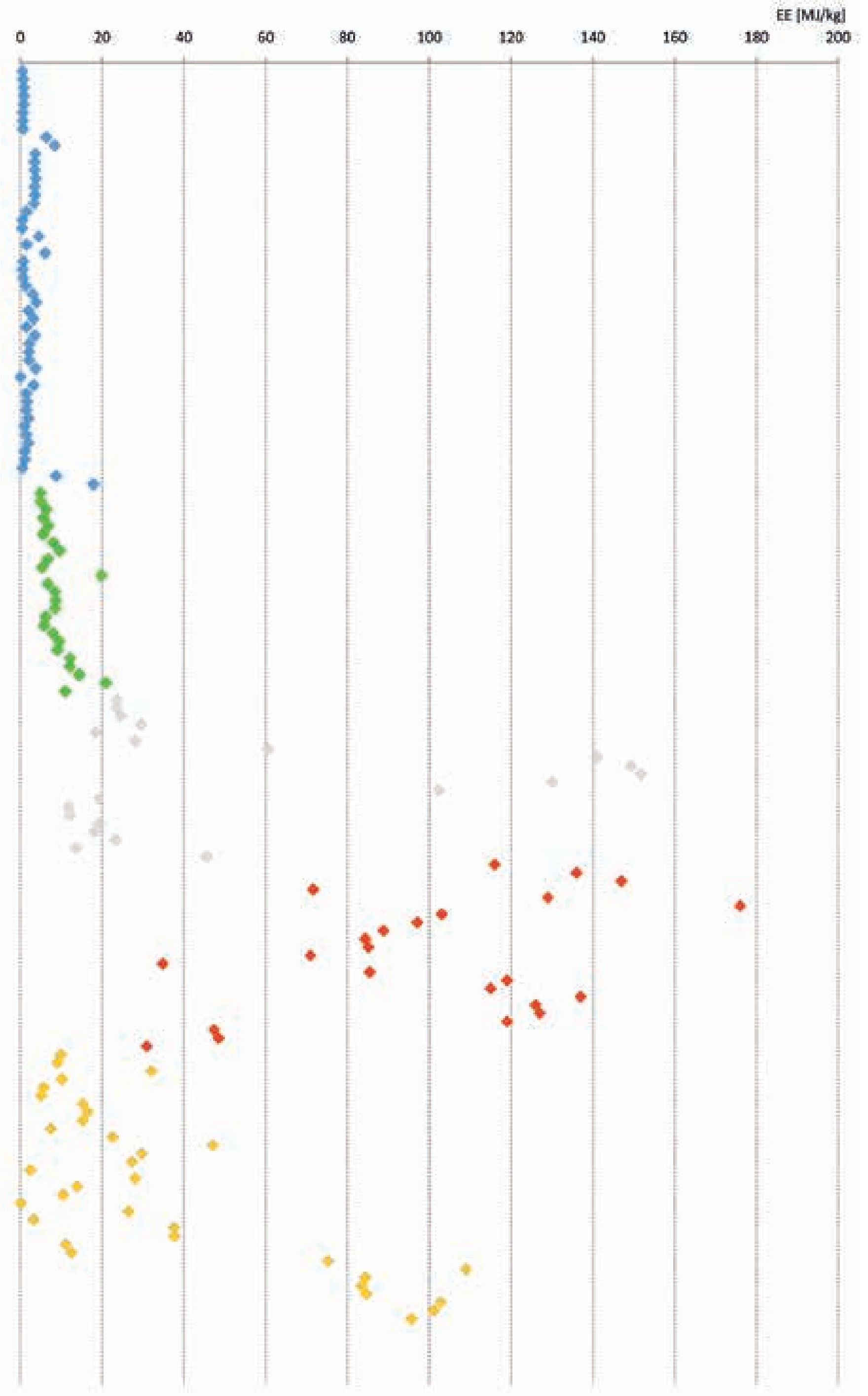


Figure 45
EE in material groups for 1kg.

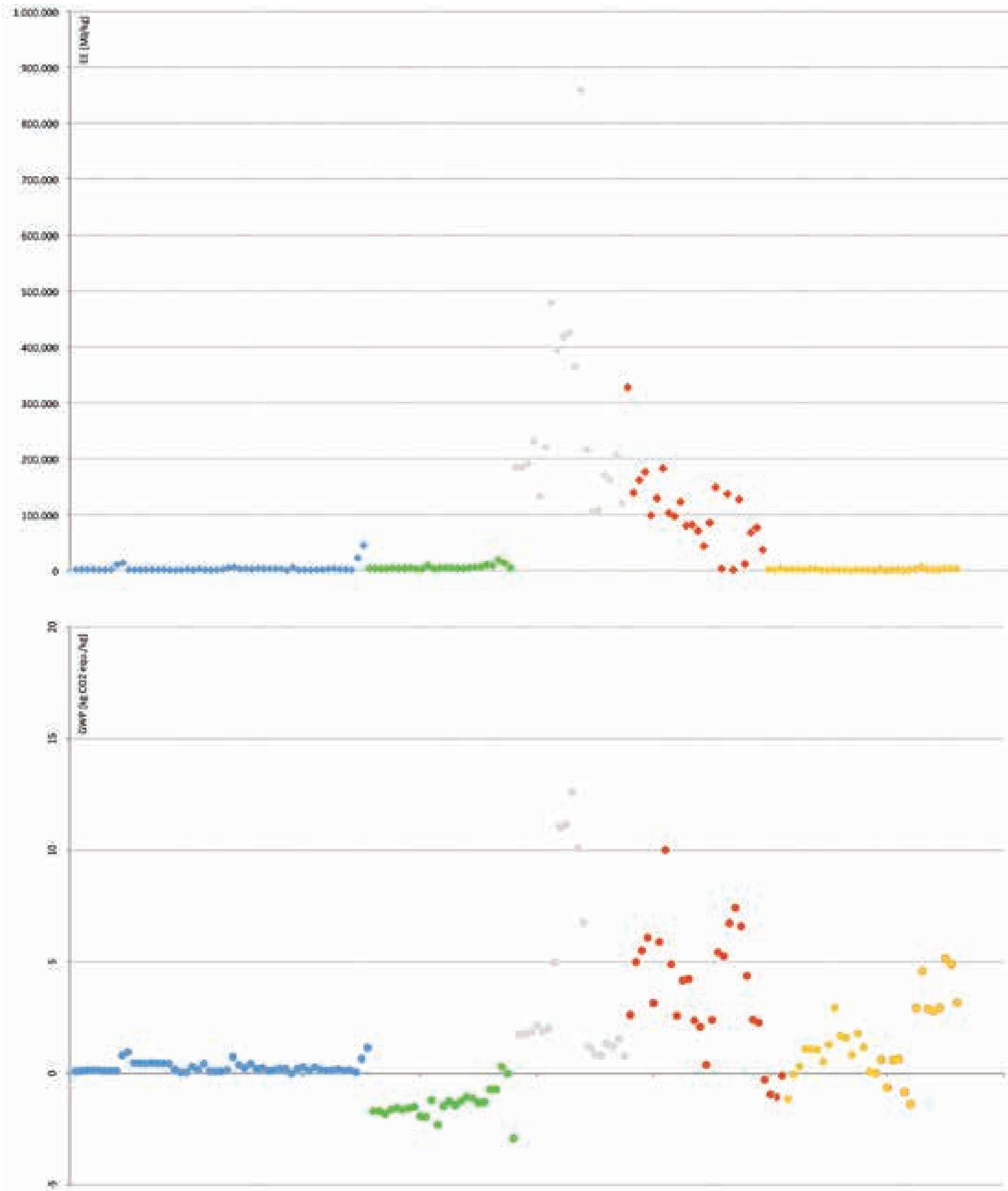


Figure 46
Up: EE in material groups for 1cbm, down: GWP in material groups for 1kg .

Metals and synthetic materials account for the highest values in all assessments with one exception. In Figure 46, the maximum value is represented at 176 MJ/kg for the synthetic material PA vapour barrier. In the volume based evaluation (Figure 46 up) metals show the highest values due to their high density. This is also true for the GWP assessment (Figure 46 down). Looking at the metal, aluminium embodies the highest amount of energy with values from 130 -152MJ/kg.

Synthetic material ranges from 31 MJ/kg for linoleum to 176 MJ/kg for PA vapour barrier. The definition of a main data field is not possible for this material group. In this material group, values for EE and GWP vary significantly for both, mass and volume.

Insulation material has an even more extreme data span. The lowest amount for 1 kg insulation material can account for 1 MJ, the highest for 101 MJ. Loose aerated concrete and PU foam represent extreme values. Two groupings can be identified. The main values for mineral insulation material span from 10-30 MJ/kg and from 700-2,000 MJ/cbm. Synthetic insulation material spans from 75-100 MJ/kg and 2,000-3,000 MJ/cbm.

Mineral material and wood based products show similar values within their material group. Metals and synthetic materials vary. Insulation material is divided by material origin. Synthetic insulation material can account for three times as much as mineral based insulation material.

§ 5.8.1.2 Functional unit in the building context

Comparing materials based on their weight or volume is the first step to gain an understanding of the ecological qualities of building materials. The previous material consideration is isolated from the building context. In order to approach this aspect, functionality and considered time play an important role.

A Functionality

The example of insulation material demonstrates the limitation of this type of comparison. Only functionality is the relevant parameter in order to judge the ecological qualities from one material over another. For insulation material the function can be defined by one physical quality: heat conductivity.

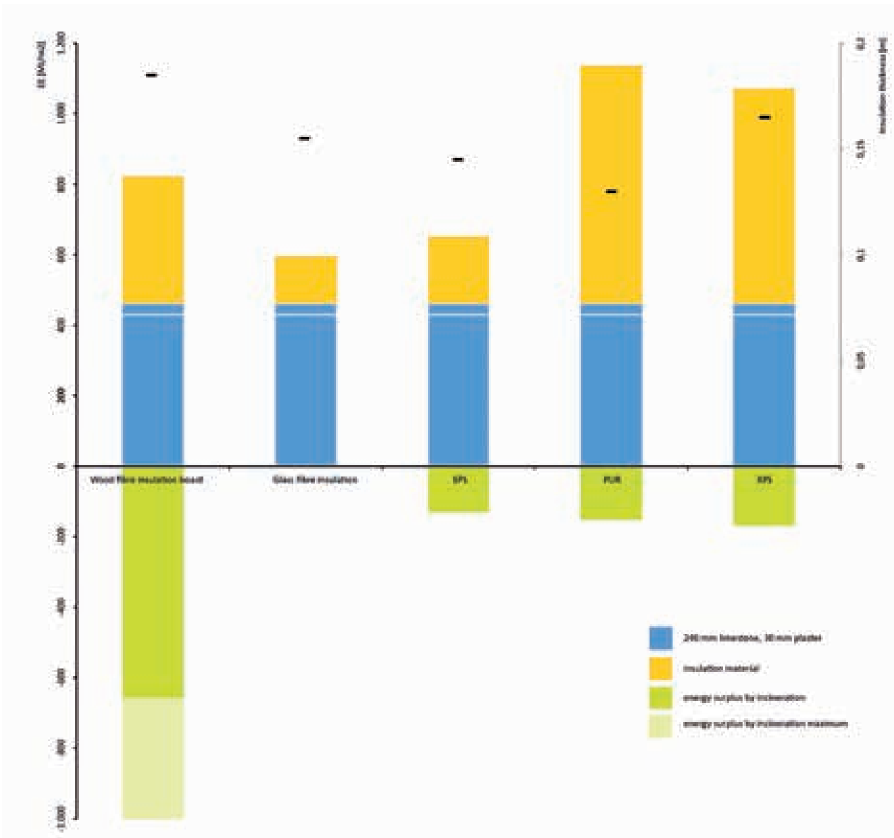


Figure 47
Insulation combination for 0,2 W/sqmK (240 mm limestone, 30 mm plaster).

Insulation combination for 0.2 W/sqmK, numbers for Figure. 47					
Insulation material	**Insulation thickness (mm)**	**EE for insulation production (MJ/ sq m)**	**EE for insulation End of life (MJ/ sq m)**	**EE for insulation p+EoL (MJ/ sq m)**	**EE for complete wall (MJ/sq m)**
Wood fibre board	185	361	-714	-353	109
Glass fibre insulation	155	134	0	134	596
EPS	145	190	-131	58	520
Polyure-thane-hard foam board	130	674	-153	521	983
XPS Extruded Polystyrene foam	165	610	**-169**	441	903

Table 26

Different types of insulation are added to a 240 mm limestone wall with 30 mm plaster. All fulfill heat coefficient of 0,2 W/sqmK. The wall thickness varies from 130 -185 mm. The difference in EE is similar: 109-983 MJ. The slimmest wall bears the highest amount of EE while the thickest shows the lowest value.

The hierarchy does not change but the distances between the material shift. Glass fibre insulation (155mm) delivers the same thermal resistance as EPS with 145mm. The EE per square meter varies from 134 to 190 MJ. Synthetic insulation material is still more energy intensive to produce but the ratio is significantly lower. This tendency becomes even more evident when considering the End of life. The calorific value of synthetic insulation contributes to a better EE performance. An extensive separable demolition is prerequisite for this scenario. This is also true for wood fibre insulation. Here the End of life scenario is even more significant. The energy gained at the end of life can account for the complete effort to erect the wall including the insulation material.

The interpretation shifts when including the function into the evaluation. It influences the scope of the evaluation. The goal of the previous evaluation was to approach the basic relations of material and to identify dependencies. In the architectural planning process, this can be part of general knowledge. The chronological line of action often includes the definition of a function and, subsequently, the choice of a material.

Therefore functionality plays an important role for the ecological evaluation.

B Considered time span

The considered time span for the material evaluation in this chapter is 1 year and thereby excluded the material's technical life span and it hence it's exchange cycles. In the architectural planning process the goal is the identification of the material with desired qualities and the least possible environmental impact over time.

This choice of the considered time span can effect the proposition essentially. The difference from 30 to 80 years for the considered time span can essentially shift the material weighting. While mineral materials have a long technical life span light building elements have to be exchanged and hence accounted multiple in the assessment.

Figure 48 shows the technical life span of material according to their material group (in the same colour code and sequence used in §5.2). It shows the different life spans and indicates that mineral material is favourable for long time use while for example insulation material have a shorter life span.

The evaluation with the considered time span of 1 year is useful for a basic understanding. Next to the function of an ecological comparison, the considered life span is an important assessment parameter.

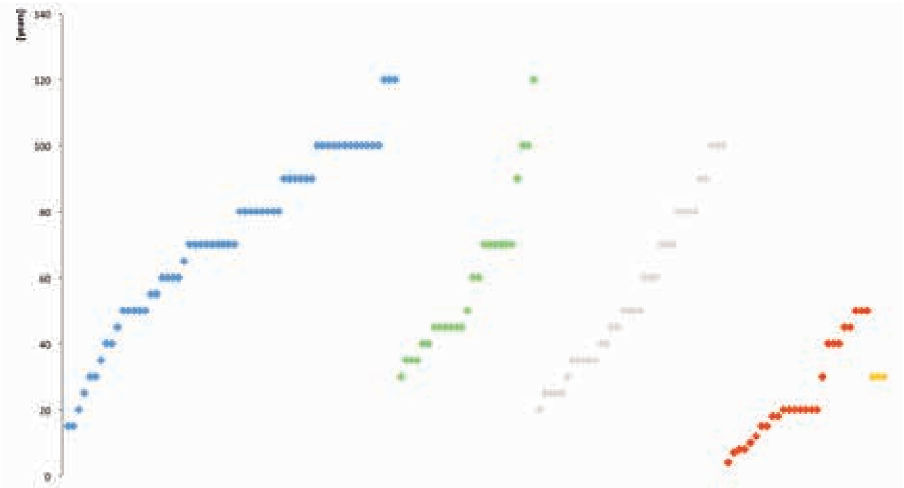


Figure 48

Technical life span of materials and building elements according to the Leitfaden Nachhaltiges Bauen, 2001 (German ministry for transportation, construction and urban planning published in 2001). With short technical life span the material has to be exchanged multiple depending on the considered time span. Long lasting materials like mineral material or metals will most likely only accounted once if their technical life span does not fall below the considered life span.

- mineral material except glass
- metal
- synthetic material
- wood
- insulation

Figure 49
Key for Figure 48

§ 5.9 Conclusion Chapter 5

Mineral material embodies the least amount of EE per mass and volume. This is followed by the wood based products. For this second group, the GWP values exceed all other groups. Insulation material can be distinguished in mineral based material with lower values and synthetic material with 2-3 times higher values. These are similar to the range of synthetic material. Metals show the highest values for both EE and GWP:

Mineral material has a very long duration. However, recycling on the same quality level is rarely done. Most of the time, the mixed rubble is used for other purposes than mineral materials production. Wood based products have the least problematic End of life scenario. Though the reuse rate is relatively low (in comparison to metals, for example), the material or energetic recycling delivers relevant gains. Synthetic material can be burnt very efficiently when sorted according to type of plastic. Metals have the best reuse and recycling potential. They can be reused on a big scale, and re-melted and reintroduced to the production process. The insulation material behaves according to its material group. When synthetic insulation material can be separated without any permanent connection, the calorific value delivers a relevant energetic gain. Mineral insulation on the other hand can only be put in landfill. If it is installed without any permanent connection it has potential for material recycling.

Material mixture with a permanent connection decreases the recycling potential. EIFS is an example for that. No recycling method is yet found.

LCA works mass-based. The heavier the material, the more energy it will bind.

Material information management increases the potential for reuse and material recycling.

Function and considered time influence the evaluation and play a role in connection of LCA information and the architectural planning process.

6 Framework for an ecological evaluation of the building substance

Like building material, the building substance has been assessed over the last 20 years, with an increasing tendency over the last 10 years. Several studies compare different buildings and construction methods with each other, and conclude their ecological impact. The most common comparison includes massive mineral constructions with wood constructions. Examples can be found in (Cole, 1998; Trusty & Meil; 1999 Gustavsson, Pingoud, & Sathre, 2006). The scope of these studies depends on the included parameters.

This chapter introduces categories to characterise the evaluations on building substance level based on the Ecological Evaluation Profile (EEP) for material to provide an understanding of the scope of each evaluation. The similarity between the parameters on material and building level will be acknowledged as well as the differences that are especially relevant in the category system borders.

§ 6.1 Parameters for the evaluation of the building substance

The EEP categories introduced in chapter 4 will be applied and adapted to the evaluation of buildings. They are based on the same framework conditions.

§ 6.1.1 Evaluation goal

The evaluation goal is to compare different buildings and building parameters on the level of building substance. Specifications for the framework are defined within the reference unit and its functional context. Presuming that the solutions offer the same function, the one with the lower impact will be recommended by LCA. It can be said that the general goal is to identify solutions with the best ecological performance.

The specification of the goal is required by the ISO standards 14040 and 14044, and is especially useful when not only the variant with the best environmental performance is to be identified but the particular characteristics of a building are to be investigated as well. Analysing the distribution of the building elements would be one such goal specification.

§ 6.1.2 Data source

The calculation for the building substance connects the LCA information about the building material with the building mass. The building information and LCA data should be documented. (Equivalent to the content discussed in chapter 4 (see § 4.1.2). Therefore, the following categories discuss information on the building substance only (with exception of the one on calculation method).

The person who conducted the calculation (calculator) should be mentioned in order to address potential questions.

The ideal basis for an LCA of a building is a bill of quantities and relevant documentation including plans and pictures. If a bill of quantities is not available, the calculator should have access to ground view, sections (at least 1:200) and façade sections (1:20) in order to identify the installed materials. Plans with serious planning deficiencies have to be excluded. The information on building mass can either be directly exported from 3D models (BIM) or calculated based on accurate plans.

For the communication of LCA results, a description of the main building elements' construction and materials should be given. Images facilitate understanding the results. The façade section at 1:20 shows the construction method. A description of the construction supports readability.

The presentation of results should include images that inform about the building characteristics and its construction.

§ 6.1.3 Generic and specific LCA data and its validity

EN 15978 defines the quality of building information that should be given for relevant planning stages. In § 9.4.1 the standard states that generic data is preferred over product specific data for the design phase. When focusing on details, this preference changes and product data should be preferred over generic data..

§ 6.1.4 Relevant data

The choice of data has to relate to the evaluation goal and has to comply with the adjacent categories.

At least 15 buildings should be evaluated in order to develop the relationship between different building elements. The construction method (massive or skeleton) and the main construction material should be included in the evaluation.

§ 6.1.5 System borders

The system borders define all processes for the investigated subject. The life cycle stages technically belong in this category. They are displayed separately due to their high relevance in the evaluation.

In the category System borders, included and excluded building parts need to be documented. In the EU, similar standards are available for a systematic compilation of building elements, e.g. the Swiss EKG SN 506502 or the Germany DIN 276-1:2006. Like similar standards, the latter is structured hierarchically. The seven categories Site, Site preparation, Construction, Building services and Exterior are subdivided into subgroups which include further items (triple pane system). The main groups are numbered in steps of hundred, the subgroups by steps of ten and the items within the group by steps of one. A breakdown up to the second level would have a three digit number that ends with a zero, e.g. 350.

In terms of the German standard, the most relevant group to quantify the building substance is 300 Construction. It considers only the building substance. Installation and site are dealt with separately. Table 27 shows the subcategories and the items of this group. Due to its structure, different levels of detail can be described by this scheme.

Building organisation according to ISO 276, 300 Construction							
310 Foundation pit	**320 Foundation**	**330 Exterior walls**	**340 Interior walls**	**350 Floors**	**360 Roofs**	**370 Building compo-nents**	**390 Other con-struction**
311 Preparing excavation pit	321 Ground improve-ment	331 Load bearing exterior wall	341 Load bearing interior walls	351 Floor con-struction	361 Roof con-struction	371 General compo-nents	391 Building site equip-ment
312 Excavation confine-ment	322 Surface foundation	332 Non - load bearing exterior walls	342 Non - load bearing interior walls	352 Floor cover	362 Roof window and roof opening	372 Special compo-nents	392 Scaffold
313 Water	323 Deep foun-dation	333 Exterior columns	343 Interior columns	353 Floor cladding	363 Roof cover	379 Building compo-nents, other	393 Safeguard
319 Foundation pit, other	324 Subsoil and ground slab	334 Exterior doors and windows	344 Interior doors and windows	359 Floor, other	364 Roof clad-dings		394 Demolition
	325 Floor cover	335 Exteri-or wall cladding exterior	345 Interior wall clad-ding		369 Roof, other		395 Mainte-nance
	326 Constructi-on waterp-roofing	336 Exteri-or wall cladding interior	346 Modular interior walls				396 Recycling
	327 Drainage	337 Modular exterior walls	349 Interior walls, other				397 Bad weather preparation
	329 Foundati-on, other	338 Sun protec-tion					398 Additional construc-tion
		339 Exterior, other					399 Constructi-on, other

Table 27

The chart helps to indicate the level of detail. EN 15978 states that the bill of quantities should be based on the level of information according to the planning stage. A share of included and excluded building material is not defined and needs to be specified.
The German certificate BNB requires that 95% of all materials should be included with the premise that assumptions are allowed. This kind of information should be given in this category.

§ 6.1.6 Reference unit

In contrast to the evaluation of building material, the reference unit for buildings relates to the space the building covers. The most common reference units are net floor area or gross floor area. The function of a building can hardly be narrowed down to a unit that is describable by physical numbers. Further steps toward comparability are yet to make. A minimum transmission resistance standard is a step in that direction.

The dimension of time has to be defined as well. The indicator can relate to the complete considered time span or can be presented per year. Displaying the indicator value per year requires predicting possible future developments in a scenario. Choosing this reference unit enables the comparison with operational energy, which is most commonly presented per year.

Subsequently, the planning phase should be identified as it affects the level of information that can be expected. Naturally, with further development the level of detail increases. When buildings are directly compared, all examples need to be considered at the same level of detail.

§ 6.1.7 Calculation method and tool

The calculation method for buildings consists of information on LCA and the building mass. Especially the life cycle phases and the considered time span impact the assessment. They will be discussed in the following.

Software tools as explained in § 3.2.1 or a programmed spreadsheet with traceable information can be used to connect the building mass information with LCA data. The calculation can be done with data collecting software.

§ 6.1.8 Life cycle phases

The building life stages can be systematised using EN 15978. The life cycle phases equal the ones for building material (EN 15804). By indicating the life cycle phases, the nature of buildings can be easily distinguished from the building substance. The documentation of the life cycle phases is essential for the comparability of the LCA data.

Production stage (A1-A3)

The stages include steps that relate to the production of building material. Their content is described in §4.1.7.

Construction stage (A4-A5)

The construction stage sums up all effort for transport and construction facilities on the building site. When different building materials are combined, and the effort for transport and site production is added this is considered the building substance.

The collection of data for the construction stage requires a high level of detail. Information gathering is complex but the impact on the overall building is comparably low. According to a study by Geiger (1997), transportation and site energy is negligible as it accounts for less than 1% of the total results (in his example. This is true for the recognition of all building stages.)

Usage stage (B1-B7)

The usage phase plays an important role for a complete building evaluation. And, according to construction type and performance level, the usage phase plays a major role in the complete results.

For the consideration of the building fabric only, the module B4 Replacement is considered.

End of life stage (C1-C4) and benefits and loads for the next product system (D)

The generic end of life scenarios are described in §4.1.7. In the building context, the level of connectives influences the end of life scenario. A strong connectivity between a material of a high recycling potential and one with a low potential results in a product that ends as landfill (as described in chapter 5 for EIFS).

§ 6.1.9 Considered time span

The considered time span is described in §4.1.8 as the time frame of the complete building lifetime.

Applying that to building substance generates a picture. The exchange cycles contribute a relevant share; especially with regard to the construction.

Currently, no norm defines or recommends the considered time span. It is chosen by the person conduction the investigation, and national trends can be identified. For example, studies from Switzerland by Kasser, Preisig, & Dubach, 2006 set 30 years as the considered time span. This amount relates to one generation, and addresses the scope of one person’s responsibility. In Germany, the technical period in which a building is considered usable is pivotal. A typical massive construction can stand erect for more than 100 years. König, Niklaus, Kreißig, & Lützkendorf, 2009 describe a temporary building by a lifespan below and a permanent building by over 50 years. This illustrates the German approach to the lifespan of buildings well. In German LCA’s, studies calculate 40-100 years for the main structure. The EU study IMPRO evaluated buildings in the entire EU and defined 40 years as considered time span (Nemry et al., 2008). US studies often use 50 years as their time frame due to a lower duration of the wood frame construction. (Blanchard & Reppe, 1998)

§ 6.1.10 Indicator

Different indicators were introduced in chapter 3. The most common indicators to indicate the ecological impact of the building substance are primary energy non-renewable and renewable, GWP and CED.

Considering the energy aspects of the building substance offers easy comparability with the operational energy. This follows up the discussion about the reference unit. Referring to an indicator per sqm and year offers the simplest way of comparison.

This reference unit complies with the standard for presenting operational energy. While EE in the building substance is most commonly expressed in mega joule, the operational energy is presented in kilowatt hour.

§ 6.2 Communicating LCA information on building level

According to the evaluation of material, the investigation of the building substance can be characterised by categories that can be displayed by table and by description. Chapter 4 shows Table 13 (page 106) which is here extended by the category "Case study description". This is necessary to reflect the complexity of a case study, and to understand the relationship between the building characteristics and environmental impact.

Overview for the framework parameters (T - table, D - description)		
Parameter for LCA	**Evaluation level**	**Case study level**
Evaluation goal	T / D	
Data source	T / D	
Generic or specific data	T	
Validity	T	
Relevant data	D	
System border	T /D	
Reference unit	T	
Calculation	D	
Life cycle phases	T	
Duration	T	
Indicator	T	
Case study description		T

Table 28
This table shows recommendations on which type of information to provide, descriptive information or information given in table form.

§ 6.2.1 Evaluation level -EEP table

The evaluation on building substance level can be categorised by the same categories as those on material level. Consequently, the EEP is the same as shown in Table 14, page 107. Accompanying the table, the following topics need to be explained in text form (analogue to the method for material):

- Evaluation goal
- Data source
- Relevant data
- System border
- Calculation method

§ 6.2.2 Case study level

The ecological evaluation on building substance level aims at relating the building characteristics to environmental impact. Therefore both sides, the individual features and the environmental impact need to be shown. Consequently each case study should be at least characterised by the designer and calculating person, a description of the building construction, the size of the building and the results for the eco-indicator.

Case study name
Category
Design and calculation by
Design and construction supervised by
Construction description
Gross floor area (sqm)
Weight (kg/sqm)
Building envelope
Structure
Interior
Other
Total

Table 29
Format to characterise a case study

§ 6.3 Conclusion for chapter 6

Ecological information on building substance level can be communicated by categories similar to the material evaluation. The information can be of a descriptive nature as well as being presented in a table. Characterising the case studies is equivalent to the description of the material group and its production process. Here, the building features need to be communicated in order to relate these to environmental impact.

7 Ecological evaluation of the building substance of 25 offices

This chapter evaluates the substance of 25 buildings regarding their ecological impact according to the parameters introduced in chapter 6. It starts with the characterisation of the evaluation using the parameters introduced earlier. For a comprehensive presentation some information is given for the entire evaluation and other is displayed per case study. The EEP (Ecological Evaluation Profile) table is used to demonstrate the scope of the evaluation.

§7.2 shows the 25 case studies. The chapter is round off with the analysis of the evaluation.

§ 7.1 Framework for the subsequent evaluation

The evaluation of the building substance considers 1 sqm ground floor area, and the end of life scenarios after a time frame of 50 years. This information is expressed in Table 30. The information given there is relevant for all case studies.

Ecological Evaluation Profile	
Evaluation goal	Building comparison
Data source	Ökobau.dat, EPD
Generic or specific data	Both
Validity	2011-2013
Reference unit	1 sqm GFA
Calculation tool	Lixcel

Table 30
The EEP shows the parameters to characterise an evaluation on building substance on the left hand side..

Ecological Evaluation Profile			
Life cycle phases	A1	Raw material supply	x
	A2	Transport	x
	A3	Manufacturing	x
	A4	Transport	
	A5	Construction/ installation process	
	B1	Use	
	B2	Maintenance including transport	
	B3	Repair and transport	
	B4	Replacement including transport	
	B5	Refurbishment including transport	
	B6	Operational energy use	
	B7	Operational water use	
	C1	De-construction demolition	
	C2	Transport	
	C3	Re-use recycling	x
	C4	Final disposal	x
	D	Re-use recovery and recycling potential	x
Considered time span		50 year	
Validity		varies 2011-2013	
Indicator		EE (GWP)	

Table 30
The EEP shows the parameters to characterise an evaluation on building substance on the left hand side..

§ 7.1.1 Evaluation goal

The evaluation is guided by the sub-question introduced in the first chapter.

What are the building elements with the highest potential for efficient impact to optimise the EE?

How can EE be optimised on the building level?

§ 7.1.2 Data source

The main databases used are Ökobau.dat and EPDs. Ökobau.dat is applied in the version of the corresponding year. In the controlling process, Ökobau.dat was updated to the latest version of Ökobau.dat (2011_12).

The information on the building fabric was generated in the course "Sustainable Construction" at the Detmolder Schule, conducted by fifth-semester students Bachelor of Architecture during the years 2008 to 2010 and 2012. The assignment included the design of an office building including an ecological evaluation. Each year, approximately 70 students attended the course which resulted in over 250 office designs and respective ecological evaluations.

The assignment was based on the following parameters: The office has to have a gross floor area of 12.700 sqm +/- 30%. The number of levels/storeys is limited to seven. The site can be chosen freely but it should be located in Germany (in order to learn to apply German construction rules). Thus, the cases refer to the climate of Western Europe. Low energy performance is to be integrated, with a concept that focuses on the cubature and the orientation of the building.

§ 7.1.3 Relevant data

The case studies chosen from the 250 studies available had to fulfil a certain standard. They had to comply with the following parameters:

- The construction is free of serious planning failures (structure, building envelope)
- Completeness of plans: Ground view, section, façade section and details
- Image/Perspective
- Calculation is plausible

The results of the first year showed some weaknesses in readability of the graphs.

§ 7.1.4 System borders

Only the building itself is considered, not the building site. Parking spaces and other adjacent facilities are excluded.

Cost groups according to DIN 276	
320	Foundation
330	Exterior walls
340	Interior walls
350	Floors
370	Roof

Table 31
Building elements according to the ISO 276 that are included in building evaluation

§ 7.1.5 Calculation method and tool

A tool to calculate the ecological impact of the building substance in collaboration with students has to meet certain criteria:

- The calculation has to be transparent.
- The workload has to be balanced (the introduction should be done in one work session, conducting the evaluation should be done in 4 weeks)
- The students have to be able to work on their own computers
- The results should be easily comparable

This framework excluded software products such as, for example, GaBi (or later GaBi built), SimaPro or GreenCalc. An Excel spreadsheet was developed to meet the requirements. The main reasons here for were the investment in time and the operability from home. Along with the programmed Excel spreadsheet the students received an excerpt of the then latest version of Ökobau.dat containing approximately 200 products. In order to distinguish the two files more easily, the first one was named "Lixcel" and the second one "Ökobau.dat excerpt". Lixcel will be explained in more detail as it serves as the critical basis for the evaluation.

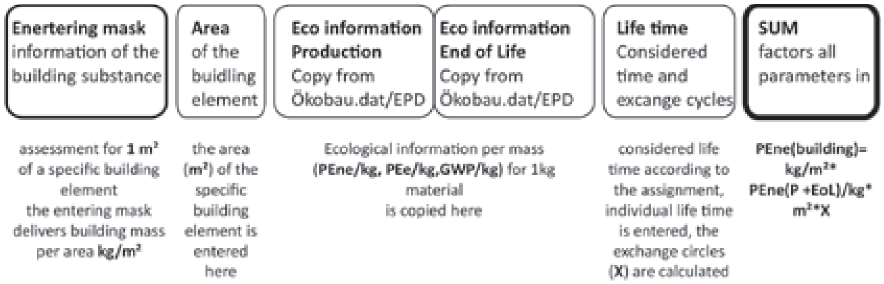


Figure 50
Scheme for the calculation tool

Lixcel 1.0 was developed in 2008 and revised in 2009 to version 2.0. Lixcel contains five main components as shown in Figure 50. The input screen, the area, the ecological information for production and end of life, the lifetime aspects and the sum.

The input screen includes the building information (see Figure 51) or one square meter of a certain building material. The coloured part marks the information that needs to be entered for each case study, the blank part is calculated.

Building part	KG	No	Description (voluntary)	Material/ Function	Product	Material group	Thickness [mm]	Densitiy [kg/m³]	Weight per area [kg/m²] / Volumen per are		Area (m2)
Building envelope	340	AW1.1		Woodboard	MDF	Wood products	20	750	15 0,02	kg m³	2503

Figure 51
A section of the calculation screen

The screen is vertically structured according to the cost groups (German: Kostengruppe, short KG) of the German standard DIN 276. The standard organises the entire building process. For the here described purpose KG 320 and 370 where used to define (vertical) categories. Horizontally, one building material is entered which belongs to a vertically organised unit.

As explained, the input screen ascertains one square meter of a building material associated in a building element group (KG). The next unit “area of building element” requires entering the number of square meter of the planned building element in the building.

The ecological information in the next unit is copied from a database that displays eco-indicators for one kilogram or one cubic meter material. Both production and end of life flows are to be copied. The indicators were chosen to be primary energy non-renewable (MJ), primary energy renewable (MJ), and global warming potential (kg CO_2 equivalent). This decision was made in 2009, after working with seven indicators which where recommended by the German ministry (Runder Tisch Nachhaltiges Bauen, 2001) and are later confirmed by e.g. EN 15804. Showing primary energy non-renewable and renewable, GWP, ODP, AP, EP and POCP gave too much information for an easily comprehensible result.

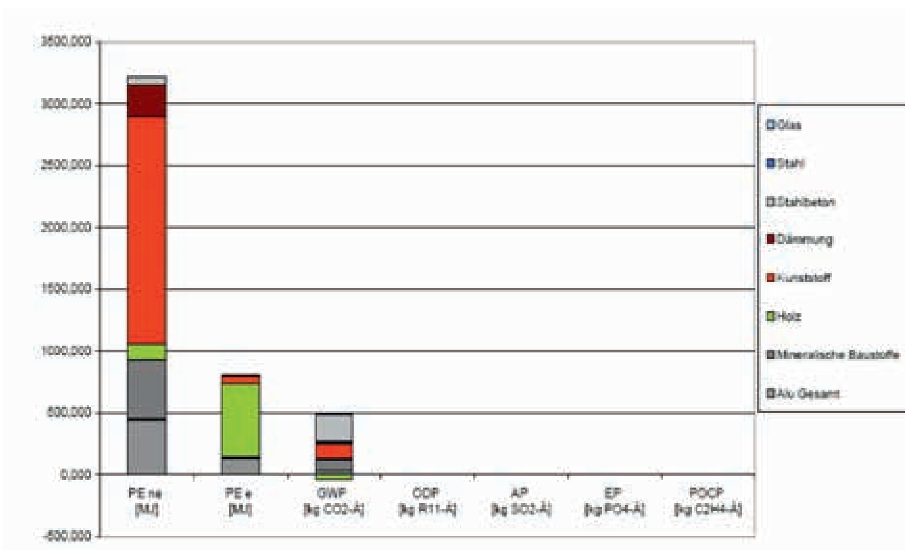


Figure 52
Result graph Lixcel 1.0. Not all indicators are visible which leads to a revision of the indicator and resulting graph

Life span		
Time of consideration	Material duration	Material exchange cycles
10		
		1
		1
10	30	

Life span		
Time of consideration	Material duration	Material exchange cycles
50		
		2
		2
50	30	

Figure 53

Life span input screen. When considering 10 years the material is included once in the calculation, twice when the consideration time is changed to > 30 years.

The time of consideration is a very important aspect and is part of the next unit "lifetime". Here, the duration of a specific building material is gathered. (The coloured cells mark the input, the blank cells the calculation cells.) Time of consideration can be easily changed for all cells in that column by replacing the green bold number. The sheet calculates the material exchange cycles instantly, and rounds them up to display a reality reflecting result. This procedure follows EN 15978 §9.3.3.

		ECOLOGICAL VALUES COMPLETE BUILDING			ECOLOGICAL VALUES PER SM BGF		
Phase	Time of consider-ation	Primary Energy not renewable PEne [MJ/m²]	Primary Energy renewable PEe [MJ/m²]	Global Warming Potential [kg CO2-E/m²]	Primary Energy not renewable PEne [MJ/m²/a]	Primary Energy renewable PEe [MJ/m²/a]	Global Warming Potential [kg CO2-E/m²/a]
Production 50J		[illegible]	[illegible]	[illegible]	1089445	[illegible]	80653
End of Life 50J		[illegible]	[illegible]	[illegible]	-100070	6720	21021
Total 50J	50 years	[illegible]	[illegible]	[illegible]	**3192**	**516**	**328**
Materials							
Mineral material	50 years P+EoL	[illegible]	[illegible]	[illegible]	**3033**	90	**335**
Wood products		[illegible]	[illegible]	[illegible]	**-106**	416	**-19**
Plastics		[illegible]	[illegible]	[illegible]	**179**	2	**6**
Metal		[illegible]	[illegible]	[illegible]	**70**	7	**5**
Insulation		[illegible]	[illegible]	[illegible]	**16**	1	**1**
Building elements							
Building envelope	50 years P+EoL	[illegible]	[illegible]	[illegible]	**2086**	106	**125**
Structure/Floors/ Foundation		[illegible]	[illegible]	[illegible]	**958**	30	**195**
Interior walls (not loadbearing)		[illegible]	[illegible]	[illegible]	**92**	3	**7**
Rest		[illegible]	[illegible]	[illegible]	**55**	375	**1**

Figure 54

The results of the assessment are shown in this screen. They are organized in materials and in buildingelements. On the right hand site the value per one square meter is shown.

The last unit "sum" calculates all factors into one. The first unit collects the data for one square meter; the second defines the quantity of this. The product of both is multiplied with the sum of ecological indicators for production and end of life, including a factor for the lifetime exchange cycles.

For the sake of clarity the resulting graph and information structure were improved in Lixcel 2.0. The content, however, was not changed.

In contrast to L1.0, L2.0 contained an overview sheet which displayed all results and provided a table that gave information the graph. L1.0 also contained a graph but it was connected to the main calculation sheet, which made it difficult to identify mistakes.

In Figure 51, the drop down menu can be seen. By using this menu, materials and building element groups can be viewed independently. They have to be copied to the overview sheet (Figure 51, green cells). Materials and buildings element were chosen to be the evaluation parameters as they are main characteristics for buildings. By doing so, the distribution of these parameters can be extracted which delivers input on the question of the relevance of each parameter.

Six graphs are linked to this table. They provide a quick result overview, and as an added benefit they turned out to be good controlling instruments for the correctness of a calculation. (E.g. more than 15% red in the material diagrams in most cases indicated a mistake in the mass ascertainment. In 90% of the calculations the roof foils where mistakenly entered with a thickness of up to 5mm.)

Absolute and relative evaluations haven been chosen to, firstly, get an overview over the total amount and, secondly, to read the distribution of the building..

Figure 55
Key for building elements (left) and for building material (right)

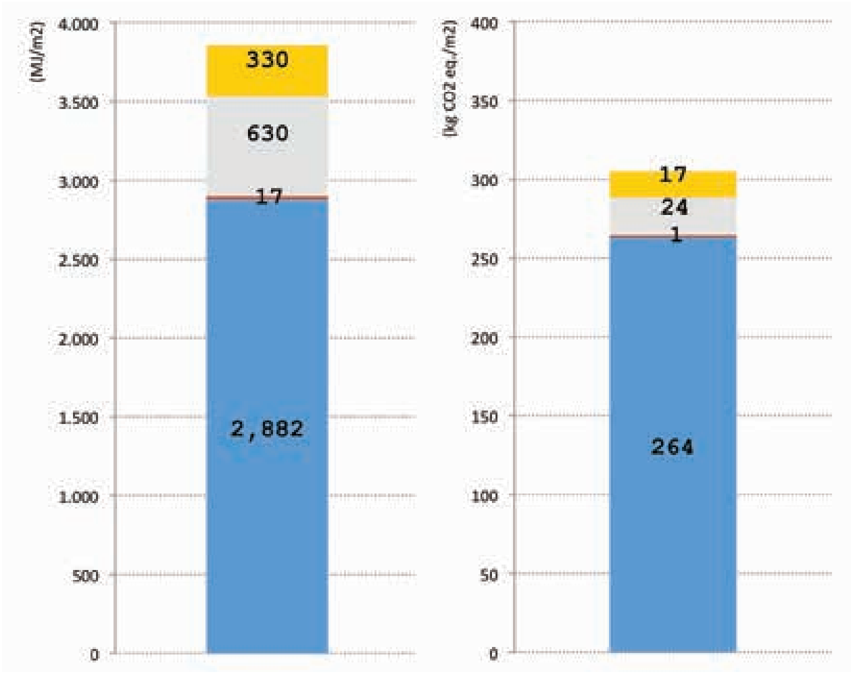


Figure 56
Material distribuition (left EE, right GWP)

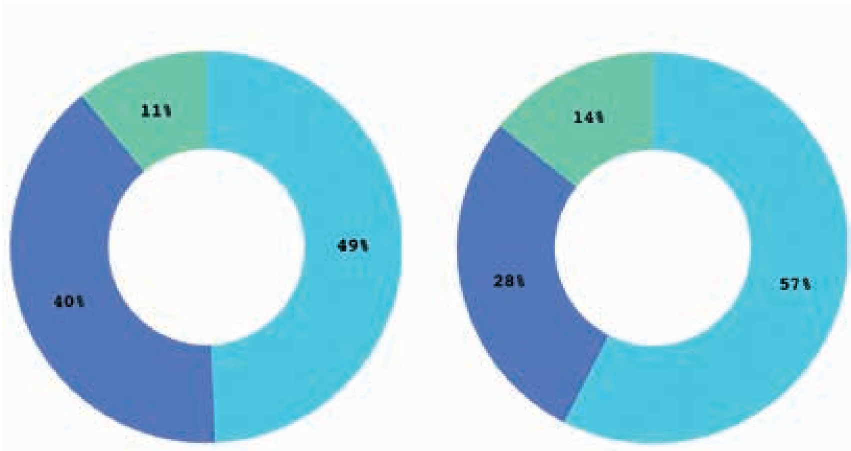


Figure 57
Resulting graph showing the building element distribution (left EE, right GWP)

As explained in the beginning Lixcel was developed in 2008 for the university course Sustainable Construction. The same year the DGNB pilot certification phase for office buildings took place. Due to an employment at a company that took part in certification process, this Excel spreadsheet (unnamed at that time) was applied to calculate the material aspect of criteria 1-5 and 10-11. During this process, the DGNB accepted this calculation method, arguing that several other companies developed similar Excel based instruments (but mostly without the lifetime aspect). Since LCA professionals authorised the general procedure of this Excel spreadsheet, Lixcel was considered a sufficient tool to evaluate the ecological impact of buildings and building elements in the planning phase.

The case studies are elaborated up to the early construction phases. An allowance of 10% is added in order to incorporate an uncertainty factor.

Building parameter included	Building parameter excluded
Foundation with insulation and sealing	Technical facilities
Load-bearing and structure	Effort for assembly on site
Vertical and horizontal building envelope	Doors, door frames, handrails
Staircases	Drainage system
Suspended ceilings, elevated floors, not load bearing interior walls	Window ledge, skirting boards
Floor covering	

Table 32
Building elements included and excluded in the ecological evaluation

§ 7.1.5.1 Fixed input parameters

Certain building materials are equated for all calculation in order to provide comparability.

The building foundation is assumed to be a flat foundation with a thickness of 700 mm. All reinforced concrete has a share of 2.7 vol.% iron.

Each staircase from one storey to another is considered with 2.2 cbm reinforced concrete.

A Supervising and controlling of calculation

Each calculation is checked according to the following criteria in order to guarantee accuracy.

- Plausibility
- Mass has to be in the range of 1,000-3,000 kg/sqm
- PE values have to be in the range of 1,000-3,000 MJ/sqm
- Plastic share has to be below 10% (for regular construction)
- Masses
- Window glass thickness between 8 and 15 mm
- Frame ratio below 20%
- Plastic foil below 1mm

§ 7.1.6 EEP for each building

Unlike materials, the office buildings are considered separately (not grouped). A screen will present the relevant information for each office building. Table 33 shows its categories.

Office building number
Category
Design and calculation by
Design and construction supervised by
Construction description
Gross floor area (sqm)
Weight (kg/sqm)
Building envelope EE (MJ/sqm)
Structure EE (MJ/sqm)
Interior (MJ/sqm)
Other (MJ/sqm)
EE total (MJ/sqm)
GWP total (kg CO_2 eq./sqm)

Table 33
Like introduced in chapter 6 the case studies are characterised by the parameter displayed.

Design and calculation by

The name of the student and the semester in which the design and the calculation was conducted are named in this category.

Design and construction supervised by

The students presented their design in the scope of the course, supervised by a professor and the author. It was explained earlier that the calculation supervising was done by the author (so no extra category was used for that).

Construction description

The construction description is the core element of the table. It describes the buildings construction subdivided in the items structure, façade and interior construction. The distribution of these items is displayed in the second circle diagram, and a relation can be created.

The material and the material thickness are named if sensible.

Gross floor area (sqm)

The gross floor area is chosen here as it is the most common indicator and provides comparability.

Weight (kg/sqm)

The weight indicates the construction method and is a control number to identify mistakes. For example, a main wood structure with a weight of over 2,000 kg/sqm wood lead to a follow-up control.

Building envelope, Structure, Interior

The organisation of the description continues with the separate breakdown of Building envelope, Structure and Interior in order to provide assignment of construction description, graph and number.

Other

Building elements that do not fit in the list of Building envelope, Structure and Interior are gathered here. This could apply to sun shade devices, for example.

EE total

The sum of the above mentioned parameters is displayed in EE total.

GWP total

The sum of the above mentioned categories in the indicator GWP is shown here.

All information can be presented in a table.

§ 7.2 Case studies office buildings

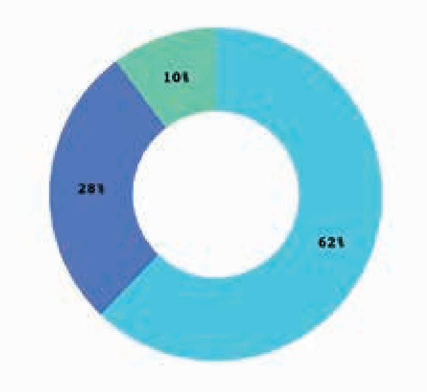
In the following 25 building case studies will be introduced according to the framework described in the previous abstract.

Short name	Calculation done by	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./sqm)
OB-01	Frederic Zielke, Tim Freund (NK WS 09/10)	3,038	217
OB-02	Valerie Gisbrecht, Daniel Schröder (NK WS 09/10)	1,573	206
OB-03	Pia Hartmann/ Janina Pörtner (NK WS 12/13)	2,506	239
OB-04	Martina Dril-ler/Johanna Stüve (NK WS 12/13)	2,959	232
OB-05	Lars Frenz/ Marcel Füchten-cordsjürgen (NK WS12/13)	2,180	220
OB-06	Marcel Hackmann/ Christoph Strugholtz (NK WS 12/13)	1,974	182
OB-07	Jannik Flöttmann/ Jan Baumgart-ner (NK WS 12/13)	2,530	231
OB-08	Nils Kruse , Julian Lianarachchi (NK WS 12/13)	4,029	377
OB-09	Matthias Joachim, Manuel Mün-sterteicher (NK WS 12/13)	2,324	277
OB-10	Sanida Corovic, Ebru Yalcin (NK WS 12/13)	1,900	225
OB-11	Fatima Ibrahimi, Nazan-Zeynep Gökal (NK WS 12/13)	1,909	210
OB-12	Vanessa Zeng, Stephanie Rohden (NK WS 08/09)	2,456	235
OB-13	Tristan Fürstenberg, Daniel Wie-gard (NK WS 08/09)	1,371	27
OB-14	Janina Schröder, Maik Gottlob (NK WS 08/09)	2,564	214
OB-15	Ann Kathrin Habighorst, Sarah Seigis (NK WS 08/09)	2,890	409
OB-16	Theresa Jock, Lena Kipshagen (NK WS 08/09)	1,807	111
OB-17	Christian Zeiger, Phillip Meise (NK WS 08/09)	1,382	164
OB-18	Petra Janouskova, Veronique Stegmann (NK WS 08/09)	2,577	224

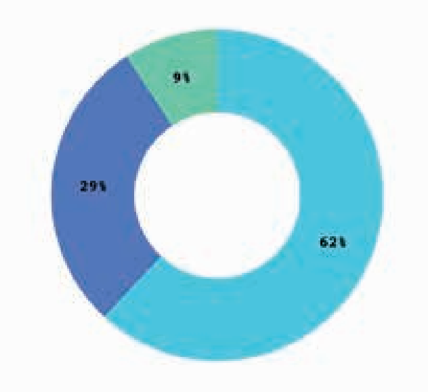
Short name	Calculation done by	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./sqm)
OB-19	Julian Rodenkirchen, Jens Diestel-kamp (NK WS 08/09)	3,859	305
OB-20	Fabian Huneke, Tim Böker (NK WS 12/13)	1,812	77
OB-21	Stanislaw Sabelfeld, Philipp Böd-deker (NK WS 08/09)	2,438	224
OB-22	Ann Kathrin Jungk, Madina Azim (NK WS 08/09)	2,104	218
OB-23	Senta Barwinsky, Ramona Krichel (NK WS 08/09)	2,195	171
OB-24	Inga Schulze-Geißler, Helena Block (NK WS 08/09)	2,888	70
OB-25	Jonas Becker, Felix Küch (NK WS 10/11)	1,591	152

§ 7.2.1 Office building 01

OB 01				
Category	Case study information			
Design and calculation by	Frederic Zielke, Tim Freund (NK WS 09/10)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Steel structure, steel columns, troughed steel sheets with OSB boards form slabs, concrete core staircase Double skin façade: (primary) curtain wall, steel mullion transom façade with glass and insulated clay fillings, (mineral wool) (secondary) steel sword are connected to the main structure and hold perforated steel sheets Metal framework with clay planking			
Gross floor area (sqm)	16,510			
Weight (kg/sqm)	1.227			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	1,889	62	135	62
Structure	837	28	63	29
Interior	312	10	20	9
Other	0	0	0	0
Total	**3,038**		**217**	

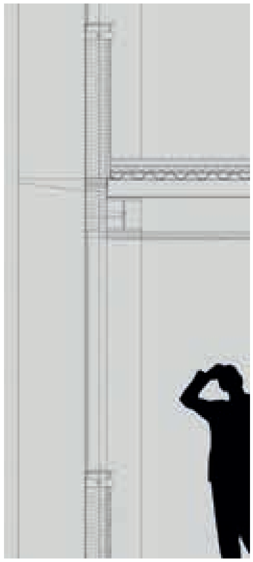


1



2

Figure 58
OB 01 Distribution building elements (1) EE, (2) GWP)



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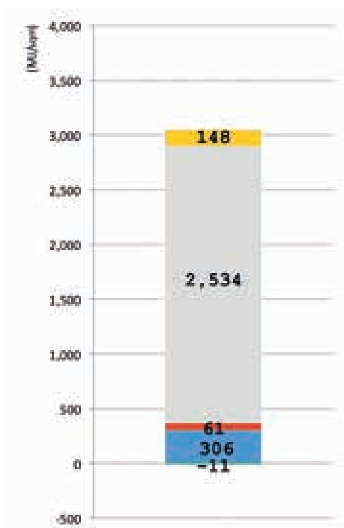

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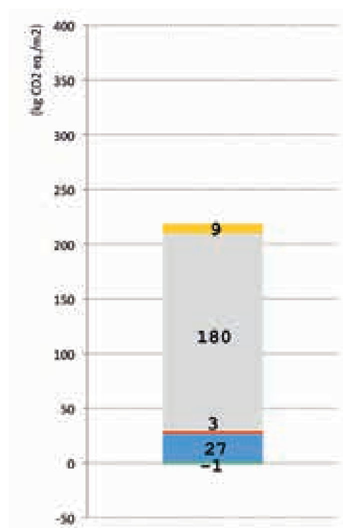


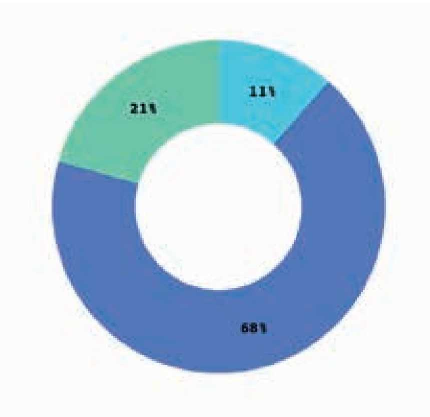
4

Figure 59

OB 01 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.2 Office building 02

OB 02				
Category	**Case study information**			
Design and calculation by	Valerie Gisbrecht, Daniel Schröder (NK WS 09/10)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Steel columns, concrete ceilings (200mm), concrete core stairways Plastered OSB, 300mm stamped mud, 15 mm, clay board, 180 mm foam glass, plastered Stamped mud interior walls , suspended ceiling			
Gross floor area (sqm)	14,007			
Weight (kg/sqm)	2,072			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	181	11	40	20
Structure	1,068	68	162	80
Interior	324	21	1	0
Other	0	0	0	0
Total	**1,598**		**203**	



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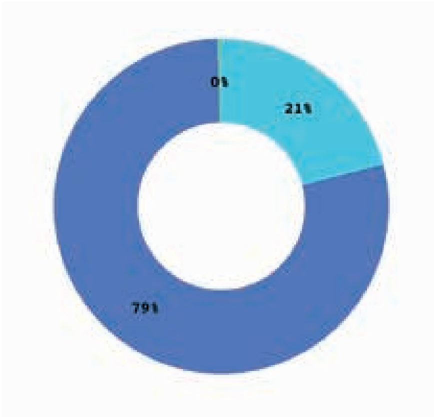
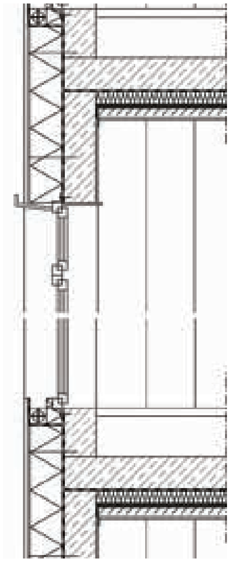


2

Figure 60
OB 02 Distribution building elements (1) EE,(2) GWP)



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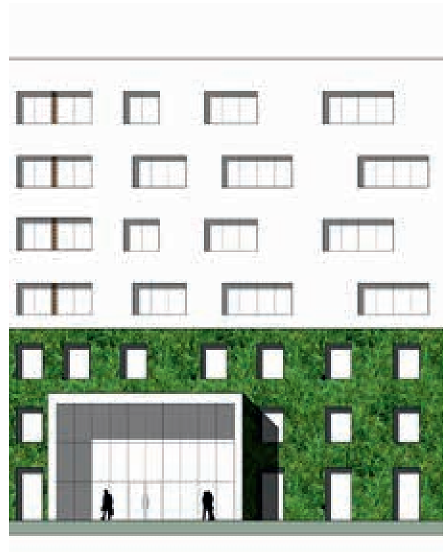

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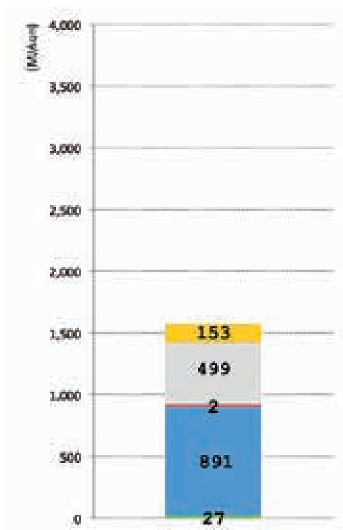

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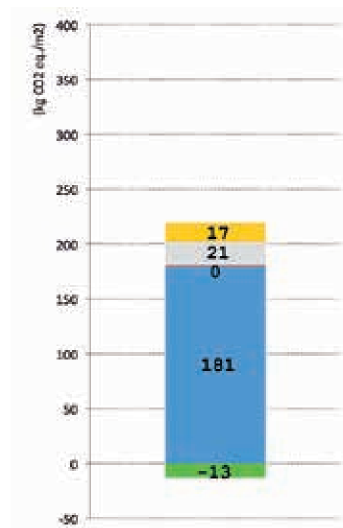
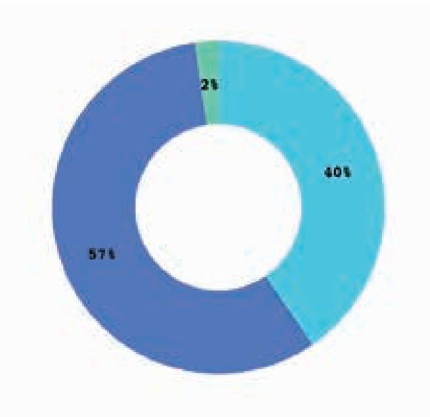


4

Figure 61
OB 02 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.3 Office building 03

OB 03				
Category	**Case study information**			
Design and calculation by	Pia Hartmann/ Janina Pörtner (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete slabs, concrete core staircases Modular façade, wooden frame construction 200/50, gypsum planking, wooden battens 30mm, vapour barrier, insulation 200mm, OSB 12mm, vertical batten 30mm, horizontal fibre cement boards 13mm Metal framework with gypsum planking			
Gross floor area (sqm)	11,081			
Weight (kg/sqm)	2.989			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	928	40	72	32
Structure	1,315	57	149	66
Interior	53	2	3	2
Other	0	0	0	0
Total	**2,296**		**225**	



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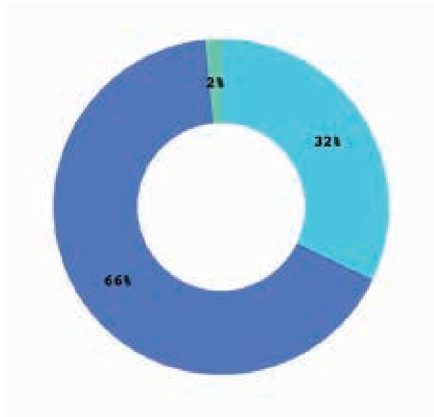

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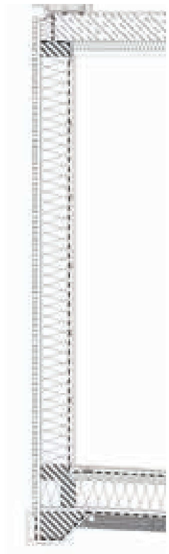
Figure 62
OB 03 Distribution building elements (1) EE, (2) GWP



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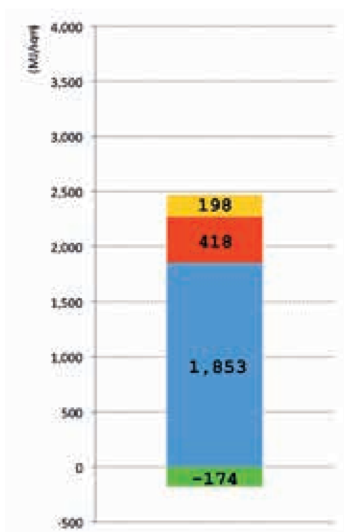

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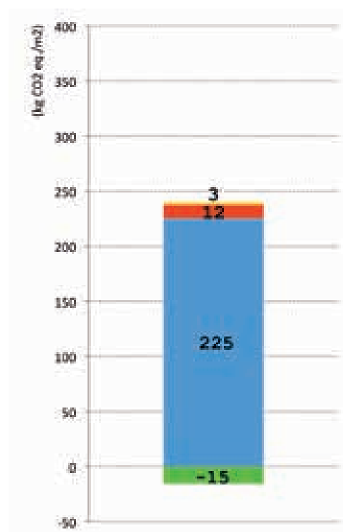

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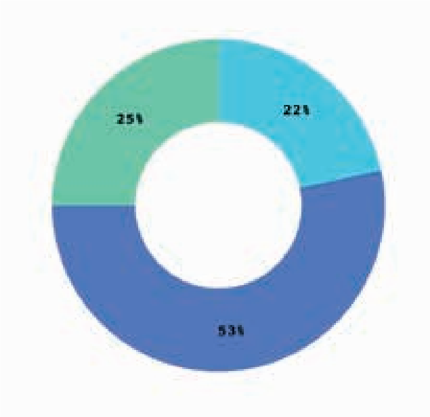
Figure 63
OB 03 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.4 Office building 04

OB 04				
Category	Case study information			
Design and calculation by	Martina Driller/Johanna Stüve (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete slabs, concrete core staircases Corner façade: Metal framework with gypsum planking, elevated floor with linoleum covering			
Gross floor area (sqm)	11,592			
Weight (kg/sqm)	1,578			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	640	22	42	18
Structure	1,579	53	156	67
Interior	740	25	34	15
Other	0	0	0	0
Total	**2,959**		**232**	



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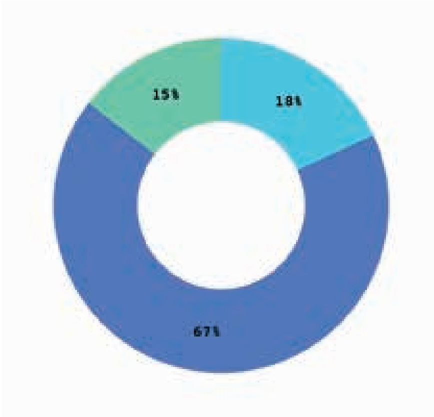

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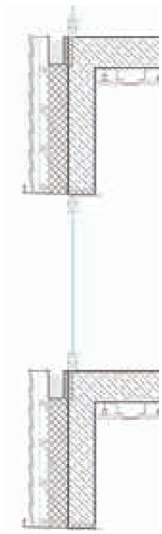
Figure 64
OB 04 Distribution building elements (1) EE, (2) GWP



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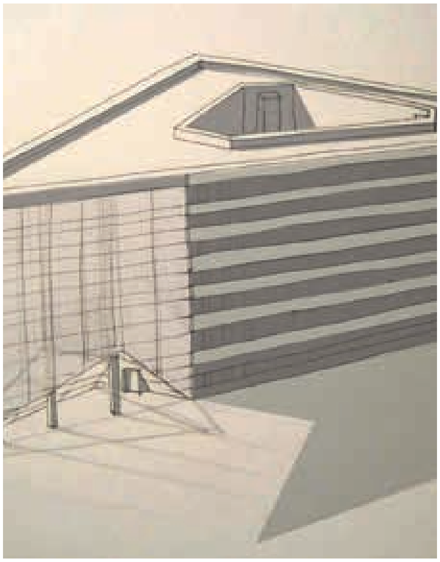

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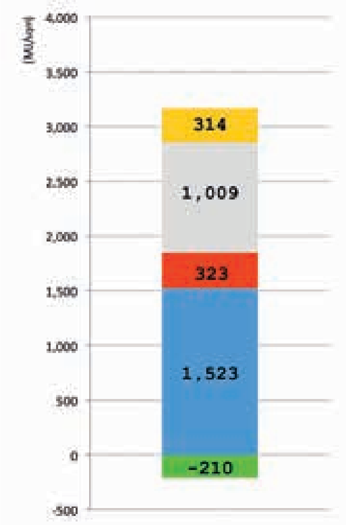

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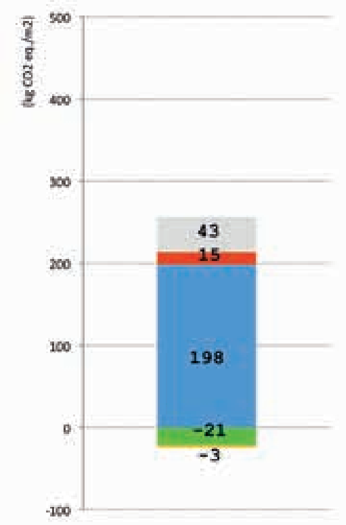

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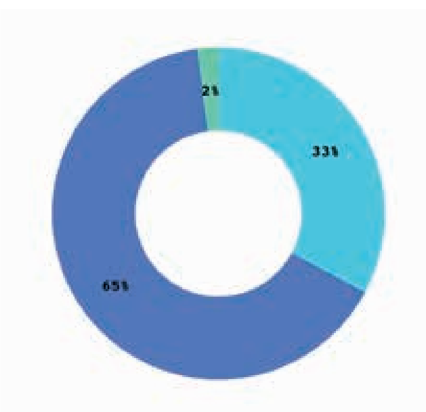
Figure 65

OB 04 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.5 Office building 05

OB 05				
Category	**Case study information**			
Design and calculation by	Lars Frenz/ Marcel Füchtencordsjürgen (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with floating screed Double skin façade: concrete sandwich with windows, wooden frame (primary) and a glass curtain wall (trombe wall) (secondary) Metal framework with wooden planking			
Gross floor area (sqm)	16,510			
Weight (kg/sqm)	1,253			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	662	33	73	33
Structure	1,311	65	146	67
Interior	41	2	0	0
Other	0	0	0	0
Total	**2,041**		**220**	



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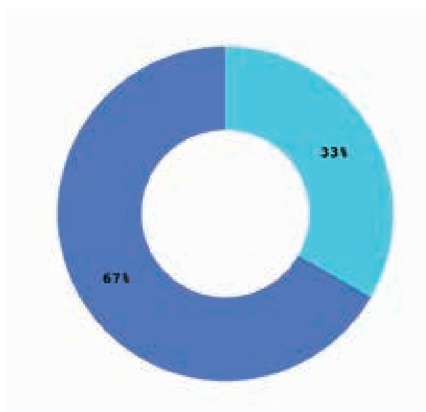

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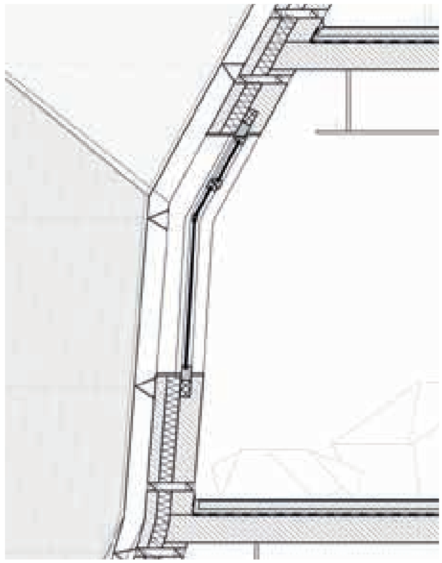
Figure 66
OB 05 Distribution building elements (1) EE, (2) GWP



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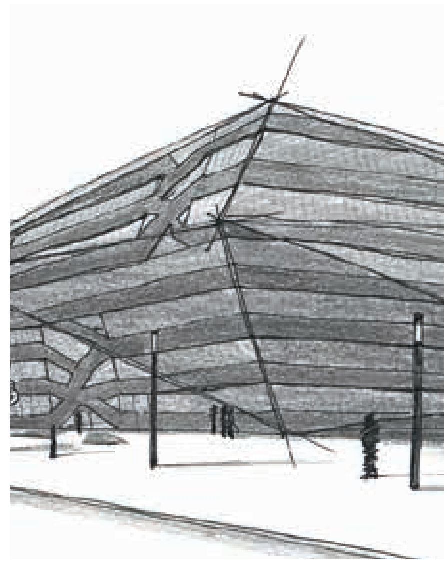

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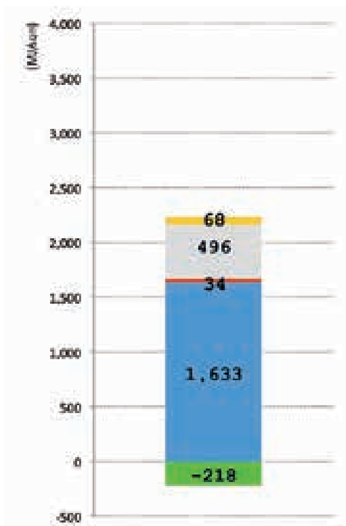

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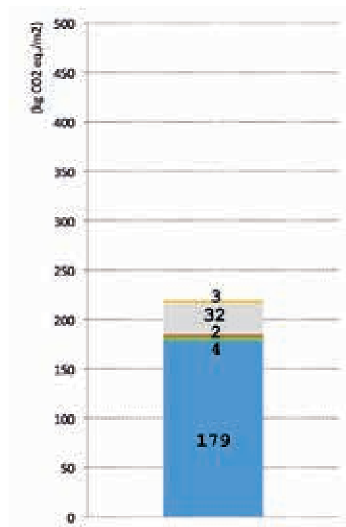

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Figure 67

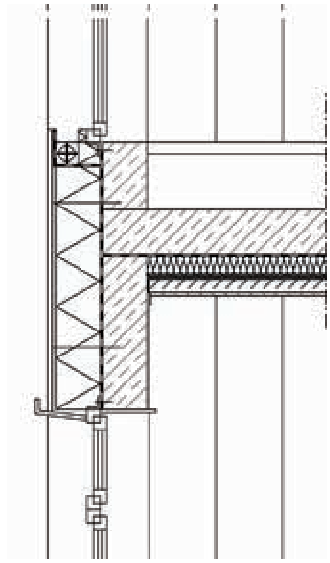
OB 05 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.6 Office building 06

OB 06				
Category	Case study information			
Design and calculation by	Marcel Hackmann/ Christoph Strugholtz (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs, elevated floor Modular façade with wood structure and coated wood fibre board (rear façade) Metal framework with gypsum planking			
Gross floor area (sqm)	10,965			
Weight (kg/sqm)	1,011			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	478	24	-1	-1
Structure	973	49	141	77
Interior	523	26	43	23
Other	0	0	0	0
Total	**1,974**		**182**	

1 2

Figure 68
OB 06 Distribution building elements (1) EE, (2) GWP



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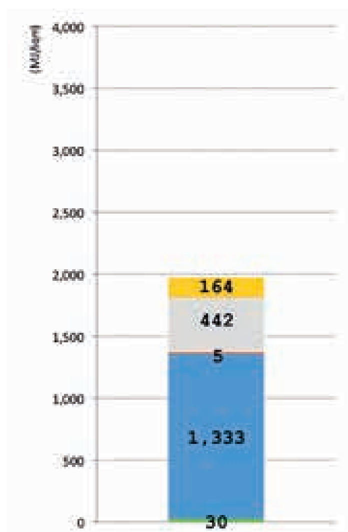

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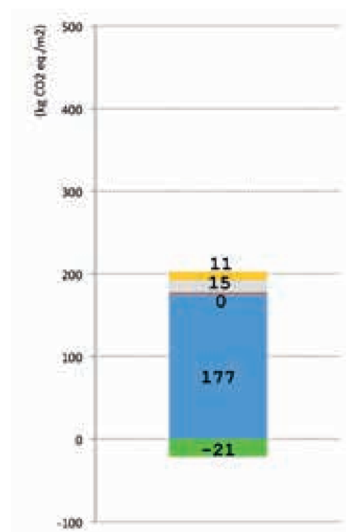

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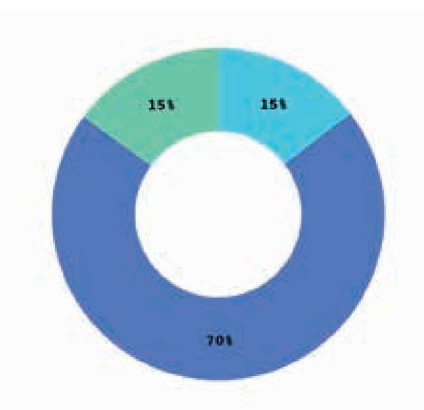
Figure 69
O B 06 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.7 Office building 07

OB 07				
Category	**Case study information**			
Design and calculation by	Jannik Flöttmann/ Jan Baumgartner (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with elevated floor (wooden boards) Double façade: Aluminium transom mullion façade (primary), substructure aluminium, textile membrane (secondary) Massive interior walls (concrete) with glass parts, partly metal framework with gypsum planking Glass roof with steel substructure for the atrium			
Gross floor area (sqm)	13,185			
Weight (kg/sqm)	2,408			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	535	15	38	8
Structure	2,566	70	412	91
Interior	548	15	2	0
Other	0	0	0	0
Total	**3,649**		**452**	



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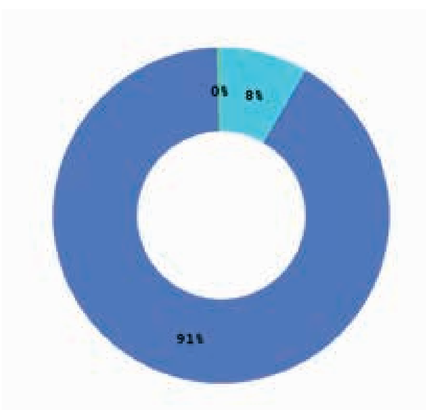

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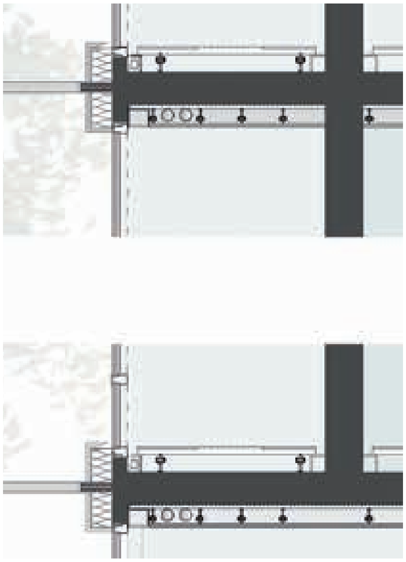
Figure 70
OB 07 Distribution building elements (1) EE, (2) GWP



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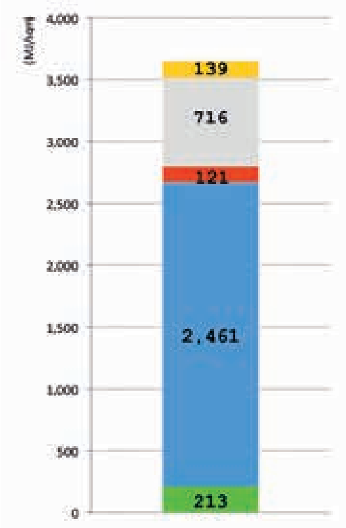

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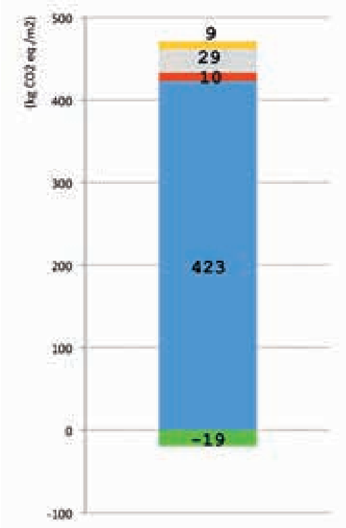

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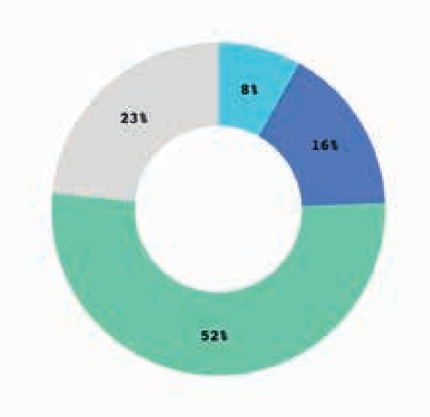
Figure 71

OB 07 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.8 Office building 08

OB 08				
Category	Case study information			
Design and calculation by	Nils Kruse , Julian Lianarachchi (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	ddd250mm ceiling thickness, massive façade and double glazing			
Gross floor area (sqm)	12,161			
Weight (kg/sqm)	1,301			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	350	8	51	14
Structure	710	16	112	30
Interior	2,259	52	130	35
Other	1,018	23	80	21
Total	**4,339**		**373**	



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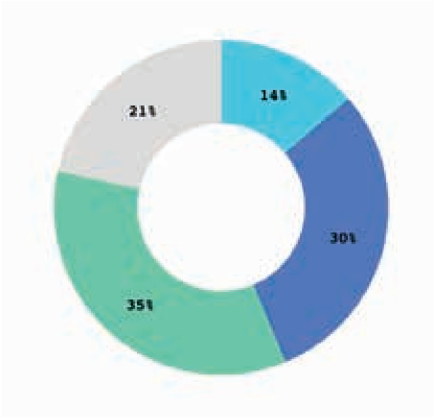

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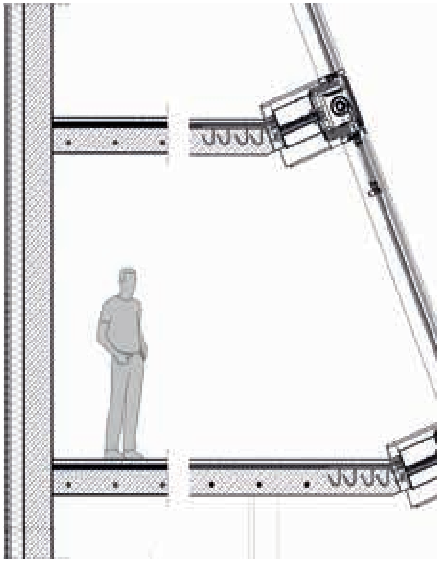
Figure 72
OB 08 Distribution building elements (1) EE, (2) GWP



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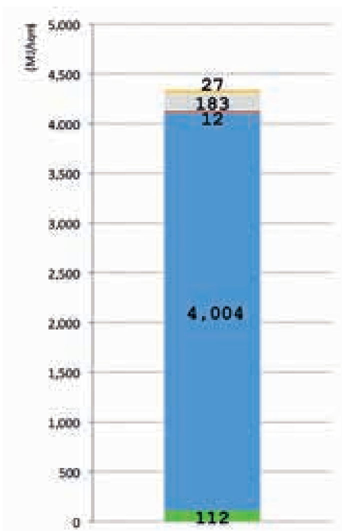

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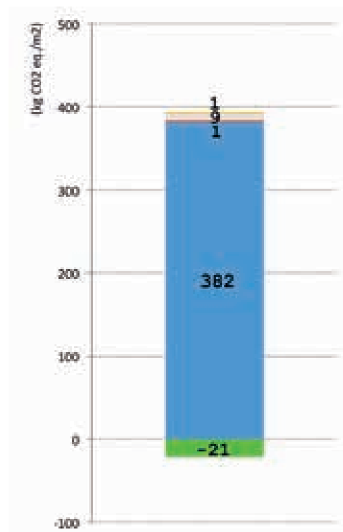

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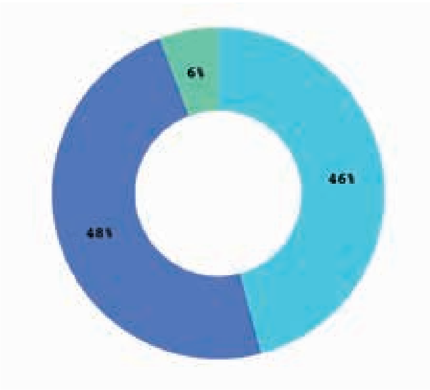
Figure 73

OB 08 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.9 Office building 09

OB 09				
Category	**Case study information**			
Design and calculation by	Matthias Joachim, Manuel Münsterteicher (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Cavity wall with load-bearing limestone and reared brick, concrete bulkheads as load bearing interior walls, concrete core staircase and concrete slabs Four layers of glass, aluminium-wood windows, glass atrium with steel substructure Metal framework with gypsum planking, elevated floor (dry screed)			
Gross floor area (sqm)	14,400			
Weight (kg/sqm)	2,018			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	1,008	46	100	37
Structure	1,063	48	158	59
Interior	126	6	10	4
Other	0	0	0	0
Total	**2,298**		**267**	



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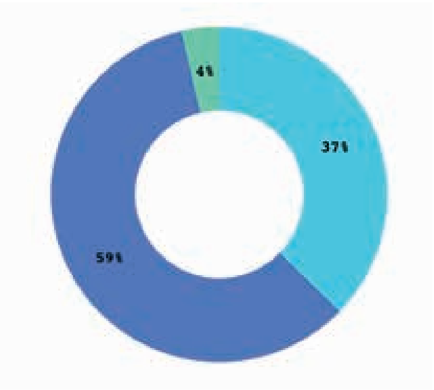

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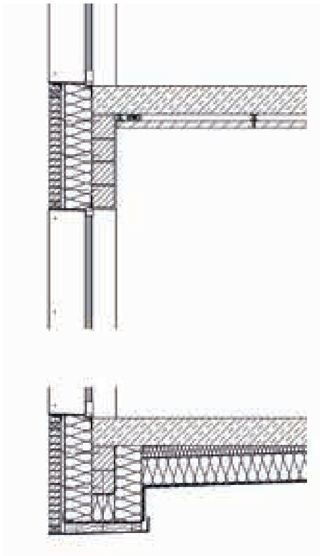
Figure 74
OB 09 Distribution building elements (1) EE, (2) GWP



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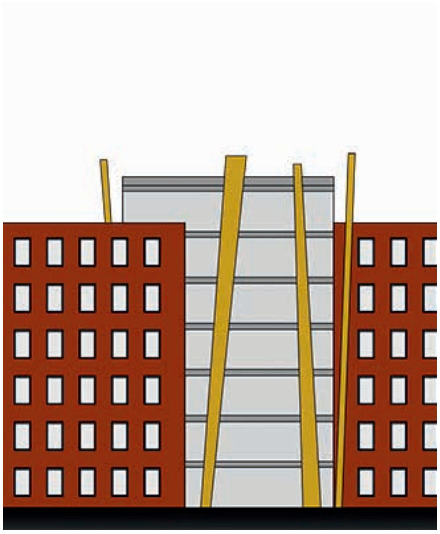

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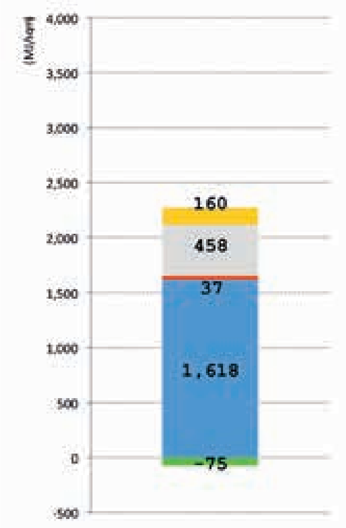

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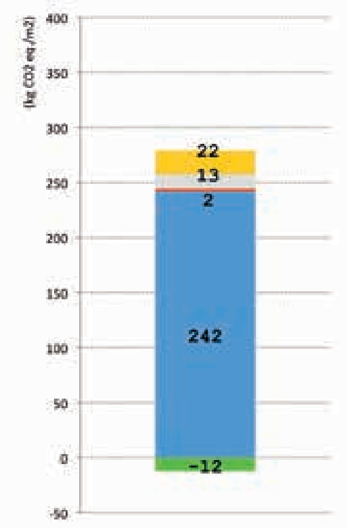

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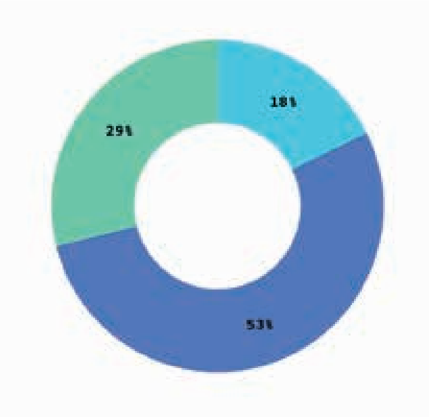
Figure 75

OB 09 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.10 Office building 10

OB 10				
Category	Case study information			
Design and calculation by	Sanida Corovic, Ebru Yalcin (NK WS12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with floating Curtain façade, wood frame with insulation (EPS), clad with coated wood fibre board (rear façade) Metal framework with gypsum planking			
Gross floor area (sqm)	12,965			
Weight (kg/sqm)	1,299			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	337	18	33	15
Structure	1,015	53	148	66
Interior	548	29	43	19
Other	0	0	0	0
Total	**1,900**		**225**	



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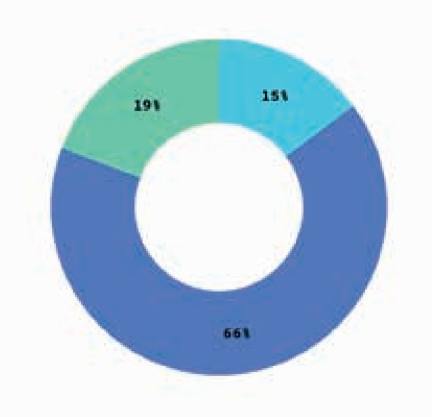

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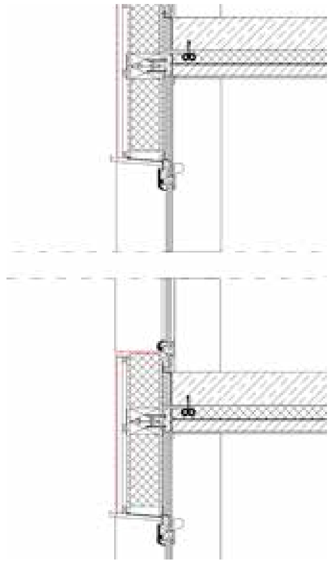
Figure 76
OB 10 Distribution building elements (1) EE, (2) GWP



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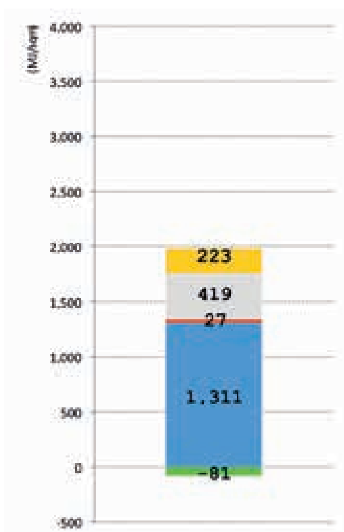

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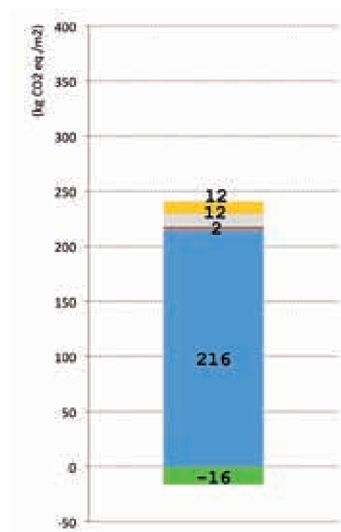

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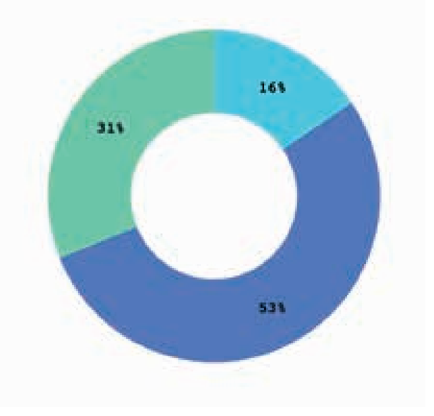
Figure 77
OB 10 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.11 Office building 11

OB 11				
Category	Case study information			
Design and calculation by	Fatima Ibrahimi, Nazan-Zeynep Gökal (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Lutz Artmann			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with floating Curtain façade, aluminium mullion transom façade, glass filling and panels with wood frame, insulated (mineral wool), wooden fibre board on the inside, fibre cement board on the outside, aluminium sheet cads the slab edge Metal framework with gypsum planking			
Gross floor area (sqm)	13,309			
Weight (kg/sqm)	989			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm))	GWP (%)
Building envelope	297	16	18	8
Structure	1,019	53	131	63
Interior	593	31	61	29
Other	0	0	0	0
Total	**1,909**		**210**	



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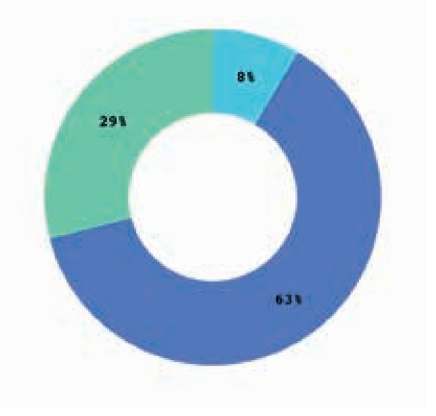

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Figure 78
OB 11 Distribution building elements (1) EE, (2) GWP

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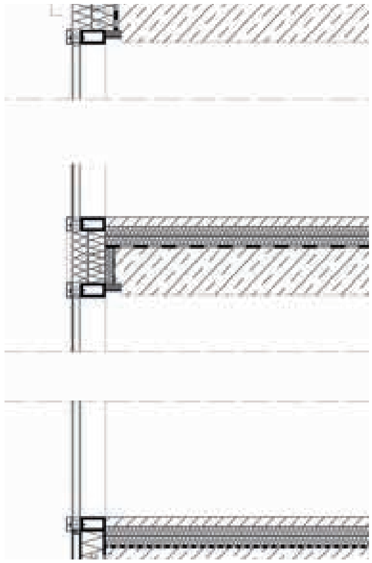

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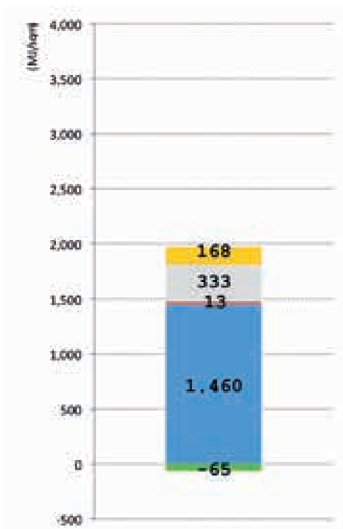

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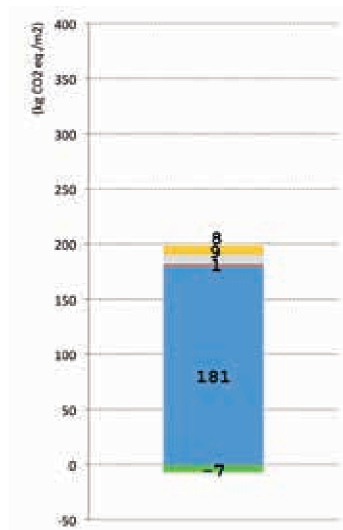

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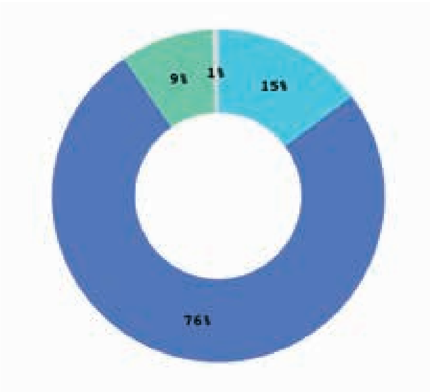
Figure 79

OB 11 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.12 Office building 12

OB 12				
Category	Case study information			
Design and calculation by	Vanessa Zeng, Stephanie Rohden (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with floating, steel structure supports the glass atrium Curtain wall, wood mullion transom façade, glass filling and panels with wood frame, insulated (mineral wool), wooden fibre board on the inside, fibre cement board on the outside, aluminium sheet cads the slab edge / Metal framework with gypsum planking, suspended ceilings			
Gross floor area (sqm)	14,159			
Weight (kg/sqm)	1,530			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	346	15	25	11
Structure	1,885	76	193	82
Interior	221	9	17	7
Other	15	1	0	0
Total	**2,456**		**235**	



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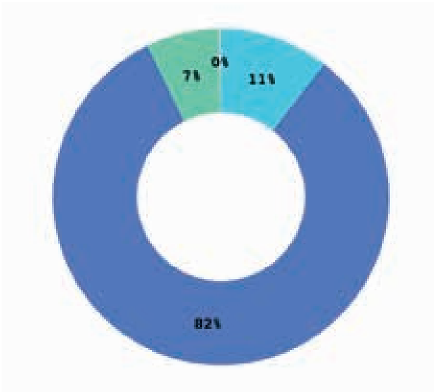

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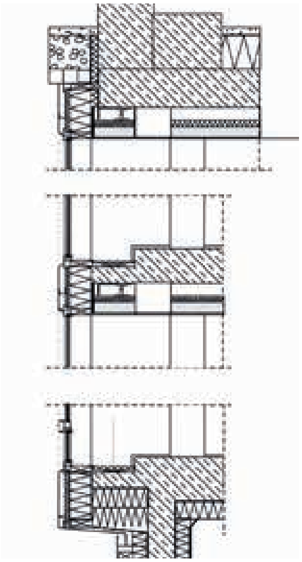
Figure 80
OB 12 Distribution building elements (1) EE, (2) GWP



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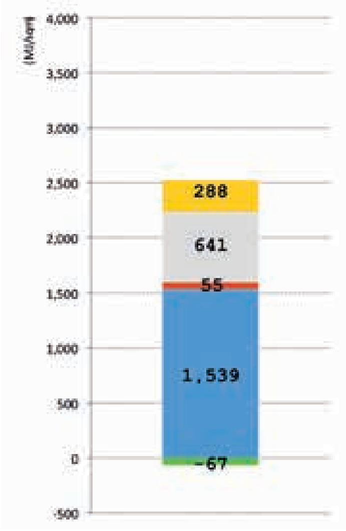

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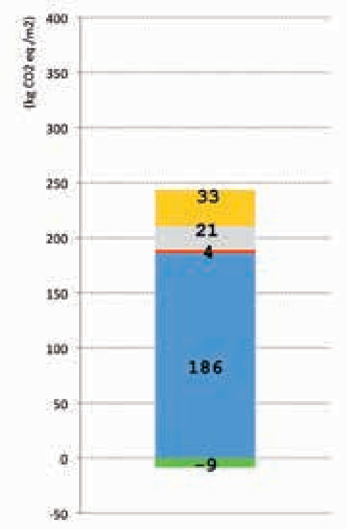

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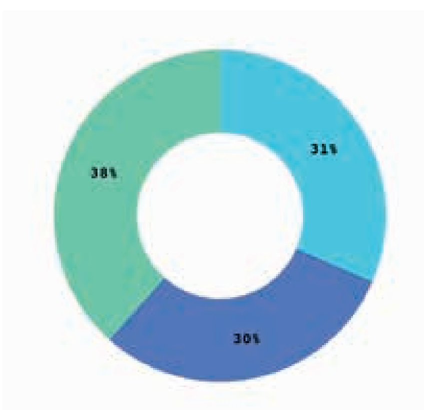
Figure 81
OB 12 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.13 Office building 13

OB 13				
Category	**Case study information**			
Design and calculation by	Tristan Fürstenberg, Daniel Wiegard (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Tristan Fürstenberg, Daniel Wiegard (NK WS 08/09) Linda Hildebrand, Ulrich Knaack Wood skeleton (Glued laminated timber beams), elevated floor (fibre boards with parquet flooring, hemp insulation) in ground floor, concrete core staircases Curtain wall, wood mullion transom with glass filling and decentralised climate unit (wood frame, aluminium plates with clay surface on the inside) Wood framework with dry clay planking			
Gross floor area (sqm)	14,700			
Weight (kg/sqm)	607			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm)**	**GWP (%)**
Building envelope	432	31	33	120
Structure	413	30	51	187
Interior	526	38	-57	-207
Other	0	0	0	0
Total	**1,371**		**27**	



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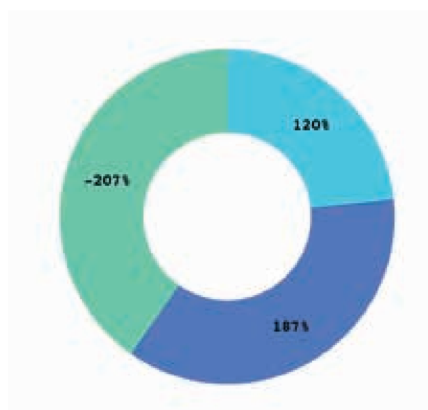

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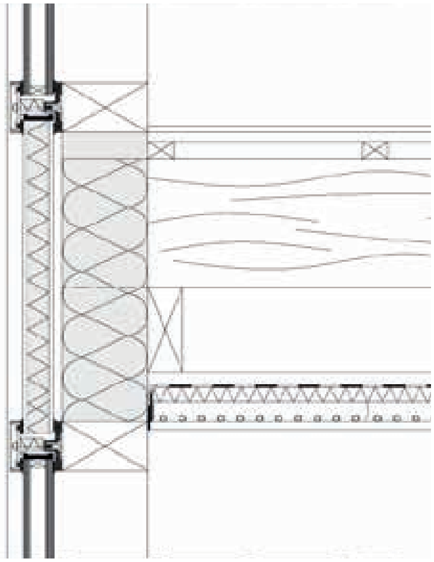
Figure 82
OB 13 Distribution building elements (1) EE, (2) GWP



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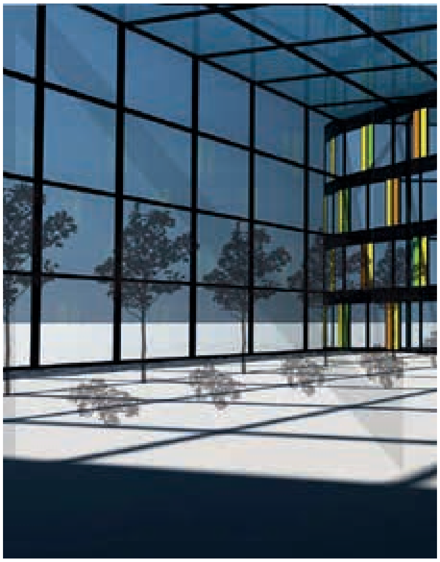

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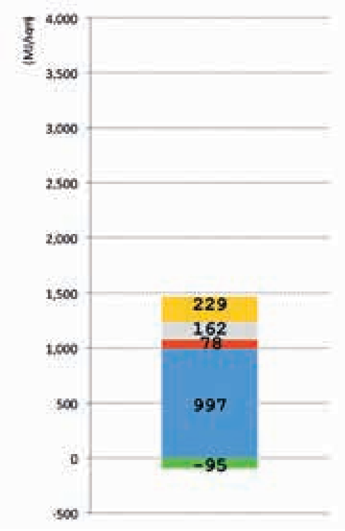

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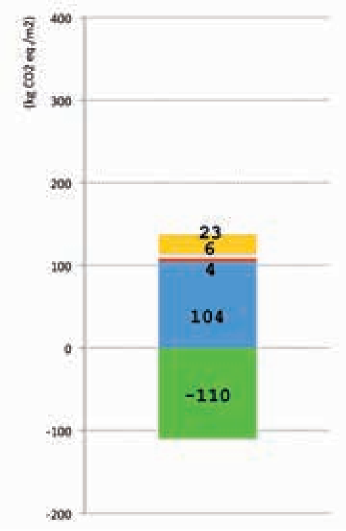

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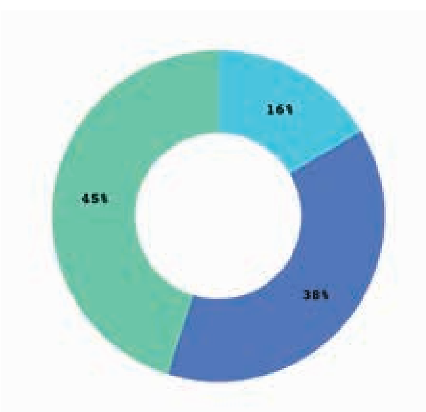
Figure 83

OB 13 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.14 Office building 14

OB 14				
Category	Case study information			
Design and calculation by	Janina Schröder, Maik Gottlob (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with elevated floor (wooden boards) Aluminium transom mullion façade, glass filling and insulated panels with aluminium cover, slab edge is with insulation and aluminium sheet Metal framework with gypsum planking, elevated floor			
Gross floor area (sqm)	14,180			
Weight (kg/sqm)	1,285			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	422	16	30	14
Structure	985	38	163	76
Interior	1,157	45	22	10
Other	0	0	0	0
Total	**2.564**		**214**	



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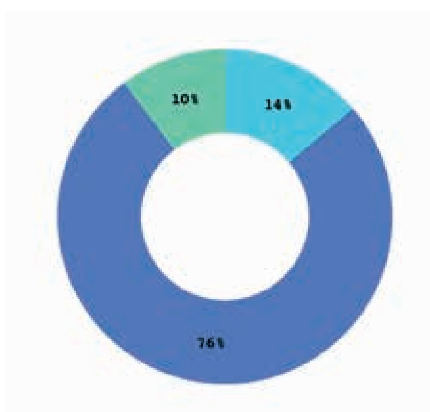

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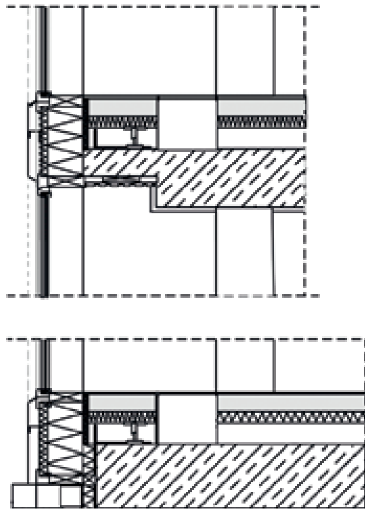
Figure 84
OB 14 Distribution building elements (1) EE, (2) GWP



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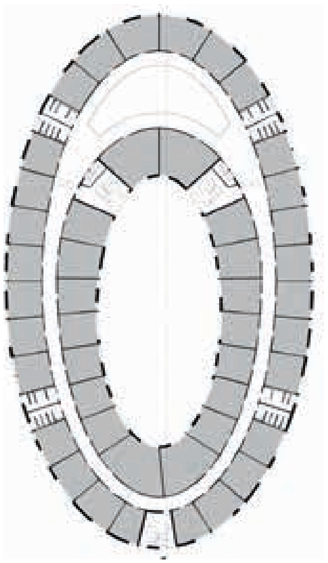

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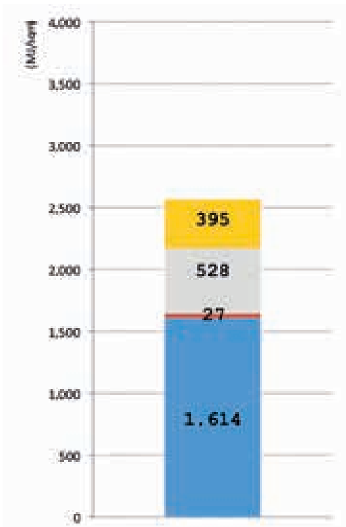

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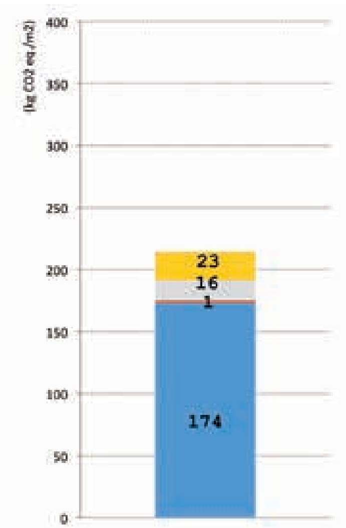

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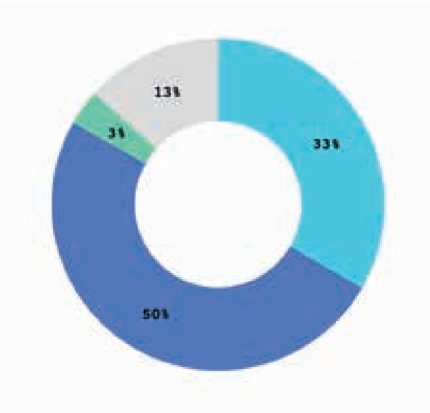
Figure 85
OB 14 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.15 Office building 15

OB 15				
Category	**Case study information**			
Design and calculation by	Ann Kathrin Habighorst, Sarah Seigis (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs with elevated floor (wooden boards) Aluminium transom mullion façade Metal framework with gypsum planking, floated screed with PVC cover Coloured metal sheets as sun shading device, substructure gal-vanized steel			
Gross floor area (sqm)	14,166			
Weight (kg/sqm)	1,109			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm))**	**GWP (%)**
Building envelope	847	33	59	22
Structure	1,263	50	151	56
Interior	88	3	34	13
Other	338	13	27	10
Total	**2,537**		**272**	



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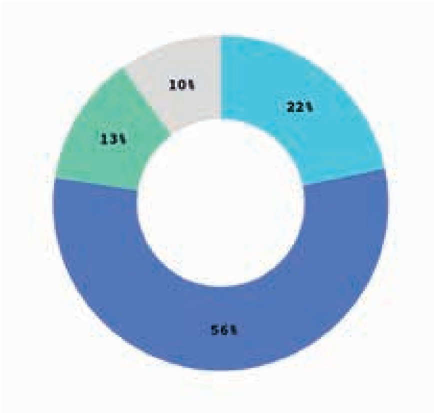

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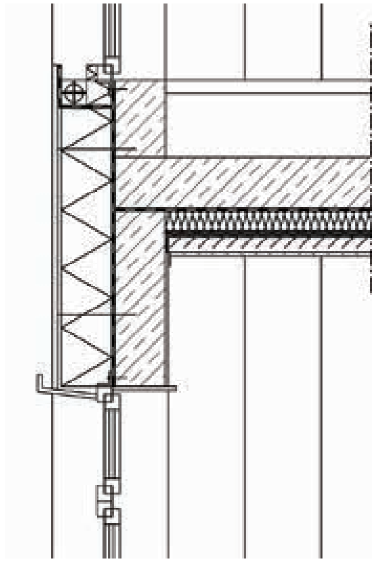
Figure 86
OB 15 Distribution building elements (1) EE, (2) GWP



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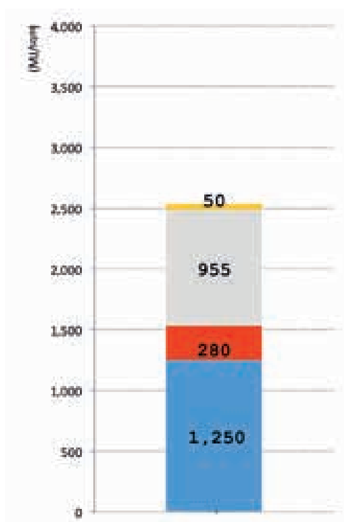

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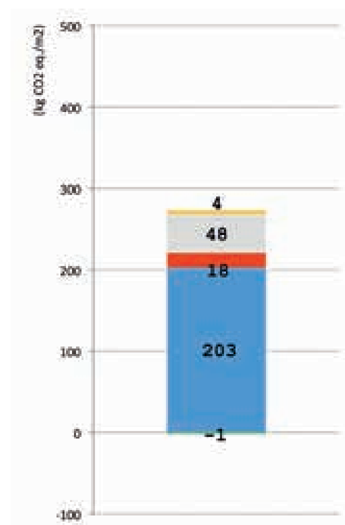

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Figure 87

OB 15 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.16 Office building 16

OB 16				
Category	Case study information			
Design and calculation by	Theresa Jock, Lena Kipshagen (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (240mm) Curtain wall: Wood frame construction, ventilated wood fibre board in parapet height Metal framework with gypsum planking, suspended ceiling			
Gross floor area (sqm)	14,166			
Weight (kg/sqm)	1,211			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	258	14	26	23
Structure	956	53	112	101
Interior	593	33	-27	-24
Other	0	0	0	0
Total	**1,807**		**111**	

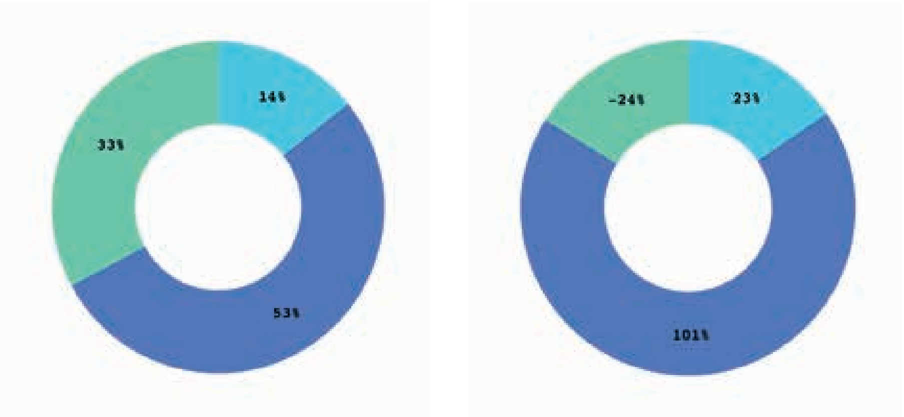

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Figure 88
OB 16 Distribution building elements (1) EE, (2) GWP

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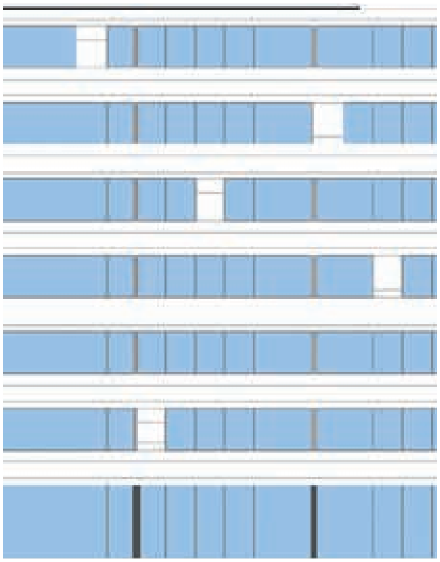

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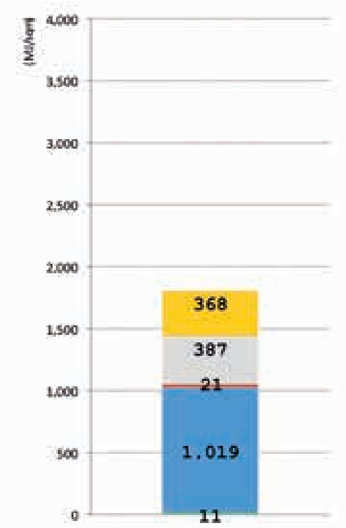

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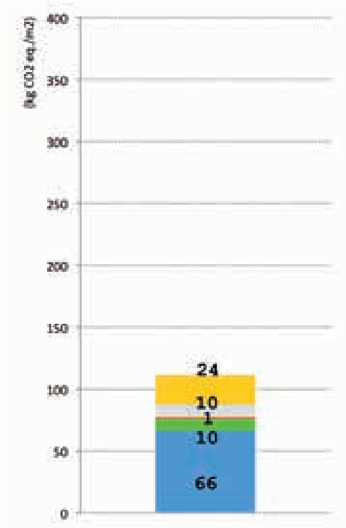

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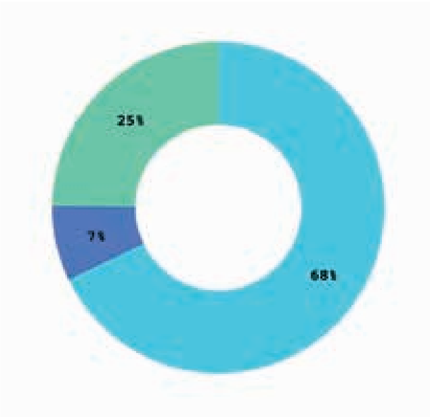
Figure 89
OB 16 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.17 Office building 17

OB 17				
Category	**Case study information**			
Design and calculation by	Christian Zeiger, Phillip Meise (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Timber frame construction, concrete core staircase and wood frame slabs Modular façade wood frame, IGU, impact protection Wood framework with gypsum planking, floated screed in ground level, else elevated floor with carpet(5mm)			
Gross floor area (sqm)	12,648			
Weight (kg/sqm)	826			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./sqm))**	**GWP (%)**
Building envelope	937	68	68	42
Structure	101	7	80	49
Interior	343	25	16	10
Other	0	0	0	0
Total	**1,382**		**164**	



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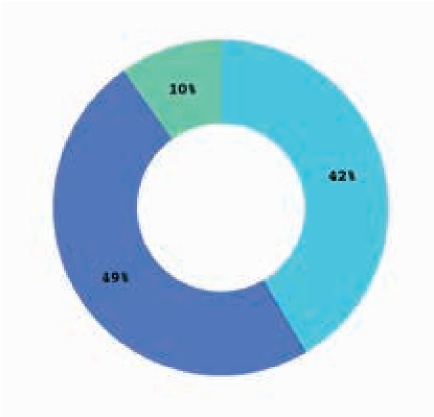

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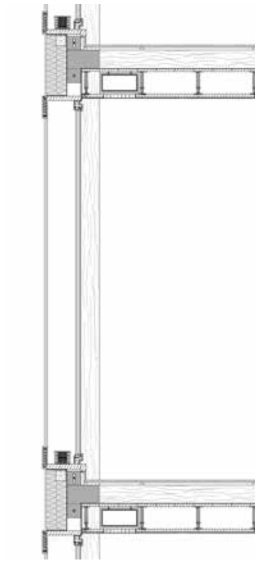
Figure 90
OB 17 Distribution building elements (1) EE, (2) GWP



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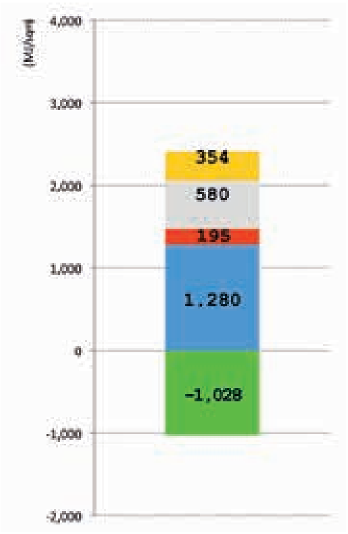

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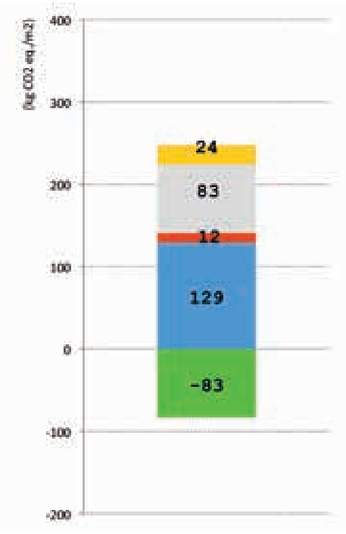

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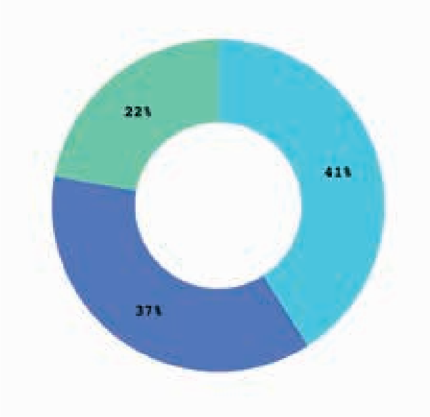
Figure 91
OB 17 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.18 Office building 18

OB 18				
Category	**Case study information**			
Design and calculation by	Petra Janouskova, Veronique Stegmann (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (240mm) Aluminium transom mullion façade Metal framework with gypsum planking, floated screed, suspended ceiling			
Gross floor area (sqm)	16,836			
Weight (kg/sqm)	1,139			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	1,056	41	73	36
Structure	950	37	101	50
Interior	572	22	30	15
Other	0	0	0	0
Total	**2,577**		**80**	



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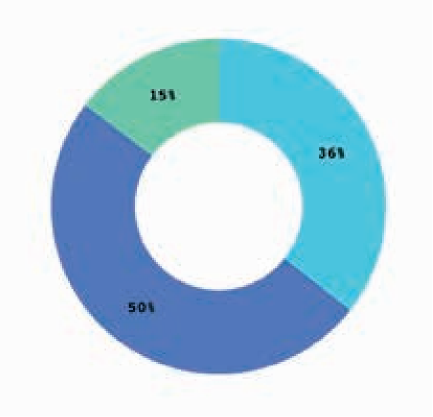

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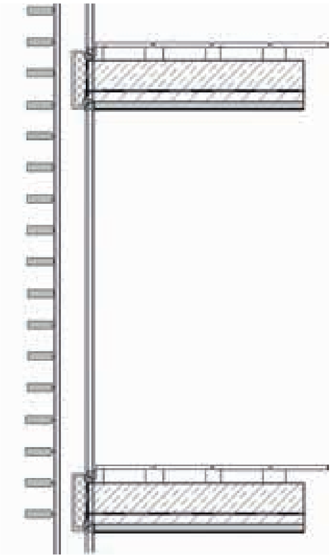
Figure 92
OB 18 Distribution building elements (1) EE, (2) GWP



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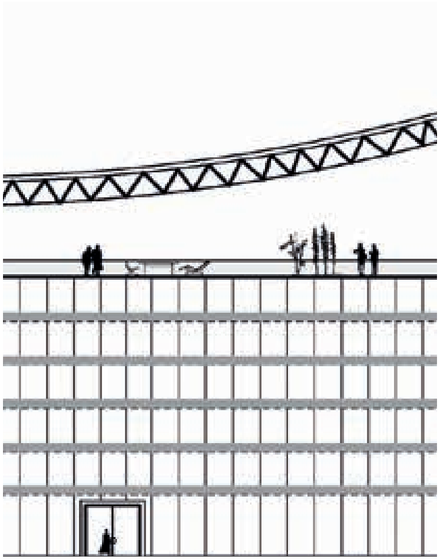

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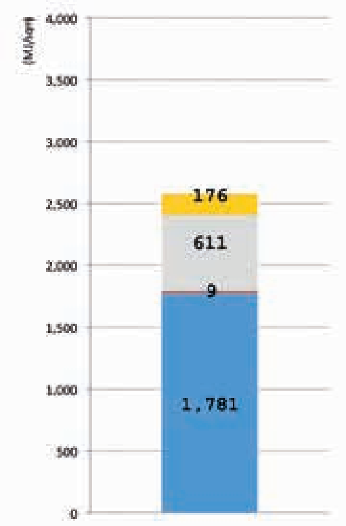

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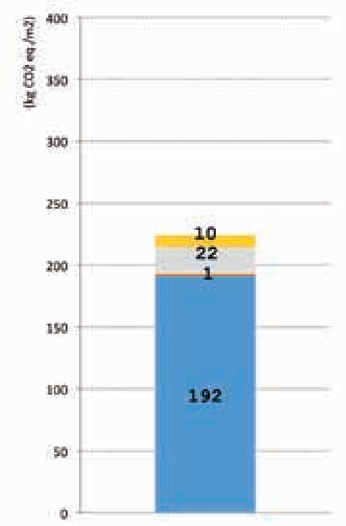

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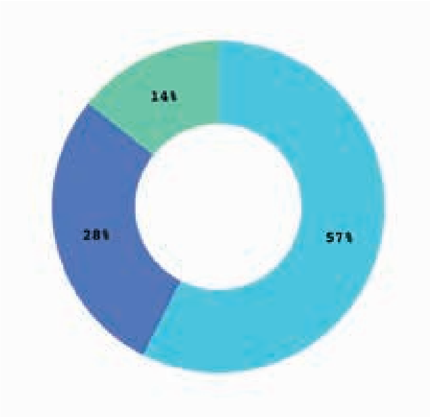
Figure 93

OB 18 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.19 Office building 19

OB 19				
Category	**Case study information**			
Design and calculation by	Julian Rodenkirchen, Jens Diestelkamp (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (240mm) Double façade, both layers aluminium transom mullion façade, glass filling, galvanized steel substructure Metal framework with gypsum planking, floated screed			
Gross floor area (sqm)	12,648			
Weight (kg/sqm)	1,584			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./sqm)	GWP (%)
Building envelope	2,218	57	150	49
Structure	1,089	28	121	40
Interior	552	14	33	11
Other	0	0	0	0
Total	**3,859**		**305**	



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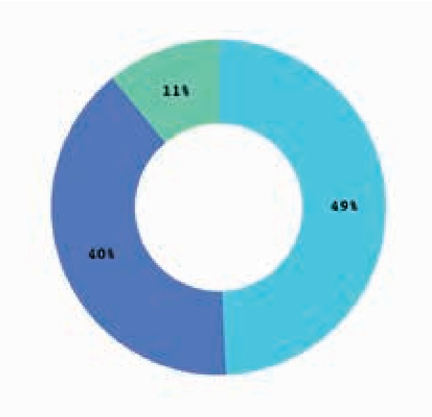

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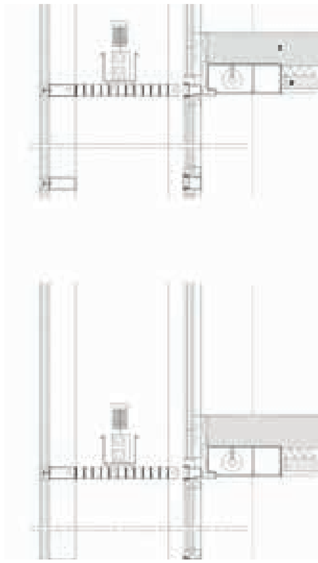
Figure 94
OB 19 Distribution building elements (1) EE, (2) GWP



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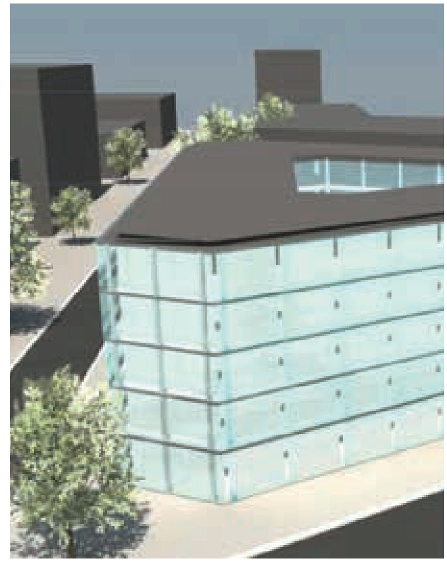

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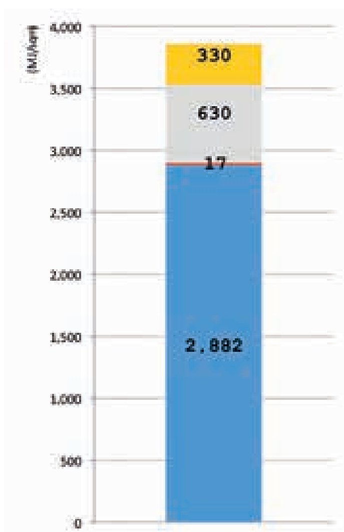

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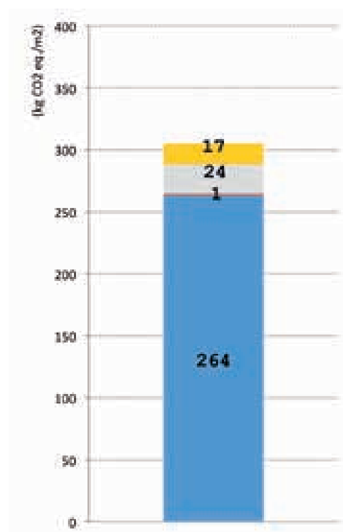

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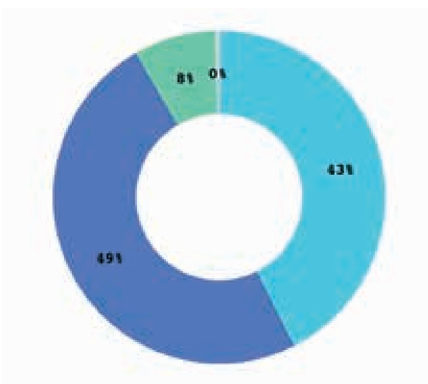
Figure 95

OB 19 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.20 Office building 20

OB 20				
Category	**Case study information**			
Design and calculation by	Fabian Huneke, Tim Böker (NK WS 12/13)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	1st-5th fl.: massive brick walls, 6th+7th fl. massive wood construction, concrete core staircase and hybrid slabs (concrete-wood) 1st-5th Fl.: MF-cold, double leaf wall, hollow brick with mineral filling (365mm), black clinker facing shell (115mm) ventilated 6th+7th Fl.: MF- cold, Massive wood (220mm), hemp insulation (240mm) closed atrium roof with foil pillows, wooden substructure, aluminium cover cap 1st-5th Fl.Brick walls (115mm), 6th+7th fl. massive wood walls floated screed			
Gross floor area (sqm)	16,496			
Weight (kg/sqm)	2,281			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./ sqm)**	**GWP (%)**
Building envelope	777	43	-49	-71
Structure	896	49	104	149
Interior	146	8	17	24
Other	-7	0	-1	-2
Total	**1,812**		**77**	



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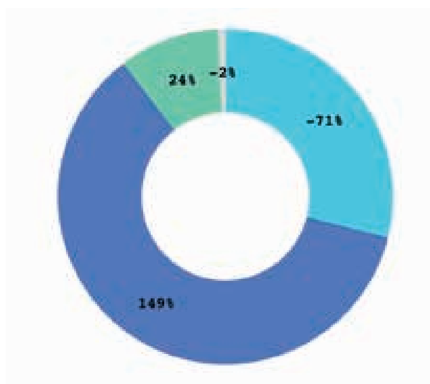

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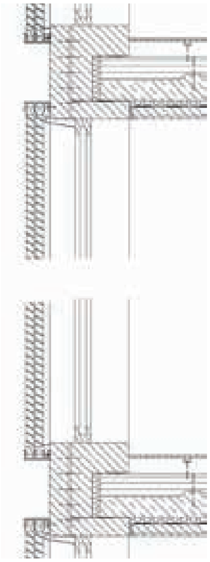
Figure 96

OB 20 Distribution building elements (1) EE, (2) GWP



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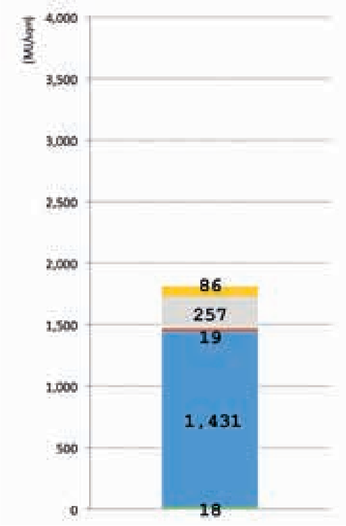

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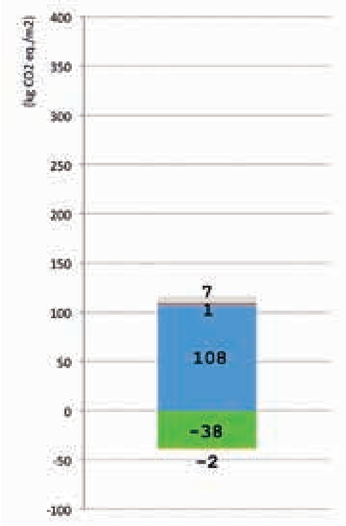

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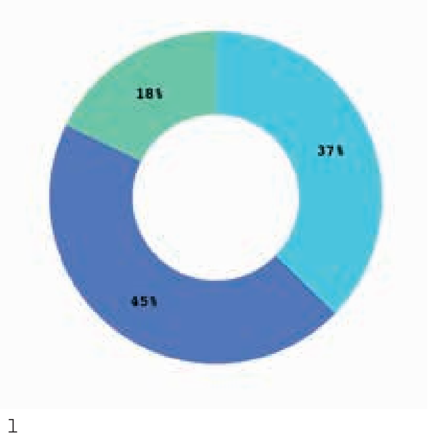
Figure 97
OB 20 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.21 Office building 21

OB 21				
Category	**Case study information**			
Design and calculation by	Stanislaw Sabelfeld, Philipp Böddeker (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs CW- Aluminium mullion transom façade, insulated slab edge (aerated concrete) Metal framework with gypsum planking, elevated floor dry screed, Linoleum cover Sun shading, metal frame			
Gross floor area (sqm)	13,332			
Weight (kg/sqm)	1,201			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./ sqm)**	**GWP (%)**
Building envelope	905	37	80	36
Structure	1,090	45	130	58
Interior	432	18	13	6
Other	11	0	1	0
Total	**2,438**		**224**	



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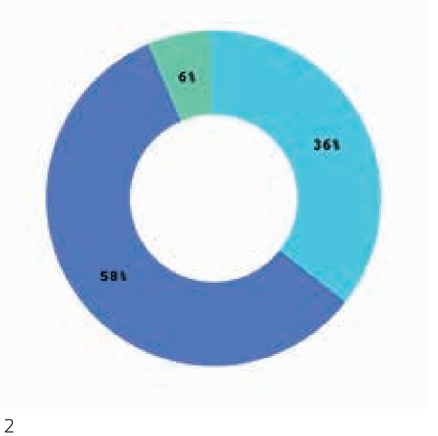

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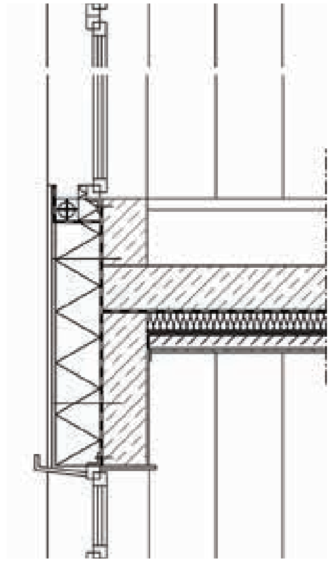
Figure 98
OB 21 Distribution building elements (1) EE, (2) GWP



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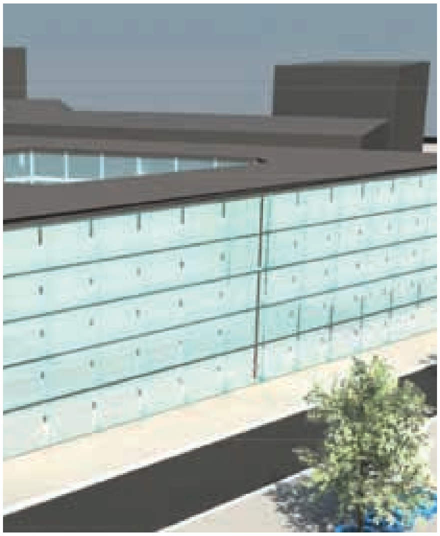

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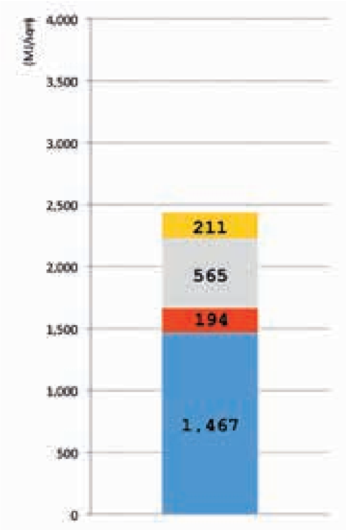

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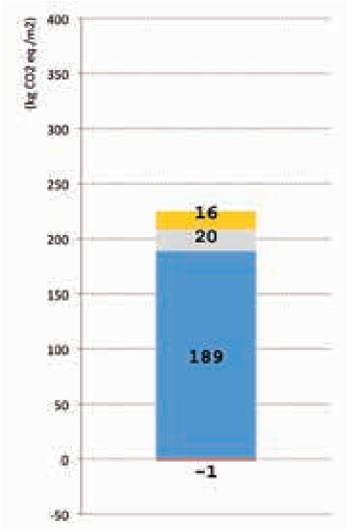

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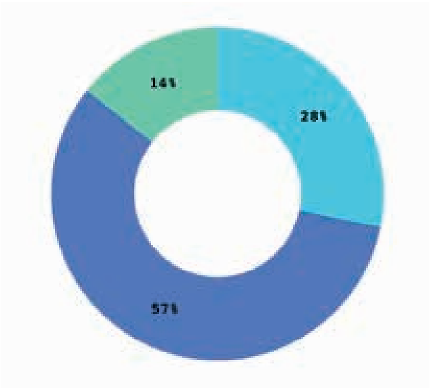
Figure 99

OB 21 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.22 Office building 22

OB 22				
Category	**Case study information**			
Design and calculation by	Ann Kathrin Jungk, Madina Azim (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (240mm) Façade West: MF-warm 240mm concrete (plastered), 150mm EPS, 15mm render Façade North/ East/ South: CW- Aluminium mullion transom façade, insulated slab edge Glass atrium: CW- Aluminium mullion transom façade Metal framework with gypsum planking, elevated floor (wooden planking), floated screed with Linoleum cover			
Gross floor area (sqm)	13,854			
Weight (kg/sqm)	1,644			
	EE (MJ/sqm)	**EE (%)**	**GWP (kg CO_2 eq./ sqm)**	**GWP (%)**
Building envelope	593	28	41	19
Structure	1,209	57	153	70
Interior	302	14	24	11
Other	0	0	0	0
Total	**2,104**		**218**	



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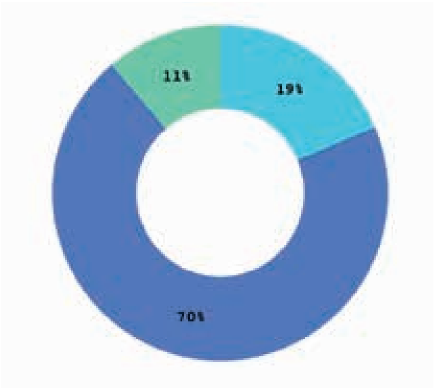

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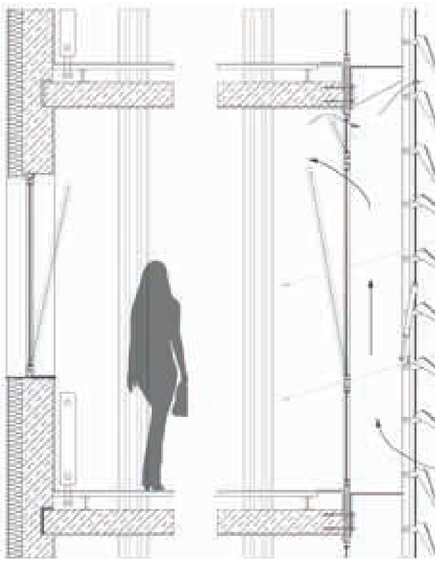
Figure 100
OB 22 Distribution building elements (1) EE, (2) GWP



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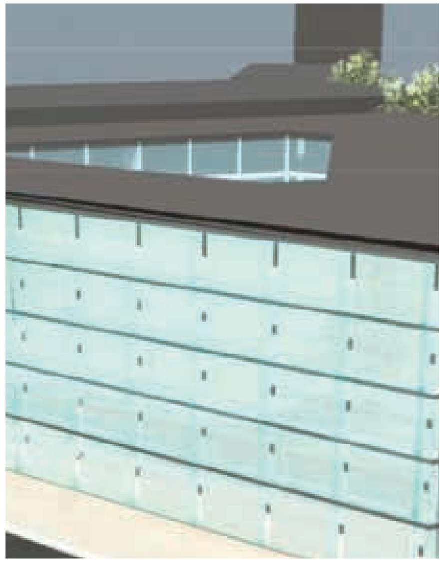

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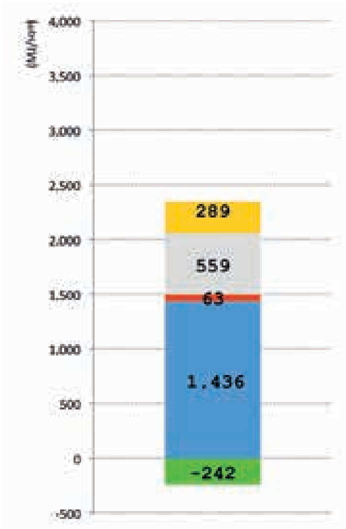

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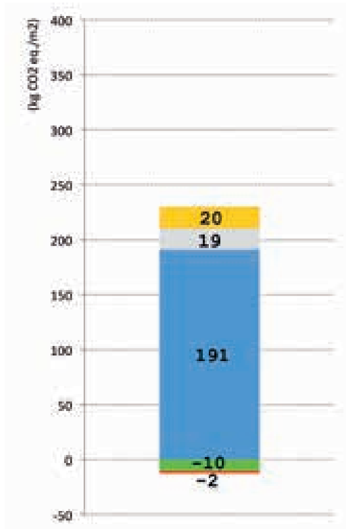

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Figure 101

OB 22 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.23 Office building 23

OB 23				
Category	Case study information			
Design and calculation by	Senta Barwinsky, Ramona Krichel (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (200mm) MF-warm: concrete (200), mineral wool (200mm), wood cover (20mm) Metal framework with gypsum planking, floated screed, suspended ceiling			
Gross floor area (sqm)	12,400			
Weight (kg/sqm)	1,441			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./ sqm)	GWP (%)
Building envelope	408	19	5	3
Structure	1,110	50	124	72
Interior	684	31	44	25
Other	0	0	0	0
Total	**2,195**		**173**	

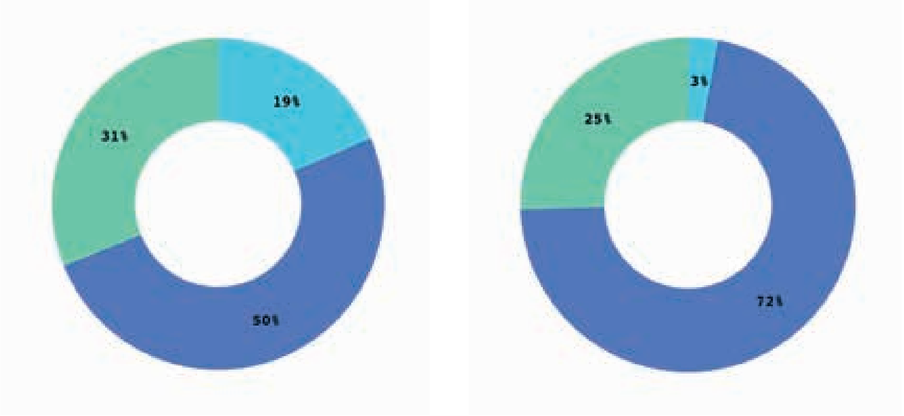

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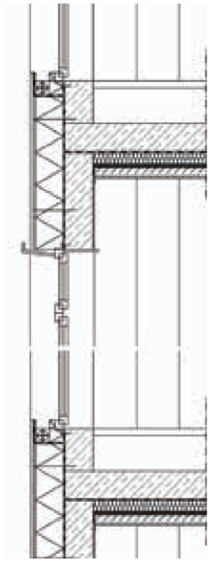
Figure 102
OB 23 Distribution building elements (1) EE, (2) GWP



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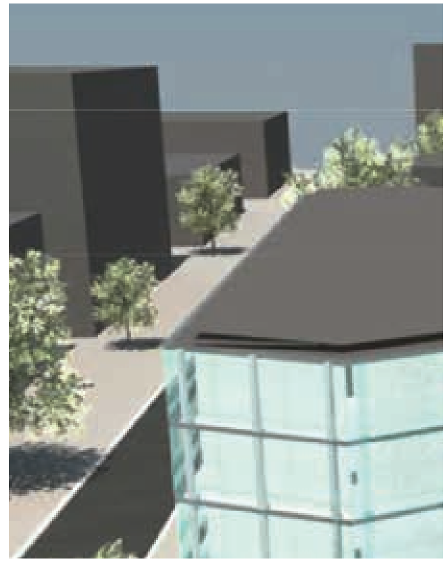

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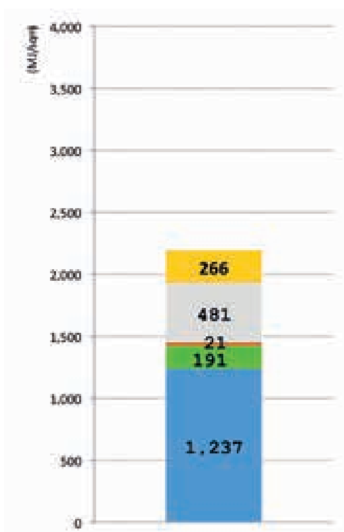

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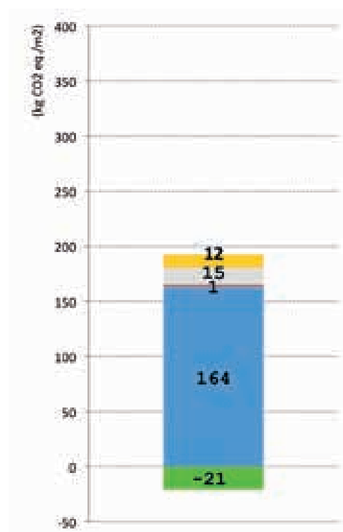

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Figure 103

OB 23 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

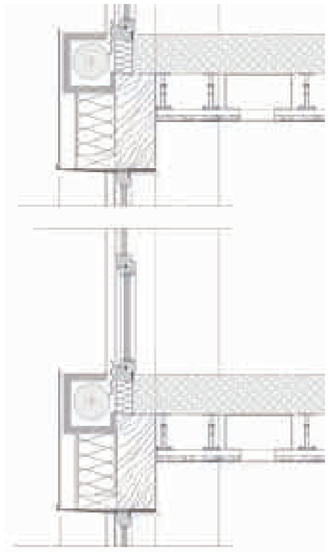
§ 7.2.24 Office building 24

OB 24				
Category	Case study information			
Design and calculation by	Inga Schulze-Geißler, Helena Block (NK WS 08/09)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs (250mm) MF- cold: massive wood (250mm), wood fibre insulation (240mm), aluminium sheet, ventilated Wooden framework with gypsum planking, elevated floor (wooden boards)			
Gross floor area (sqm)	12,495			
Weight (kg/sqm)	1,753			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./ sqm)	GWP (%)
Building envelope	215	7	8	11
Structure	1,597	55	189	270
Interior	1,176	37	-127	-181
Other	0	0	0	0
Total	**2,888**		**70**	

1 2

Figure 104

OB 24 Distribution building elements (1) EE, (2) GWP



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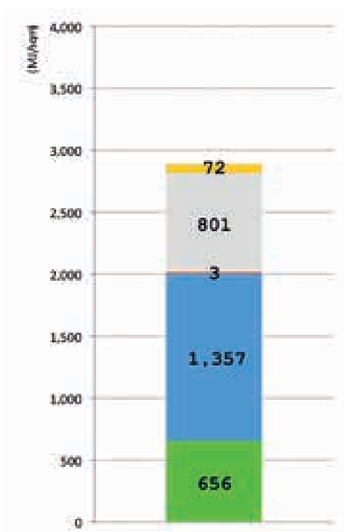

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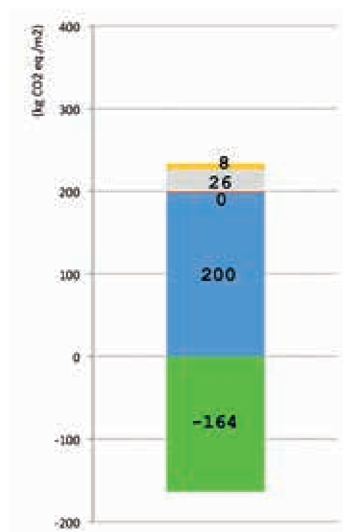

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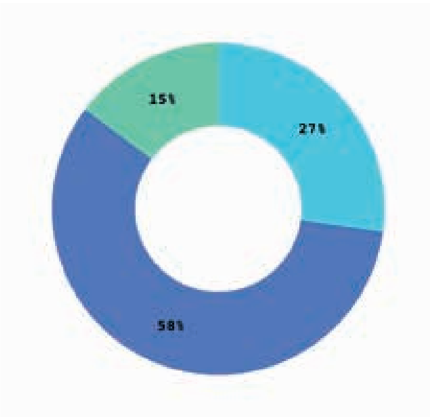
Figure 105

OB 24 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

§ 7.2.25 Office building 25

OB 25				
Category	Case study information			
Design and calculation by	Jonas Becker, Felix Küch (NK WS 10/11)			
Design and construction supervised by	Linda Hildebrand, Ulrich Knaack			
Construction description	Concrete skeleton, concrete core staircase and concrete slabs Wood transom mullion façade Metal framework with gypsum planking, elevated floor (wooden boards)			
Gross floor area (sqm)	12,446			
Weight (kg/sqm)	1,021			
	EE (MJ/sqm)	EE (%)	GWP (kg CO_2 eq./ sqm)	GWP (%)
Building envelope	433	27	31	20
Structure	923	58	109	71
Interior	235	15	13	8
Other	0	0	0	0
Total	**1,591**		**152**	



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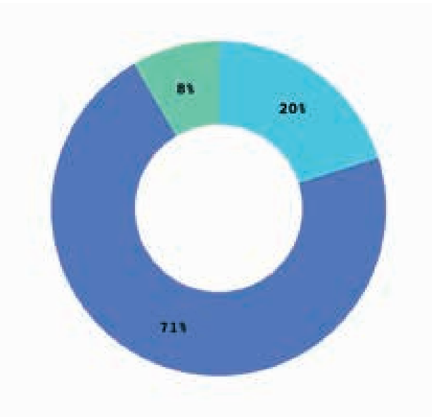

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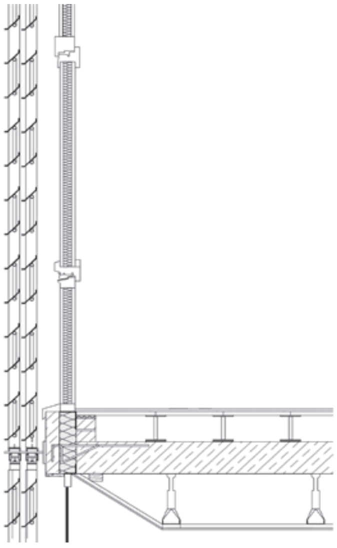
Figure 106
OB 25 Distribution building elements (1) EE, (2) GWP



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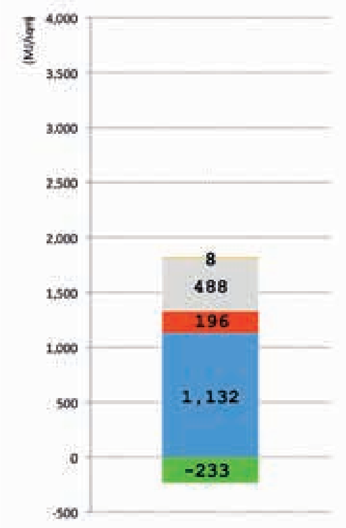

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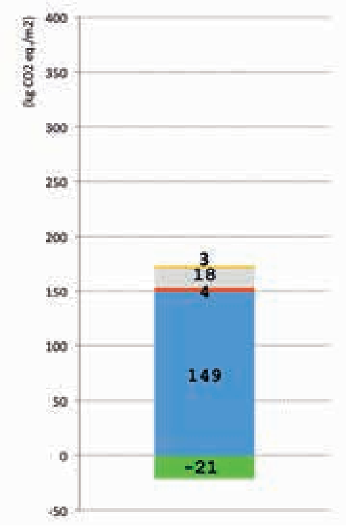

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Figure 107

OB 25 (1) Façade section (2) Image (3) Material distribution EE (4) Material distribution GWP

Figure 108
Courtyard perspective of case study OB-06 (Marcel Hackemann, Christoph Strugholtz)

§ 7.3 Building evaluation analysis

What are the characteristics of embodied energy in the building substance? How is the embodied energy distributed over the building elements for office buildings? Which building elements have the highest potential to improve environmental impact?

This sub-chapter discusses the evaluation results and aims at relating them to the architectural planning process. It discusses the findings of building evaluation in the subchapter characteristics (§ 7.3.1) and concludes with the optimisation potential (§ 7.3.2) which relates to the building elements (Figure 109).

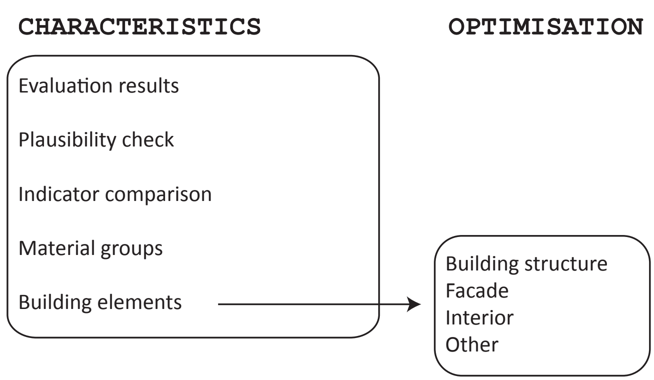

Figure 109
Scheme for § 7.3

§ 7.3.1 Characteristics

The characteristics of the evaluation will be specified by the following sub-questions. Each question will be discussed in a paragraph.

What is the range of the evaluation? What are the causes for extreme (low and high) values? (§ 7.3.1.1)
Does the value range show similarities to other studies? (§ 7.3.1.2)
Do PE and GWP show similar results? (§ 7.3.1.3)
What percentage do material groups have? (§ 7.3.1.4)

What percentage do building elements have? What parts qualify for optimisation potential and should be further investigated? (§ 7.3.1.5)

These six sub-chapters differ in volume. The more extensive ones end with a small summary. The complete conclusion will be given at the end of § 7.3.1. The chapter is round off with a discussion of the optimisation potential.

§ 7.3.1.1 Evaluation results

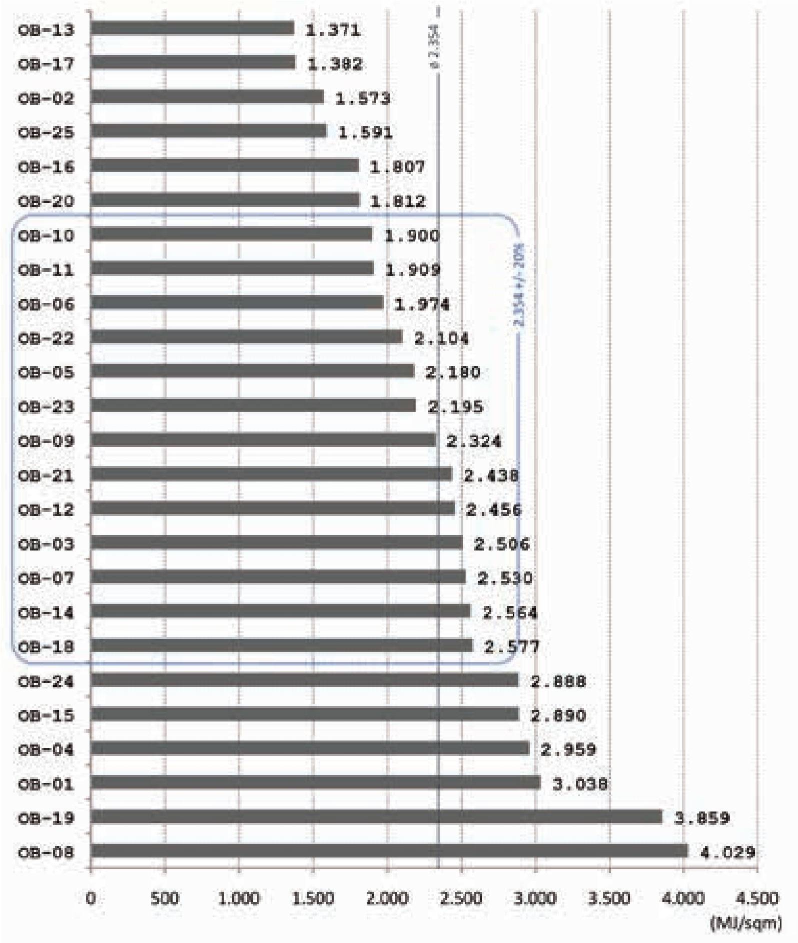

Figure 110

EE hierarchy. The case studies are here organized according to their amount EE. The box shows the average values with +/- 20% tolerance.

The characteristics of embodied energy and carbon in the building fabric can be described by the value range. EE in this evaluation varies from 1,371 MJ/sqm to 4,029 MJ/sqm (Figure 110). The average value is 2,354 MJ/sqm. 13 office buildings result in values within a range of +/-20% tolerance (blue frame: 1,883-2,825 MJ/sqm).

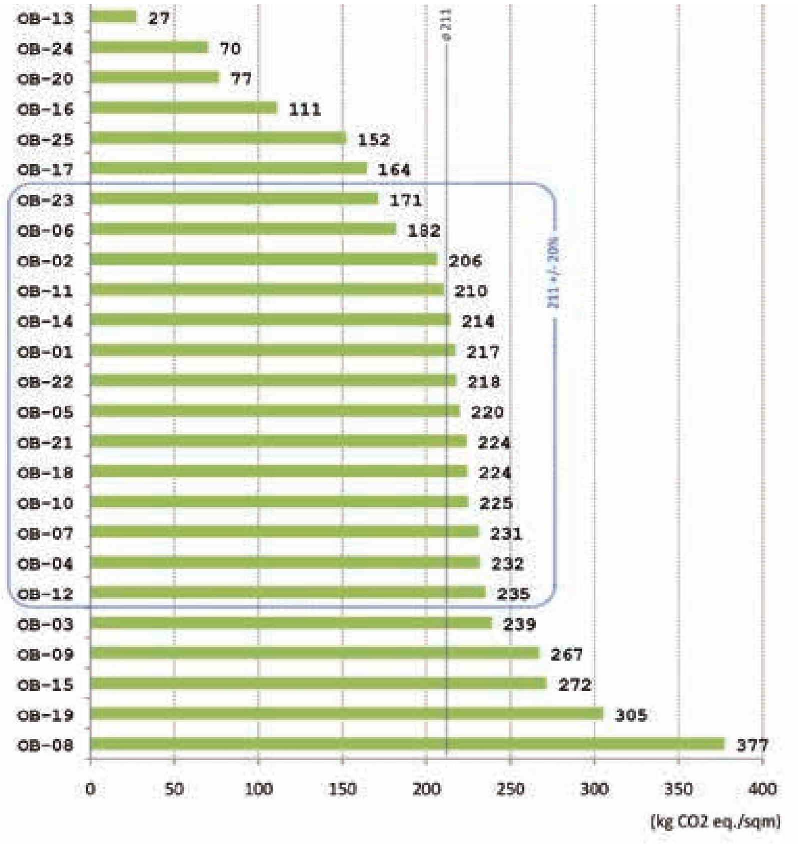

Figure 111
GWP hierarchy

GWP varies from 27 to 377 kg CO_2 eq./sqm. The average is 211 kg CO_2 eq./sqm . More than half of the buildings (15 case studies) result within a range of +/-20% (169-253 kg CO_2 eq./sqm).

OB-13 has the lowest value for both, EE and GWP. The wood construction (structure, interior walls and façade is wooden) with clay filling results in very low ecological impairment. The building has only three storeys in order to provide fire safety while using as much renewable material as possible. Mineral materials are used for the staircases and the foundation.

OB-17 follows a similar concept. The building is divided into building segments. One is three, the other four storeys high. The wooden structure accounts for under average embodied energy and carbon. OB-13 and OB-17 are the only office buildings in the evaluation with a wooden structure.

The majority of buildings that fit in the average frame overlap in terms of EE and GWP. The constructions are mostly concrete constructions; the foundation, the skeleton and the slab are mostly made of massive concrete. All of them have light façade or interior wall systems.

Values above average result from a massive concrete building envelope or a high share of metal and glass. OB-19 has one of highest values in both indicators. The floor-to-ceiling glazing with a comparably high cavity results in high glass and metal use. The combination with massive slabs and screed adds on to that.

§ 7.3.1.2 References to other studies

Other research has found similar value ranges. In Gugerli, Frischknecht, Kasser, & Lenzlinger (2004) 1,500 MJ to 5,000 MJ are defined as the common range for one sqm GFA. Most ecological building evaluations have looked at residential dwellings. (One argument for that is the huge building stock and thus, a great optimisation potential.) For example, in Kasser, Preisig, & Dubach (2006) the authors evaluate three housing projects with similar system borders (the reference unit differs; the evaluation includes external areas such as balconies which are not relevant in the evaluation here) and show a value range from 2,450-3,050 MJ/sqm.

Reference values for the Green Building Certificate by the German Government BNB have been ascertained within the research of Holger König (2008). The author evaluates studies and reference values in order to define a benchmark for the BNB certificate. He determines 3,861 MJ/sqm GFA for the production of an office building with a limited size of 6,000 sqm including technical installation. He refers to the Austrian author Bruck who developed the evaluation tool "Total Quality". In Bruck, Geissler & Lechner (2002), values for the EE per sqm NFA and year are weighted with a credit system, aiming at a grading for sustainability. The values express the ecological impact for the building without interior and only for the production phase. Below 58 MJ/sqm NFA*a equals the highest available amount of credits. Higher than 149 MJ/sqm NFA*a results in the lowest credit numbers. Factoring in the difference from GFA to NFA with 15% the range would span from 49 MJ/sqm NFA*a to 127 MJ/sqm NFA*a. The average value for the evaluation here states 2,377 MJ/sqm GFA which equals 48 MJ/sqm GFA. An addition has to be made for the end of life effort and the interior in order to provide comparability of numbers.

The values calculated in the evaluation here are similar to other studies and appear plausible.

§ 7.3.1.3 PE and GWP

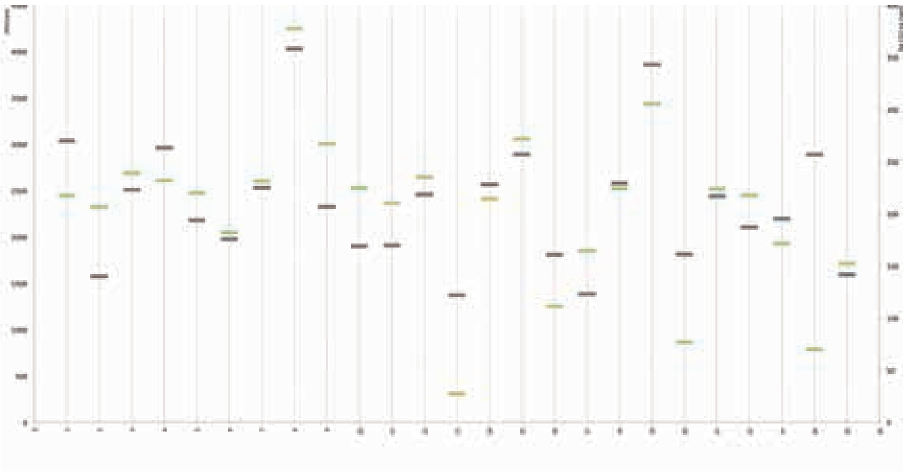

Figure 112
Comparison of indicators

PE and GWP are the indicators most commonly used. In Figure 112 theses two indicators are displayed next to each other in order to evaluate their similarity. The left hand y-axis shows EE; EC refers to the right hand y-axis.

PE and GWP have an average ratio of 13/1. In 14 out of 25 case studies the indicators have a ratio within +-20%. 11 case studies differ from this ratio. These buildings have a wood share that is significantly above average.

PE and GWP do not necessarily show similarities and can not be reduced to one indicator. Results tend to have the same tendency but need to be checked in detail. Both indicators should be displayed.

Comparison PE and GWP			
Case study No	PE (MJ/sqm)	GWP (kg CO_2 eq./sqm)	PE/GWP ratio
OB-01	3,038	217	14
OB-02	1,573	206	8
OB-03	2,506	239	10
OB-04	2,959	232	13
OB-05	2,180	220	10
OB-06	1,974	182	11
OB-07	2,530	231	11
OB-08	4,029	377	11
OB-09	2,324	277	8
OB-10	1,900	225	8
OB-11	1,909	210	9
OB-12	2,456	235	10
OB-13	1,371	27	50
OB-14	2,564	214	12
OB-15	2,890	409	7
OB-16	1,807	111	16
OB-17	1,382	164	8
OB-18	2,577	224	11
OB-19	3,859	305	13
OB-20	1,812	77	24
OB-21	2,438	224	11
OB-22	2,104	218	10
OB-23	2,195	171	13
OB-24	2,888	70	41
OB-25	1,591	152	10

Table 34

§ 7.3.1.4 EE/EC distribution for materials groups

Building element evaluation	Minimum	Maximum	Average	Minimum (%)	Maximum (%)	Average (%)
Mineral material						
EE (MJ/sqm)	306	3,860	1,536	10	93	66
GWP (kg CO_2 eq./ sqm)	27	373	188	12	381	106
Wood						
EE (MJ/sqm)	-1,028	656	-56	-74	23	-4
GWP (kg CO_2 eq./ sqm)	-164	10	-23	-401	9	24
Plastic						
EE (MJ/sqm)	2	418	89	0	17	4
GWP (kg CO_2 eq./ sqm)	-2	15	4	0	15	2
Metal						
EE (MJ/sqm)	0	2,534	589	0	83	25
GWP (kg CO_2 eq./ sqm)	0	180	28	0	83	15
Insulation						
EE (MJ/sqm)	8	368	195	1	26	9
GWP (kg CO_2 eq./ sqm)	-3	33	12	-1	86	9

Table 35

Table 35 shows the average, the minimum and maximum values for the evaluation in material groups. The predominant material is mineral based. It accounts for 66% EE and 106% EC. Wood delivers negative numbers which results in this odd number for EC. According to the material evaluation in chapter § 5.2, EC shows a significantly higher percentage compared to EE. The value range is very broad. OB-01 has a steel structure and its main mineral part is the foundation. Due to an efficient layout the ground area is comparably low and thus the mineral share accounts for only 10%.

The maximum EE is nine times the minimum. The numbers for mineral materials need to be evaluated in the context of the other material groups. Again, the negative results for wood play an important role. In OB-17 the mineral materials account for 93% and the wood based materials for -74%. The average number for EC is 188 kg CO_2 eq./ sqm. The case study with the smallest amount of EC embodies 27 kg CO_2 eq./sqm, the case study with the highest is 373 kg CO_2 eq./sqm. This is equivalent to a range of -401 to 9%. Absolute numbers give a clearer picture. The average use of mineral material embodies 1,536 MJ/sqm. OB-17 embodies less than average with 1,280 MJ/

sqm. The wood based materials embody an average of -56 MJ /sqm. The case study has an extremely high share of wood and embodies -1,028 MJ/sqm which results in the percentage described earlier. This is the lowest number for a wood percentage. The maximum amount for wood is 656 MJ/sqm.

Figure 113
Building evaluation EE.

On average, metals embody 589 MJ/sqm which accounts for an average percentage of 25%. The EC share is lower; on average 28 kg CO_2 eq./sqm are embodied which accounts for 15%. The steel construction (there is only one case study) naturally has the highest percentage of metals. 83 % (3,860 MJ/sqm) of the building's EE accounts for this material in OB-01.

Figure 114
Building evaluation GWP.

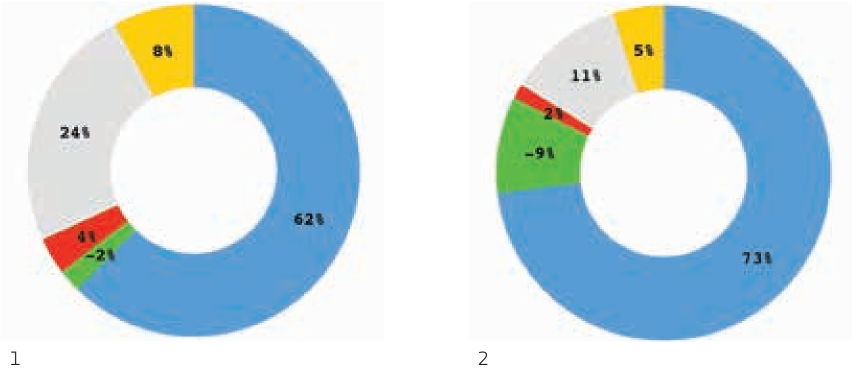

Figure 115
Average material distribution. (1) EE, (2) GWP

§ 7.3.1.5 Distribution for building elements

The distribution of building elements expresses the impact each element has, and is a basis for identifying improvement options. In contrast to the distribution material groups, the building elements are closer to the building practise.

The evaluation of the 25 office buildings show a high percentage for the building structure and a broad range for the façade. Figure 116 to Figure 119 illustrate the results of the evaluation regarding the distribution of the building elements. Table 36 displays the numbers behind the figures.

A Data description

Building element evaluation	Minimum	Maximum	Average	Minimum (%)	Maximum (%)	Average (%)
Building Structure						
EE (MJ/sqm)	101	2,566	1,070	7	76	47
GWP (kg CO_2 eq./ sqm)	51	412	136	29	270	67
Façade						
EE (MJ/sqm)	215	2,218	687	7	68	31
GWP (kg CO_2 eq./ sqm)	-1	150	49	-71	120	24
Interior						
EE (MJ/sqm)	41	2,259	520	2	52	22
GWP (kg CO_2 eq./ sqm)	-127	130	16	-207	35	8
Other						
EE (MJ/sqm)	0	338	14	0	23	1
GWP (kg CO_2 eq./sqm)	-1	27	1	0	10	1

Table 36

The lowest PE value for the building structure is 413 MJ/sqm, the highest is 2,566 MJ/sqm. In percentages, the values range from 16 to 70%. The average amount is 1,116 MJ/sqm which accounts for 47%. For GWP it is 51 to 412 kg CO_2 eq./sqm and 29-270%. The average absolute number is 143 kg CO_2 eq./sqm and the relative number is 68%.

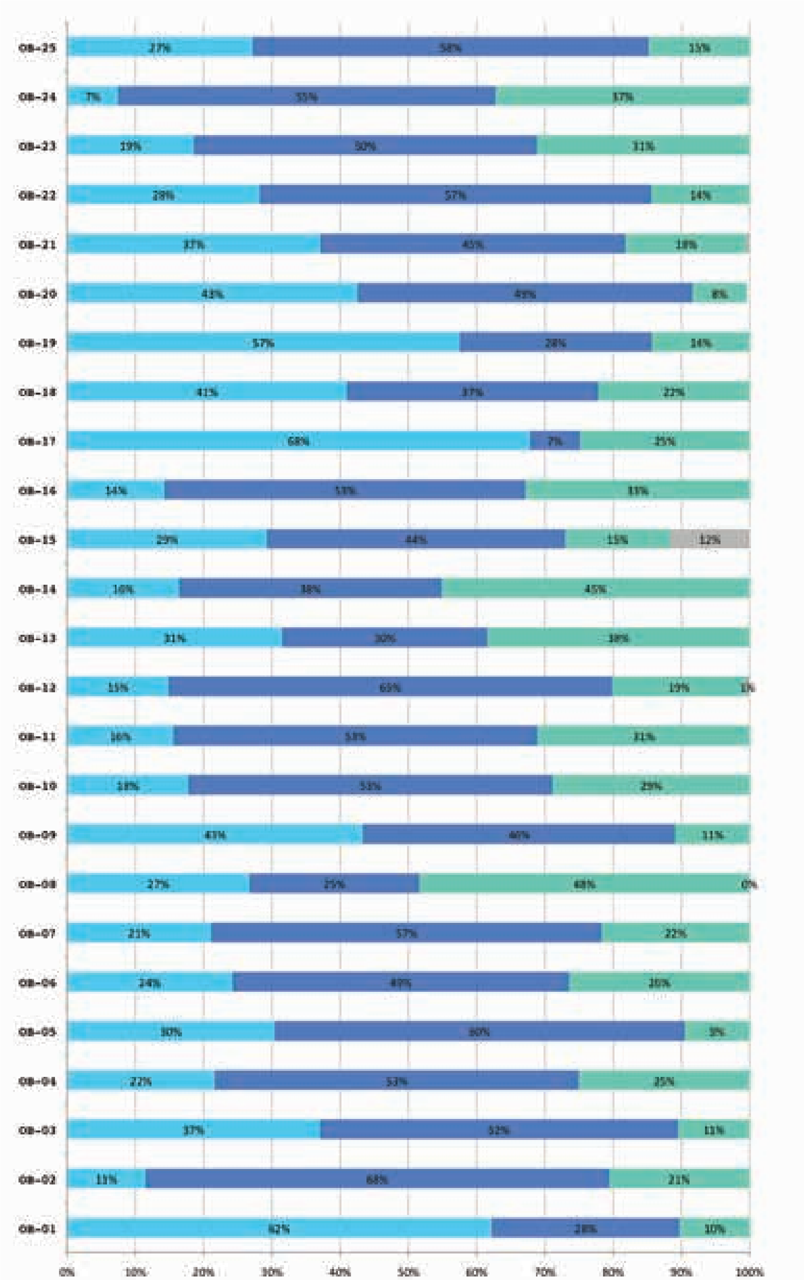

Figure 116

Relative building element distribution.

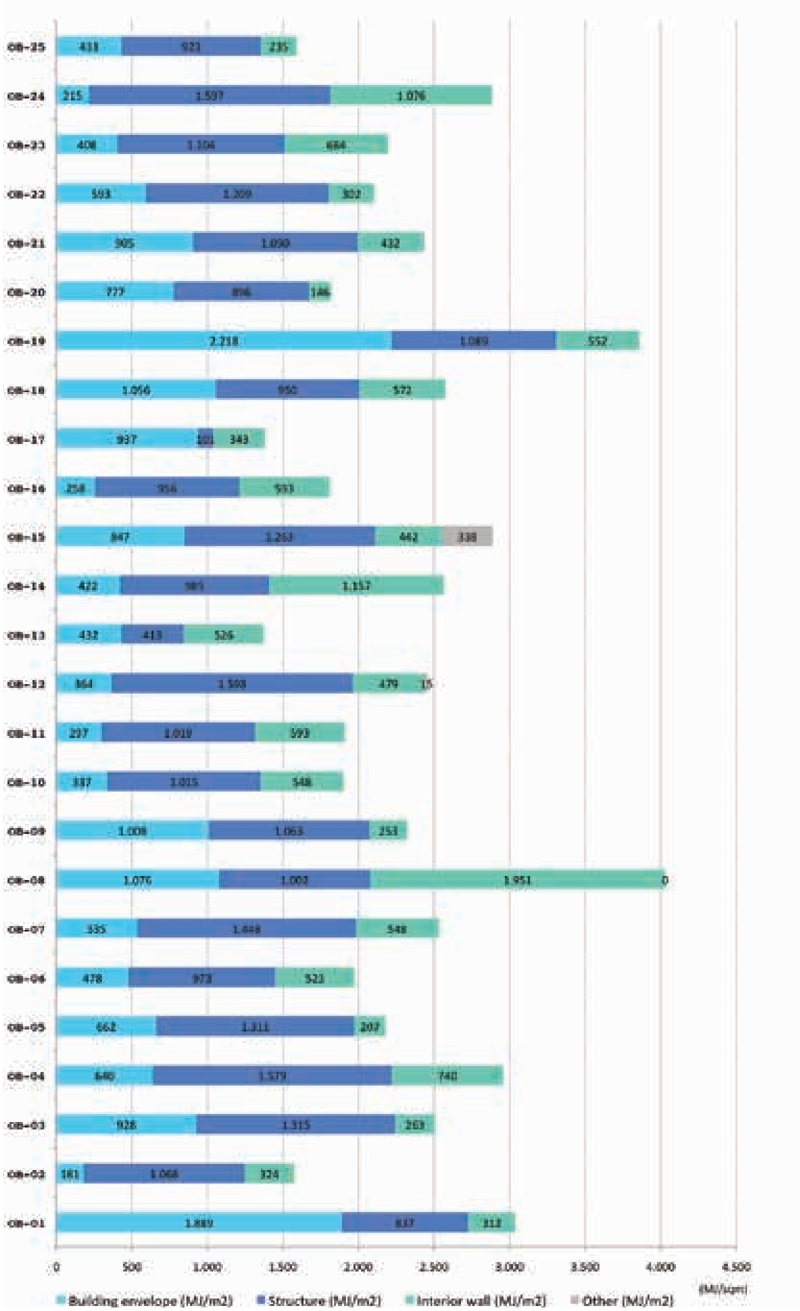

Figure 117

Absolute building element distribution PE

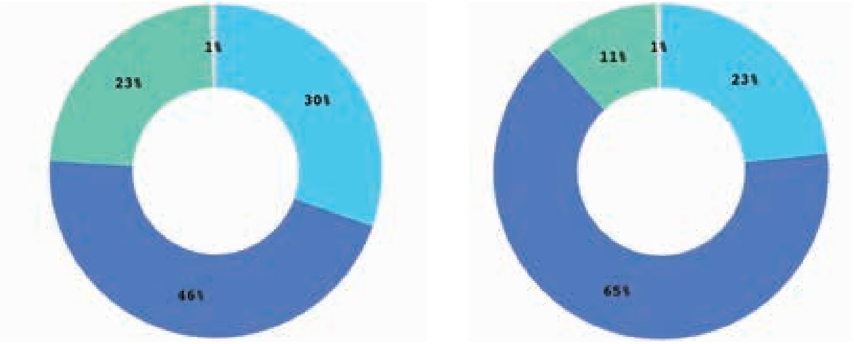

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Figure 118
Average BE distribution. (1) EE, (2) GWP

The façade's share is ranges from 181 to 2,218 MJ/sqm while it's average value is 688 MJ/sqm. In relative terms this means 7-68% and 29% for the average percentage. The GWP spans from -1 to 150 kg CO_2 eq./sqm and has an average value of 47 kg CO_2 eq./sqm. In percentages, the façade accounts a range from -71 to 120% with an average of 22%.

The interior ranges from 41 to 2,259 MJ/sqm with an average of 520 MJ/sqm. In percentages, it varies from 2 to 52% with an average of 22%. The GWP spans -127 to 130 kg CO_2 eq./sqm with an average of 16 kg CO_2 eq./sqm. This accounts for -207 to 35% with an average of 8%.

The group "Other" contains a PE range from 0-1,018 MJ/sqm (55 MJ/sqm av.) which accounts for 0 to 23% (2% av.). The GWP ranges from -1 to 80 kg CO_2 eq./sqm (4 kg CO_2 eq./sqm av.) accounting for 0 to 21% (2%).

B Data interpretation

PE and GWP show that the building structure accounts for the highest share. It is the heaviest component of a building and is made from mineral materials that include a high percentage of primary energy non-renewable. The share of mineral material, more specifically cement containing products, is even more relevant for the GWP. As described in § 5.2.4.1 cement production is related to high GHG, and consequently a high amount of concrete will result in a significantly recognisable amount of GWP and EE. All buildings have a 700mm thick foundation in the size of their base area which contributes to a base line of energy and emissions. Mineral-based load-bearing interior walls raise these further.

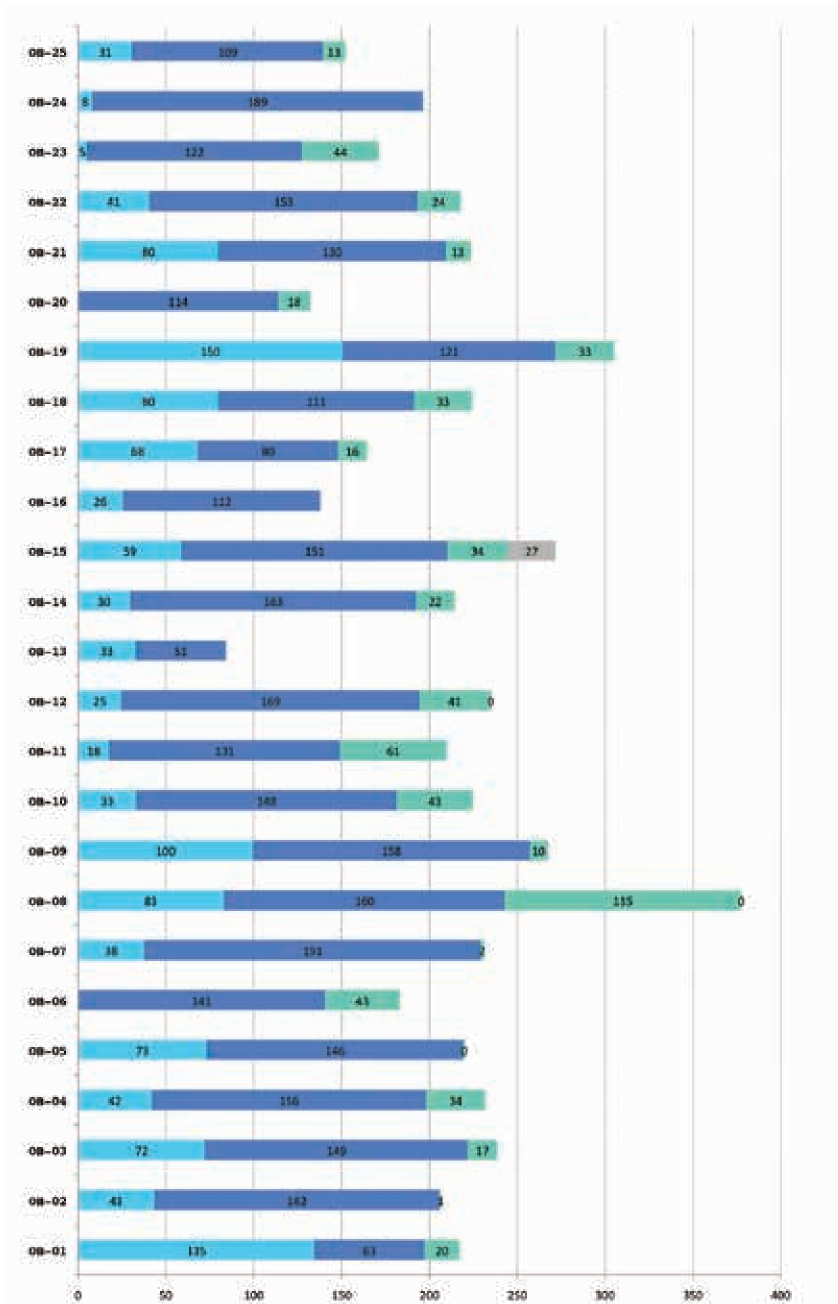


Figure 119

Absolute building element distribution GWP

On average, the façade accounts for approximately one third of the environmental impact. The indicator amounts vary due to the different façade construction types that are designed to be part of the office building. The construction method and the amount of façade surface area influence this amount.

Interior walls account for a quarter of EE and a tenth of GWP on average. The average variation is lower compared to building structure and façade. The values show a broad variety which is related to the different building layouts that include more or less interior wall area. Additionally, the type of construction influences the ecological impact.

C Conclusion (EE/GWP distribution for building elements)

The building structure accounts for the highest percentage of environmental impact. This building element embodies the highest amount of energy and emissions. Especially cement-based constructions cause high amounts of GWP.

The façade accounts for an average of one third, hence contributing a relevant amount.

The interior shows one quarter for EE and one tenth for EC. The type of interior wall and its surface area, as well as the floor type contribute to this figure. Compared to façade and building structure, the interior accounts for the lowest share.

§ 7.3.2 Optimisation Potential

The previous chapter explained the evaluation results and showed its background. In this paragraph the optimisation potential is investigated by discussing each building element. One building element needs to account for the relevant share of the total indicator amount, and possibilities to reduce this amount have to be visible in order for it to offer potential for optimisation. The share of the overall indicator amount has been described in the previous paragraph. The possibilities to reduce the indicator amount will be discussed in this paragraph.

§ 7.3.2.1 Building structure

As described in § 7.3.1.5 the building structure accounts for the highest share of environmental impact in both indicator categories. This building element consists of the foundation, the slabs and the vertical load-bearing structure.

The lowest percentage of EE for the building structure can be found in OB-17. (The building is also mentioned earlier regarding its low amounts for the total EE/EC in § 7.3.1.1.) Due to the building's low height, a complete wood construction is possible. The heightened foundation area is compensated by the light (wooden) building structure (and the high wood share in the façade.) OB-13 follows the same strategy and results in the lowest EC values which account for only 40% of the average.

A Foundation

The foundation was assumed to be 700mm high, covering the ground area according to common practise. For a skeleton construction method with slabs from 200-280mm, it approximately accounts for one third of the building structure's impact. With a rough estimation it can be assumed that a strip foundation uses approximately 20% of the material for a strip foundation.

A simplified calculation: 50% of the overall impact account for the building structure. 7.5% account for the foundation. Assuming that 80% of the material is necessary, 6% of the overall impact can be reduced. Consequently, the potential of energy reduction by switching from a full ground area plate foundation to a strip foundation is relatively small.

B Vertical load bearing structure

The average office building in the evaluation consists of a skeleton structure, a stiffening core which serves as necessary staircases and massive walls to provide fire compartments. This allows for a change in the layout over time, providing a high level of flexibility. Buildings with small offices and load-bearing interior walls limit adaptivity essentially and shorten its potential usage period. The skeleton, in contrast to massive walls, embodies fewer amounts of EE and GWP, as shown in Table 37. The vertical load-bearing structure as a skeleton construction is ten times lighter than the massive solution, and hence embodies only 10% of its energy and emission.

Building element evaluation						
	Production EE	Production GWP	End of life EE	End of life GWP	Total EE	Total GWP
Massive wall						
Indicator for the 180mm concrete wall (6,257 kg)	5,631	563	294	218	**5,925**	**780**
Skeleton						
Indicator for the column (528 kg)	475	53	486	21	**961**	**71**

Table 37
Comparison of vertical load bearing constructions. Assumption: 3m ceiling height, 5m room length. 180mm massive wall, two 200x200mm.

(This is only true when setting load-bearing as the functional unit. If room separation was included, the impact for the interior wall must be added to the skeleton solution. This adds approximately 3,200 MJ or 225 kg CO_2 eq. for the 15sqm and shifts the outcome. Yet, the tendency remains the same.)

It can be stated that the current construction method to use skeleton columns has ecological advantages compared to a massive construction.

C Slabs

For a typical office building such as described in the previous paragraph, massive slabs account for the highest environmental impact in the category of load-bearing structure. Today, concrete slabs of a typical thickness of 180-250mm are most commonly used.

Construction alternatives are now presented in order to investigate the optimisation potential. The functional unit is one sqm ceiling area with an average weight of one column. This rough estimation is based on assumptions formed in collaboration with the structural engineer Matthias Michel.

1 Concrete
400 kg/sqm slab weight + 80 kg/sqm column weight = 480 kg/sqm

2 Steel structure
80 kg/sqm slab weight + 20 kg/sqm column weight = 100 kg/sqm

3 Wood framework
130 kg/sqm slab weight + 80 kg/sqm column weight = 210 kg/sqm

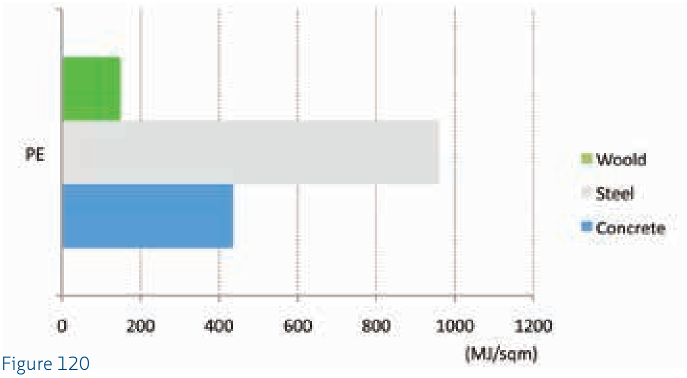


Figure 120

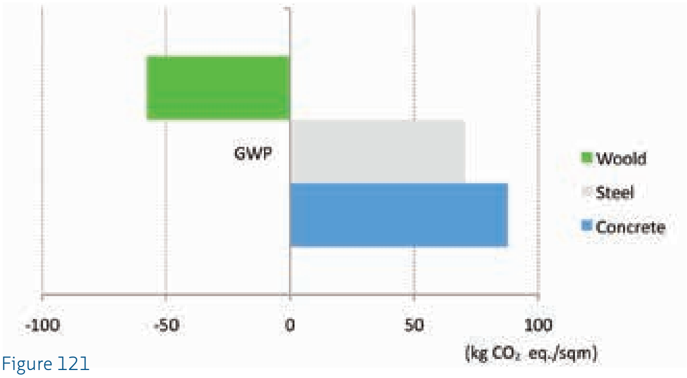


Figure 121

Building element evaluation						
	Production EE	Production GWP	End of life EE	End of life GWP	Total EE (1 sqm)	Total GWP (1 sqm)
Concrete 480 kg/sqm						
Indicator for 1 kg	0.9	0.1	0.1	0.0	**437**	**88**
Indicator for 1 sqm	414	71	23	17		
Steel 100 kg/sqm						
Indicator for 1 kg	23.6	1.7	-13.9	-0.1	**961**	**71**
Indicator for 1 sqm	2,356	175	-1395	-104		
Wood 210 kg/sqm						
Indicator for 1 kg	9.6	-1.5	-8.9	1,2	**150**	**-58**
Indicator for 1 sqm	2,025	-314	-1,875	256		

Table 38

Comparison of slab constructions

The comparison of concrete, steel and wood construction shows different results for the indicators. For EE, the steel construction results in the highest amount, followed by steel. Considering GWP, the difference between concrete and steel is insignificant. The wood construction embodies the lowest amount of energy and emissions. Wood constructions offer the most ecological solution. For a fair comparison the functional limitation of wood needs to be stated. For example, the application opportunities of wood for high-rise building construction are very limited due to fire safety regulations.

For buildings under three or even under seven storeys (depending on the location) wood construction are allowed and present an ecological solution.

Comparing steel and concrete slabs, the optimisation potential is rather limited. EE for concrete slabs is significantly lower but looking at GWP, no advantage can be identified.

D Conclusion

Reducing the foundation volume bears only little potential for improvement. The skeleton construction shows ecological advantages compared to massive construction. Wood constructions have a high potential for small and medium buildings, the height limitation being due to fire safety regulations. The ecological difference between steel and concrete can only be found in one indicator (EE) while GWP shows similar values for both variants. The reduction potential is not significant.

§ 7.3.2.2 Façade

The results from the ecological evaluation are investigated regarding their value heterogeneity in order to assess the optimisation potential with a simple method. Heterogeneity expresses the variation of results. It shows that better and worse solutions are possible. An element can embody high amounts of energy and emissions but if these values are homogeneous it expresses that no other solution is possible. This means that a building element has a low optimisation potential.

For the evaluation of value heterogeneity in Figure 122 the assessment results are expressed in a radial graph. The dots represent a building element. With increasing distance from the centre, the ecological indicator grows.

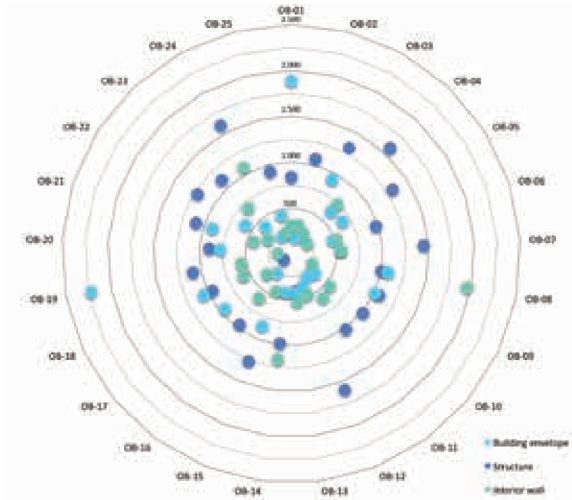
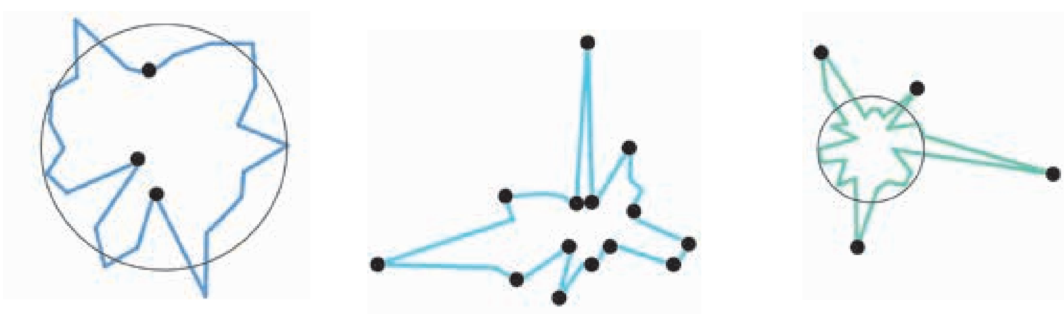


Figure 122

PE for building elements (MJ/sqm)



1 2 3

Figure 123

(1) Building structure, (2) Façade, (3) Interior

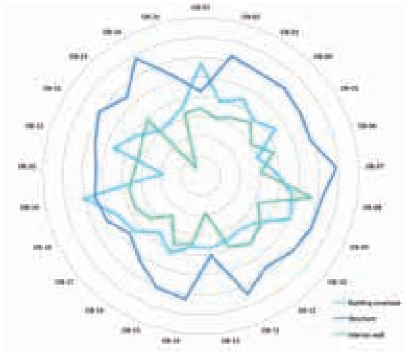


Figure 124
GWP for building elements. It shows a similar heterogeneity to Figure 123.

In Figure 123 these dots are connected to highlight how homogeneously or heterogeneously the values are distributed. The sequence is defined by the order of the case studies. The distribution for EE in the building structure is displayed in Figure 123 (1) EE. A base line can be identified to which the majority of values are close to. The value distribution is relatively homogenous. Three points significantly differ from this tendency. These are the case studies with wooden parts in the construction. They show recognisably lower amounts.

In (3) the data variation for the interior is shown. A strong tendency can be identified from which a few case studies differ. These comparably high values occur due to large areas of glass walls. Besides that, the values are relatively homogenous.

The distribution for the façade is displayed in (2). Unlike (1) and (3) no main tendency can be identified since the values show a high level of heterogeneity. The values display all kinds of ranges which span from extremely low to comparably high.

The homogeneous values for interior and building structure show a relative small range of variation. The heterogeneity of values for the façade on the other hand indicates the high level of optimisation potential. This raises further questions concerning the façade type and its ecological impact, and needs to be investigated further.

§ 7.3.2.3 Interior

Figure 123 (3) shows the value distribution for the interior; an average shape with deviations in both directions is recognisable. These differences indicate impact possibilities in the planning stage. Naturally, less wall area results in better ecological figures. This supports open floor-plan offices rather than a small cellular structure.

15 sqm interior wall						
	Production EE	Production GWP	End of life EE	End of life GWP	Total EE	Total GWP
Dry wall with gypsum	3,668.5	240.1	-194.4	4.3	**3,474.1**	**224.0**
Glass wall	6,450.5	512.9	35.2	4.6	**6,485.8**	**517.5**
Wood construction	1,399.3	-224.6	-2,366.4	75.4	**-967.2**	**-149.3**

Table 39

Assumption for gypsum wall: 1,1 kg steel frame, 100mm mineral wool, 50mm gypsum board. Assumption for glass wall: 20m wood frame 80x80mm, 6mm glass,

Besides that, the construction type's influence is even higher. The standard type is dry wall with gypsum cladding. Table 39 provides a comparison between a dry gypsum wall and a glass wall. The evaluation shows that the glass wall has approximately twice as much EE and GWP compared to the standard construction. The wood constructions show the lowest amount of EE and GWP. Case studies with glass walls instead of standard construction (like OB-08, OB-14 and OB-24) show a significantly higher amount for EE and GWP than average.

Wood constructions bear a high potential to optimise the ecological impact of the interior walls. Glass walls should be used with care since the impact is rather high.

§ 7.4 Conclusion chapter 7 and next steps

This chapter discussed the characteristics of embodied energy in the buildings substance according to the following aspects:

- Value range and its causes
- Similarity to other studies
- Distribution of material groups
- Distribution of building elements

This was followed by the investigation regarding the optimisation potential of one building element by evaluating the value distribution regarding the level of heterogeneity.

The range of EE starts with 1,371 MJ/sqm to 4,029 MJ/sqm and GWP varies from 27 to 377 kg CO_2 eq./sqm. The average EE is 2,354 MJ/sqm and the average GWP 211 kg CO_2 kg eq. Values above the average result from a massive concrete building envelope or a high metal and glass share.

Similarities to other study can be found, and it has been stated that the values vary within a plausible range.

The building structure shows the highest percentage and relative homogeneous values. The interior walls are less relevant and show optimisation potential by the choice of construction. The façade shows both, significant percentages and optimisation potential. It can be deduced that the highest optimisation potential is offered by the façade. The interdependencies of façade types and their ecological dimension need to be further investigated. It needs to be specified how the characteristics, the material choice and the construction method affect the ecological dimension.

The general categories for façade investigation will be discussed in chapter 8, and chapter 9 will show an evaluation of 60 façades.

8 Framework for an ecological evaluation of façades

This chapter describes the general framework to evaluate façades. The framework conditions for the evaluation in chapter 9.2. will explained in chapter 9.1.based on the parameter explained here.

The ecological evaluation of façades started in the context of building evaluation. In comparison to LCA evaluation for buildings less studies can be found for ecological evaluations of façades. Nevertheless, information can be found in specialist books for architects, independent studies or reports initiated by the façade industry (as in Krug & Ullrich, 2010).

Specialist books provide a general overview by showing one square meter façade area in different variations excluding its functional context (as in the Baustoffatlas by Hegger, Auch-Schwenk, & Fuchs, 2005). Most commonly only the one life phase is shown. Independent studies by institutes or research teams are more specific. Examples are "Embodied Energy in Building Material" (translated from German: Graue Energie von Baustoffen (Kasser & Pöll, 2003), the book from the Dutch NIBE Basiswerk Milieuclassificatie- Gevels en Daken (Haas, van Beijnum, Jansen, & Scholtes, 2013) or the British "Green Guide to Specification: Breeam Specification" (Anderson & Shiers, 2009). Very common is also the comparisons of lightweight and massive construction. Massive concrete or masonry façades are often compared to frame construction from wood or less common steel. (Perez-Garcia et al., 2005). Façade industries use the ecological evaluation to promote products.

As a prerequisite the parameters for the ecological evaluation of façades need to be specified in order to understand the scope of an evaluation. These parameters are discussed in this chapter according the EEP parameters introduced for an evaluation on building level (chapter 6) and introduce the framework to evaluate the ecological dimension of façades.

§ 8.1 Parameter for the ecological evaluation of façades

The EEP categories for façade will now be described. The ecological evaluation of façades is conducted with the same method as an assessment of an entire building. Data about a façade's mass is connected to the ecological information of the material installed in the case study.

§ 8.1.1 Evaluation goal

The evaluation goal is to compare different façade constructions with each other. Its nature is comparative. The framework defines the specifics of the evaluation. Just like on building level, it is equally necessary to include the function or performance of the compared unit façade area. The specification of the evaluation goal helps to detail the assessment. (The investigation of the ecological impact of opaque and transparent areas would account as such.)

§ 8.1.2 Data source

The façade assessment works similar to the building assessment. As mentioned earlier, LCA material data is connected with information on the mass of façades. The required data includes the façades mass and LCA information.

The LCA data has to comply with § 4.1.2. and has to follow the same requirements as data for a building evaluation.

For the data of the façade the following information should be transparent.

The calculating institution or person should be mentioned in order to address potential questions. The building mass can be gained from section, ground view and details in at least 1:20 or more detailed. Similar to the evaluation of an entire building, the plans need to be checked for series planing errors and excluded if one is found.

For the presentation of a case study a description of the main elements according to their construction and materials should be given. Images help the understanding. Especially the façade section or an isometric picture show the construction method and support understanding the construction specification.

§ 8.1.3 Generic and specific LCA data and its validity

The requirements for the data quality are the same for buildings and façades. The EN 15978 states that generic data should be used in the design phase and product information in the materialization phase.

§ 8.1.4 Relevant data

The choice of data has to relate to the evaluation goal and has to comply with the other EEP categories. For a general assessment at least 15 façades should be evaluated. The most common case is the comparison of two façades with contrary constructions. The scope is increased by taking more than one example into account.

§ 8.1.5 System borders

The evaluation of façade requires a more detailed consideration than the evaluation of buildings. Smaller items like screws or sealing can impact the overall result and need to be considered either by calculation or assumption. 99% of the total volume should be reflected in the assessment.

The differentiation according to the material function can be helpful especially when evaluation a functions ecological dimension.

§ 8.1.6 Reference unit

The reference unit for façades is surface area (elevation view). In contrast to the evaluation on building level the only the façade surface area is considered (rather than the entire building volume). Most commonly a representative surface area is identified, its ecological impact is calculated and related to one square meter surface area.. The functionality needs to be similar. Since an identical functionality is hardly possible some core functionalities need to be identified. Transparency in percentage and the heat transmission are common factors. Heat capacity, sound barrier and fire safety could also be used.

§ 8.1.7 Calculation method tool

The calculation tool connects LCA- and façade data. The calculation method needs to be transparent and all relevant parameter for the assessment need to be traceable. Instruments to assess the ecological impact of an entire building substance's are most likely able to do so for façades. (The requirements for the calculation tool described in § 6.1.7 apply here, too.)

§ 8.1.8 Life cycle phases

The life cycle phases have been described for the building substance in § 6.1.8. Its content is true also for façades; the production (A1-A3), replacement (B4) and the end of life phase (C1-C4, D) are the most relevant ones for the ecological evaluation of façades.

§ 8.1.9 Considered time span

The considered time is time frame over the complete service life of the façade. The considered time span has to be chosen in regard to the evaluation goal. For a façade that is investigated as part of an entire building the considered time should be equivalent to the building (most likely 50-100 years). For the comparison between different façade types one life cycle (25-30) is sufficient. The considered time span is an essential parameter when comparing two solutions against each other and it can change the perspective entirely.

§ 8.1.10 Indicator

The indicator complies with § 6.1.10 and thus § 4.1.10. For the evaluation on all level EE and GWP will be considered.

§ 8.2 Communicating LCA information on façade level

In order to communicate the scope of a façade evaluation the characteristics need to be specified by parameters. These can be given in a table to provide a comprehensive overview or in a more elaborate form by a description. This distinction has been introduced in § 4.2 and has been further used in § 6.2. The sub chapter here explains which parameters should be mentioned to characterise a façade evaluation and a useful communication format. Table 40 shows the parameters and their format. The table distinguishes in information that can be summed up for the complete evaluation and information for each case study.

Overview for the framework parameters (T- table, D- description)		
Parameter for LCA	Evaluation level	Case study level
Evaluation goal	T / D	
Data Source	T / D	
Generic or specific data	T	
Validity	T	
Relevant data	D	
System border	T / D	
Reference unit	T	
Calculation	D	
Life cycle phases	T	
Duration	T	
Indicator	T	
Case study description		T

Table 40
This table shows descriptive information and such that can be given by table. The form (table or description) are recommendations.

§ 8.2.1 Evaluation level - EEP table

The evaluation on the level of building substances be categorized by the same categories as on level of material. The EEP is consequently the same as shown in Table 14, on pagepagina 107. Beyond the table the following topics need to be explained in text form (analogue to the method for material)

- Evaluation goal
- Data source
- Relevant data
- System border
- Calculation method

§ 8.2.2 Case Study level

- Project (if known) and calculating person
- Façade type
- Description of the façade's construction
- Results for the eco-indicator

Furthermore information will be covered within the EEP table.

Case study name
Project
Construction
Transparency share (%)
Heat conductivity (W/sqmK)
Weight (kg/sqm)
EE (MJ/sqm)
GWP (kg CO_2 eq./sqm)

Table 41
The table shows the parameter to explain a case study.

§ 8.3 Conclusion for chapter 8

The environmental impact of façades can be assessed by LCA tools. Ecological information on façade level can be communicated by categories similar to the material and building evaluation. The information can have a descriptive nature or can be displayed in a table. This is equivalent to the description within the material group and its production process. In the façade evaluation the construction and material need to be communicated in order to relate these to the extent of the total environmental impact.

9 Ecological evaluation of 20 façade fabrics

This chapter evaluates the building substance of 20 façades and two variants of each regarding their ecological impact. It communicates the scope and its results based on the framework shown in chapter 8. This chapter starts with a description of the evaluation according to the earlier introduced parameters and explains its framework for the following evaluation.

§ 9.1 Framework for the subsequent evaluation

The evaluation on the façade substance considers 1 sqm façade area, the production and the end of life scenarios in a time frame of 30 years. This information is expressed in Table 42. The information given here is relevant for all case studies (evaluation level).

Parameter for the ecological evaluation of building material	
Evaluation goal	Façade comparison
Data source	Ökobau.dat, EPD
Reference unit	1 sqm façade area
Calculation tool	Lixcel Façade
Generic or specific data	Both
Validity	varies 2011-2013

Table 42
Parameteres for façade evaluation

Parameter for the ecological evaluation of building material			
Life cycle phases	A1	Raw material supply	x
	A2	Transport	x
	A3	Manufacturing	x
	A4	Transport	
	A5	Construction/ installation process	
	B1	Use	
	B2	Maintenance including transport	
	B3	Repair and transport	
	B4	Replacement including transport	
	B5	Refurbishment including transport	
	B6	Operational energy use	
	B7	Operational water use	
	C1	Deconstruction demolition	
	C2	Transport	
	C3	Reuse recycling	x
	C4	Final disposal	x
	D	Reuse recovery and recycling potential	x
Duration		25 year	
Indicator		EE (GWP)	

Table 42
Parameteres for façade evaluation

§ 9.1.1 Evaluation goal

The leading question for the evaluation is expressed in the research question:

What are the characteristics of embodied energy in façades? How can embodied energy in façades be optimised?

In order to answer these sub-questions, an evaluation of 20 façades and their variations (optimisation and re-design) will be done. The output will subdivide the question further into more precise questions which are answered on the basis of the evaluation's outcome

§ 9.1.2 Data source

The ecological information is based on the LCA data on material level presented in chapter 5. Therefore the data source will explain the source of the façade mass.

The course Sustainable Construction at the Detmolder Schule delivered the basis for this comparison (as for the building evaluation shown in chapter 7). The assignment included three steps: First, an existing façade had to be analysed regarding the EE and GWP. Subsequently, the façade had to be optimised regarding the ecological indicator while redesigning it to the current passive energy level. The third part challenged the application in a more creative way. The students' task was to redesign the conventional façade and apply their vision of the ideal façade. Hence, the names for the three variations are 'Existing', 'Optimisation' and 'Design'.

The façade's functions were taken into account by the consideration of the load-bearing capacity, the share of transparency and its heat conductivity.

The data here used is generic and can vary for specific products.

§ 9.1.3 Relevant data

The course was held in 2011 and 80 students attended. The façades were chosen by correctness of data and relevance for the evaluation. The façade case studies were chosen to deliver the most possible variety within the constraints of availability. 20 façades with each two variations are evaluated.

§ 9.1.4 System border

In comparison to the evaluation on building substance level the evaluation of façades is more detailed. The maximum of 1% weight and indicator for neglected materials is not exceeded.

§ 9.1.5 Calculation tool

The calculation tool for façades works similar to the one to evaluate the complete building substance (see 7.1.5) .This building tool was adapted to façade characteristics. Similar to Lixcel, volume information of a façade per sqm façade area is multiplied by the material density and subsequently with the indicator as shown in Figure 125.

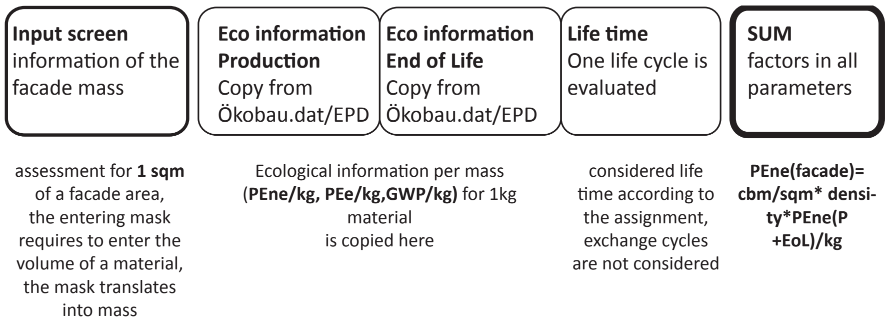
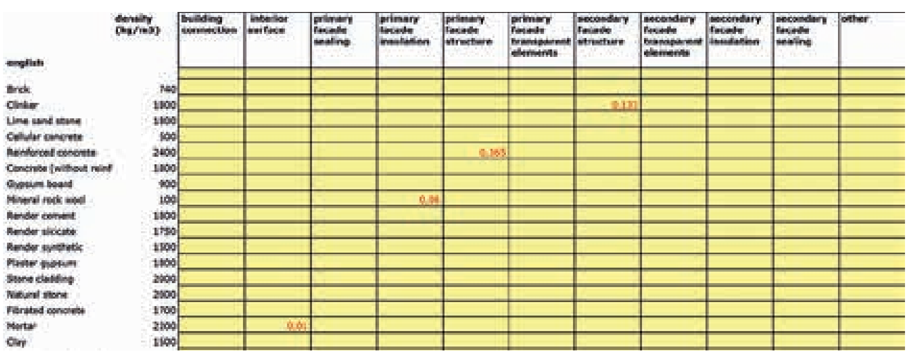


Figure 125
Principle to explain the parts of the calculation tool.



english	density (kg/m3)	building connection	interior surface	primary facade sealing	primary facade insulation	primary facade structure	primary facade transparent elements	secondary facade structure	secondary façade transparent elements	secondary facade insulation	secondary facade sealing	other
Brick	740											
Clinker	1800							0.131				
Lime sand stone	1800											
Cellular concrete	500											
Reinforced concrete	2400					0.165						
Concrete (without reinf	1800											
Gypsum board	900											
Mineral rock wool	100				0.08							
Render cement	1800											
Render silicate	1750											
Render synthetic	1300											
Plaster gypsum	1800											
Stone cladding	2000											
Natural stone	2500											
Fibrated concrete	1700											
Mortar	2100		0.01									
Clay	1100											

Figure 126
Input screen for Lixcel-Façade

The most relevant part of the tool is the input screen (Figure 126). It assesses eco-indicators for one sqm average façade area. If a representable sqm can not be found, a bigger area should be investigated. The volume per material should be calculated and subsequently divided by the considered area. These numbers can then be transferred into the input screen.

Here, 65 materials in five material groups with their eco-indicators have been provided. These are arranged vertically on the very left side. The mask includes more than 15 open rows so that materials not mentioned can be filled in manually.

The input screen is divided into different functions horizontally. 11 options can be chosen from: building connection, interior surface, primary façade sealing, primary façade insulation, primary façade structure, primary façade transparent elements, secondary façade structure, secondary façade transparent elements, secondary façade insulation, secondary façade sealing and other. These parameters were chosen to identify functions with high environmental impact. The input screen has to be filled with content for each of the three façade (the existing, the optimised and the designed).

Lixel-Façade consists of four sheets. Sheet two to four are calculation sheets for the three façade variations. The results are automatically shown on the first sheet. (An excerpt is shown in Figure 127.) Weight, EE and GWP are displayed. The numbers are shown and a graph is generated based on the figures used in the evaluation.

	GWP		
	Existing facade	**Optimization**	**Creative/In novative**
Brick	0.00	0.00	0.00
Clinker	54.09	46.08	0.00
Lime sand stone	0.00	0.00	0.00
Cellular concrete	0.00	23.51	0.00
Reinforced concrete	67.04	13.07	0.00
Concrete (without reinforcement)	0.00	0.00	0.00
Gypsum board	0.00	0.00	0.00
Mineral rock wool	7.68	0.00	0.00
Render cement	0.00	0.00	0.00
Render sikicate	0.00	0.00	0.00
Render synthetic	0.00	0.00	0.00
Plaster gypsum	0.00	4.27	4.27
Stone cladding	0.00	0.00	0.00
Natural stone	0.00	0.00	0.00
Fibrated concrete	0.00	0.00	0.00

Figure 127
The figure shows an excerpt of the first page displaying the results for GWP. A graph is generated based on these figures.

§ 9.1.6 EEP for each façade case study

The evaluation has been characterised in the previous paragraphs. Here the parameters for each case study will be shown. Each paragraph names a part of the evaluation that should be communicated in order to understand the scope of the evaluation.

Calculation and optimised by

The name of the student and the semester (in which the calculation was conducted) are named under this category.

Project

As explained earlier in this chapter, the assignment included the ecological analysis of a façade that is part of an existing building. For the sake of traceability, the name of the project and the city name, if known, are given.

Supervised by

The supervisors are named. During that time Prof. i. V. Lutz Artmann was working at the chair in Detmold and helped to supervise the façades regarding their construction.

Construction description

The façades are organised by typology in Punctured Wall Façade (PWF) and Curtain Wall (CW). These are the two main categories. PWF is further divided in warm façade (WF) and ventilated façade (VF). CW is further divided in mullion and transom (MT) and system façade (SF). This façade organisation was developed with Dr. Bilow in order to find a simple yet general typology. The organisation also refers to the book Principles of Façades he published with Knaack, Klein and Auer in 2007. (Knaack, Klein, Bilow & Auer, 2007)

The façade typology delivers basic information of the construction. More details are given in the description of the construction. The materials are named with their material thickness. Existing, Optimised and Design façade are explained separately to retrace the changes from one example to the other. The subsequent categories (which are named next) follow this subdivision.

Transparency share (%)

The transparency share indicates the area of openings in relation to the opaque area. This relation is expressed in percentage. The assignment included a minimum transparency of 25%. For the investigation of glass façades in comparison to partly opaque areas this percentage ranges up to 100 %. This is only possible because the frame area is accounted for opening, respectively transparency.

Heat conductivity (W/sqmK)

The heat conductivity was introduced in order to approach the topic of a functional unit. All buildings were required to include a certain value of 0.35 lambda, at least in the optimisation. This refers to the area without fenestration. It was controlled by a simple web based calculation tool called u-wert.net. This worked for well for the punctured walls. Complex curtain wall façades were checked regarding their plausibility by information from façade companies such as Schüco, Reiko or Wicona. Similar products were researched and compared to the façade on an existing building.

Weight (kg/sqm)

The weight is displayed to help identify mistakes. Additionally, it is a basis to understand the relation of weight and EE/GWP.

EE total (MJ/sqm)

The result of the calculation is shown in primary energy non-renewable per square meter of façade surface. The primary energy is used according to the previous conditions, which are used in chapters 5 and 7.

GWP total (kg CO_2 eq./sqm)

In addition to EE, the contribution to the global warming effect is expressed in the GWP per square meter of façade surface as used in the previous chapters.

PWF- WF 01			
Category	Case study information		
Calculated and optimised by			
Project			
Supervised by			
Variation name	Existing façade	Optimisation	Design
Construction			
Transparency share (%)			
Heat conductivity (W/sqmK)			
Weight (kg/sqm)			
EE total (MJ/sqm)			
GWP total (kg CO_2 eq./sqm)			

Table 43

The table shows the categories that can be communicted wihtin a table. Their content is described in the previous paragraphs.

§ 9.2 Case studies

This chapter shows the result of the ecological evaluation for the building substance of 20 façades. They are categorized by the façade typology. Eleven punctured wall façades and nine curtain wall façades are presented.

Short name	Calculation done by	A EE (MJ/sqm)	B EE (MJ/sqm)	C EE (MJ/sqm)	A GWP (kg CO_2 eq./sqm)	B GWP (kg CO_2 eq./sqm)	C GWP (kg CO_2 eq./sqm)
PWF-WF 01	Maren Kreft (WS 11/12)	1,287	1,385	797	129	94	61
PWF-WF 02	Jan Maasjosthus-mann (WS 11/12)	797	739	664	69	42	18
PWF-WF 03	Lena Wilke (WS 11/12)	818	769	549	84	75	32
PWF-WF 04	Nicole Rempel (WS 11/12)	1,300	928	810	136	102	69
PWF-WF 05	Karl Patrick Wessel (WS 11/12)	957	1,458	1,529	95	99	97

Short name	Calculation done by	A EE (MJ/sqm)	B EE (MJ/sqm)	C EE (MJ/sqm)	A GWP (kg CO_2 eq./sqm)	B GWP (kg CO_2 eq./sqm)	C GWP (kg CO_2 eq./sqm)
PWF-V 06	Lisa Heynen (WS 11/12)	400	338	325	30	20	20
PWF-V 07	Sabrina Mix (WS 11/12)	847	765	81	110	90	38
PWF-V 08	Carina Kisker (WS 11/12)	1,228	938	846	133	78	57
PWF-V 09	Lorena Altrogge (WS 11/12)	605	705	547	48	61	17
PWF-V 10	Wadislaf Witlif (WS 11/12)	1,962	1,598	1,199	186	158	136
PWF-V 11	Maximilian Ernst (WS 11/12)	1,463	1,325	518	137	46	9
CW-MT 12	Katharina Port-mann (WS 11/12)	2,343	2,024	1,391	136	149	69
CW-MT 13	Katharina Görtz (WS 11/12)	875	946	453	58	33	27
CW-MT 14	Tobias Planizter (WS 11/12)	1,863	1,887	1,989	137	119	87
CW-MT 15	Eugen Friesen (WS 11/12)	2,256	2,447	2,316	183	159	155
CW-MT 16	Julia Weber (WS 11/12)	562	537	420	38	37	31
CW-MT 17	Maren Krille (WS 11/12)	939	580	548	67	35	33
CW-MT 18	Andreas Kremer (WS 11/12)	1,954	1,032	953	137	127	57
CW-MF 19	Kerstin Kramme (WS 11/12)	1,259	1,017	846	85	48	10
CW-MF 20	Eduard Rempel (WS 11/12)	1,426	1,354	1,008	71	66	49

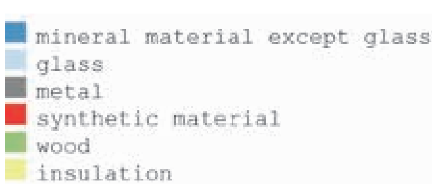


Figure 128
This key has been used before. As a reminder it is shown again as it is used for the following figures.

§ 9.2.1 Punctured window façade- warm façade 01

PWF- WF 01			
Project	NUWOG, Neu-Ulm		
Calculated , optimised and re-designed	Maren Kreft (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	15mm lime plaster, 200mm concrete, insulating core 100 mm mineral wool, customized brick 115mm, non-operable two layered IGU, aluminium frame, concrete embrasure	15mm lime plaster, 300 mm aerated concrete, 40 mm air, 115 mm customized brick, non-operable triple pane IGU, aluminium wood frame, concrete embrasure	15mm lime plaster, 300 mm aerated concrete with lime and pumice, 80 mm cotton insulation, 40 mm air, 180 mm balls in 3 layers in PP nets customized brick, non-operable triple pane IGU, aluminium wood frame, embrasure from cans
Transparency share (%)	38	38	38
Heat conductivity (W/sqmK)	0.67	0.39	0.32
Weight (kg/sqm)	660	433	527
EE (MJ/sqm)	**1,287**	**1,385**	**796**
GWP (kg CO_2 eq./sqm)	**129**	**94**	**61**

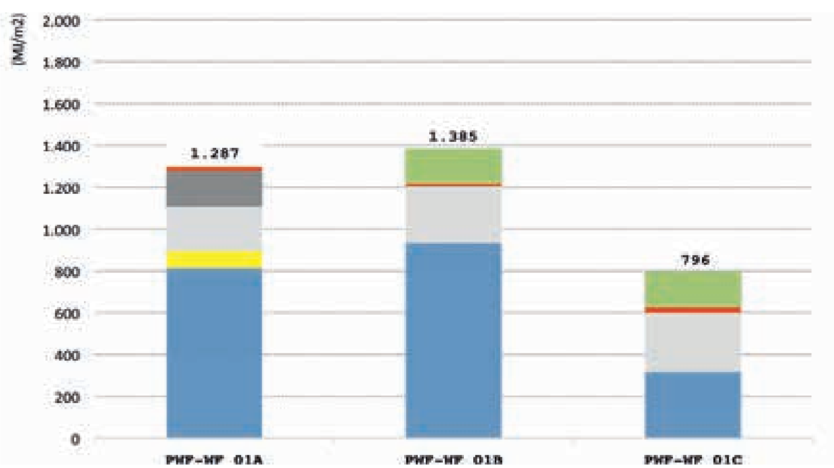


Figure 129
EE for PWF -WF 01

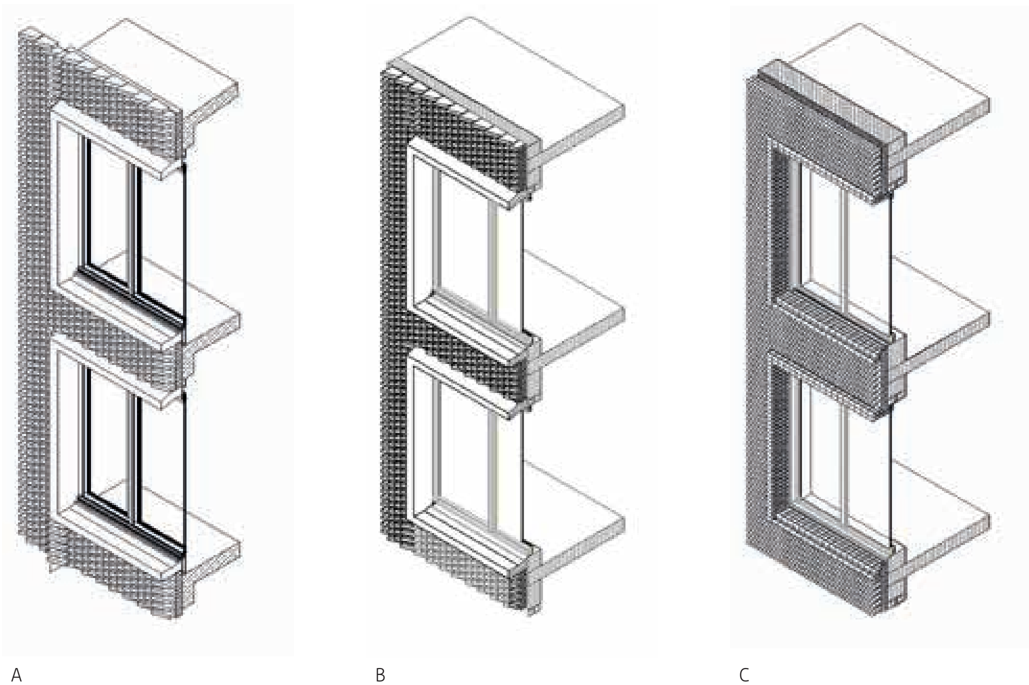


Figure 130
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

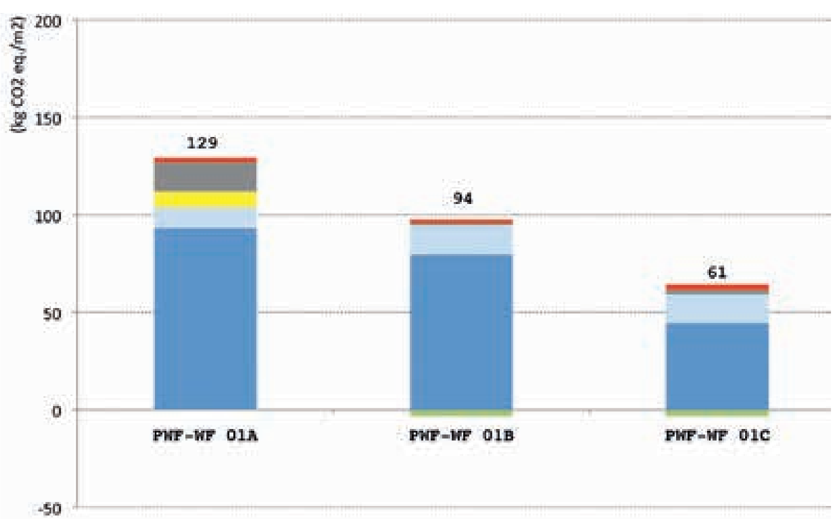


Figure 131
GWP for PWF -WF 01

§ 9.2.2 Punctured window façade- warm façade 02

PWF- WF 02			
Project	Housing in Berlin, OIKOS		
Calculated , optimised and re-designed	Jan Maasjosthusmann (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	12.5mm gypsum board, aluminium foil, wood substructure, 80mm EPS, 180mm concrete, operable double pane IGU with wood frame	30mm clay board, 180mm wood fibre board, 180mm concrete, opera-ble double pane IGU with wood frame	30mm clay board, 120mm wood fibre board, 180mm aerated concrete, operable double pane IGU with wood frame, standardized aluminium paint pots
Transparency share (%)	25	25	28
Heat conductivity (W/sqmK)	0.37	0.35	0.35
Weight (kg/sqm)	415	474	155
EE (MJ/sqm)	**797**	**739**	**664**
GWP (kg CO_2 eq./sqm)	**69**	**42**	**18**

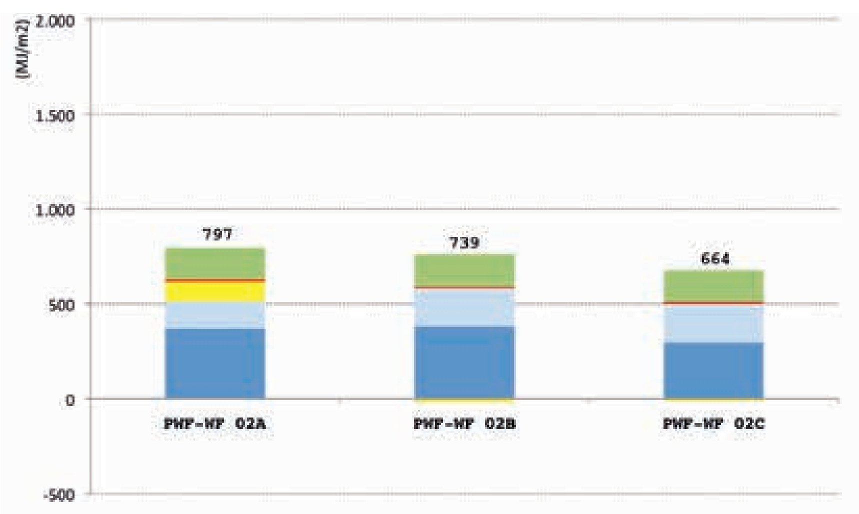
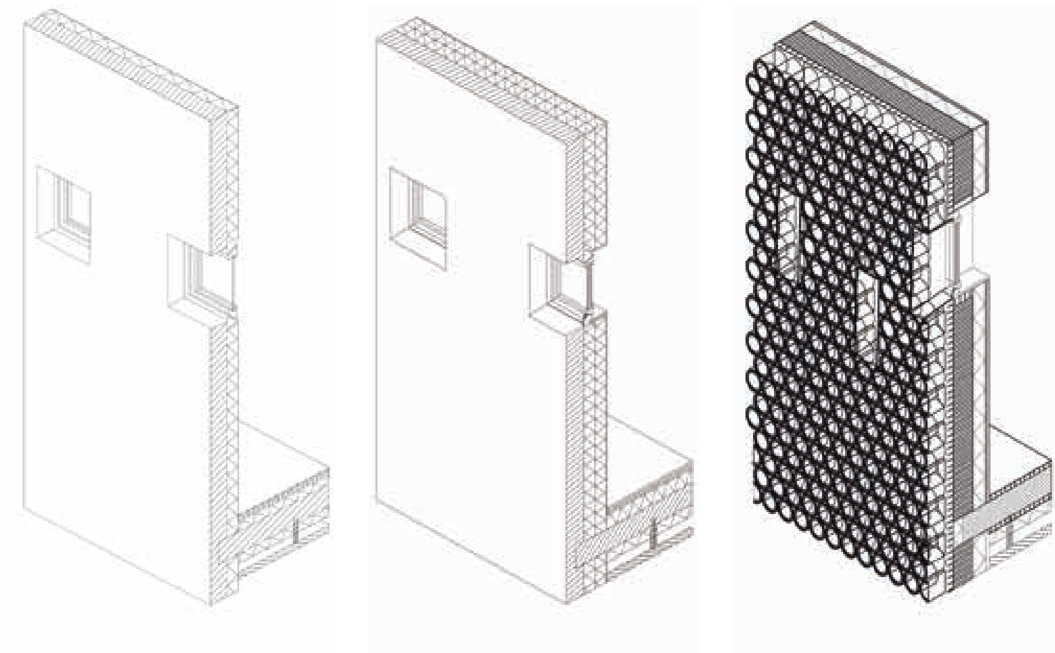


Figure 132
EE for PWF -WF 02



A B C

Figure 133
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

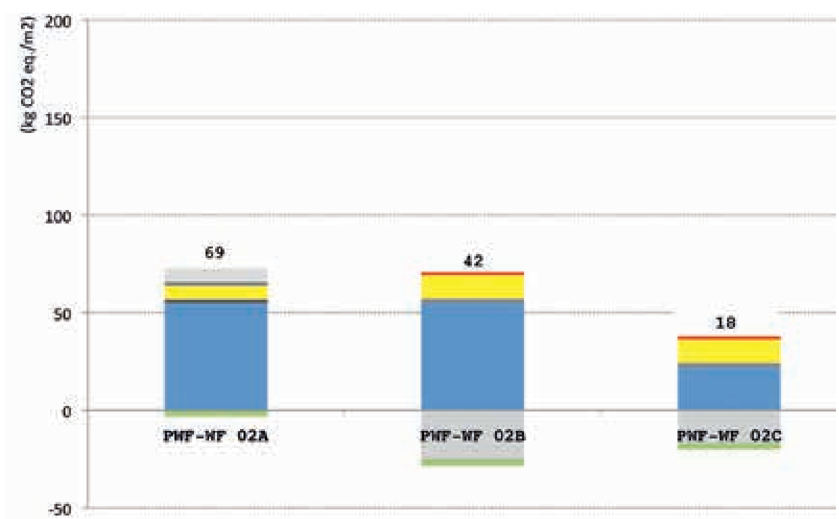


Figure 134
GWP for PWF -WF 02

§ 9.2.3 Punctured window façade- warm façade 03

PWF- WF 03			
Project	School in Papels		
Calculated , optimised and re-designed	Lena Wilke (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	180mm lightweight concrete (900kg/cbm), 100 mm XPS, 120mm con-crete, non-operable IGU with aluminium window frame	180 mm lightweight concrete, aluminium substructure, 150mm mineral wool, fibre ce-ment boards, non-oper-able triple pane IGU with aluminium window frame	180 mm lightweight con-crete, wood substructure, 180mm wood fibre insu-lation, foil, HPL boards, non-operable triple pane IGU with wood window frame
Transparency share (%)	18	18	18
Heat conductivity (W/sqmK)	0.25	0.27	0.30
Weight (kg/sqm)	255	183	166
EE (MJ/sqm)	818	769	549
GWP (kg CO_2 eq./sqm)	84	75	32

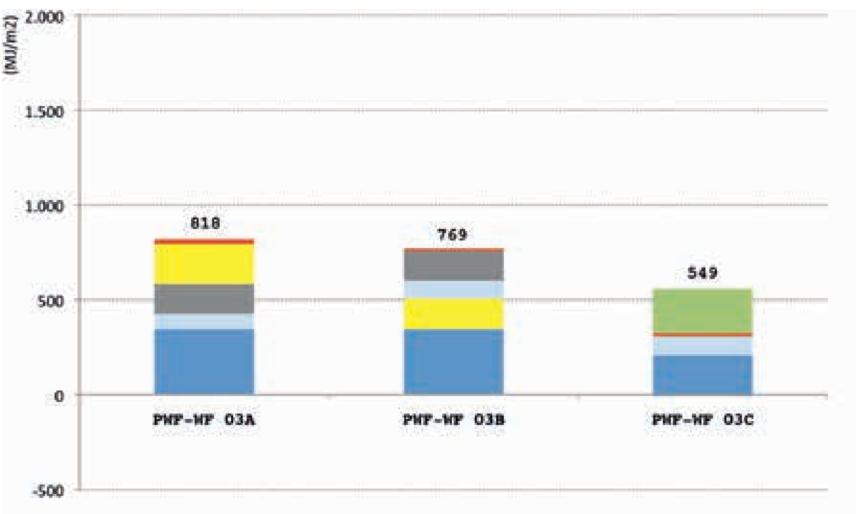
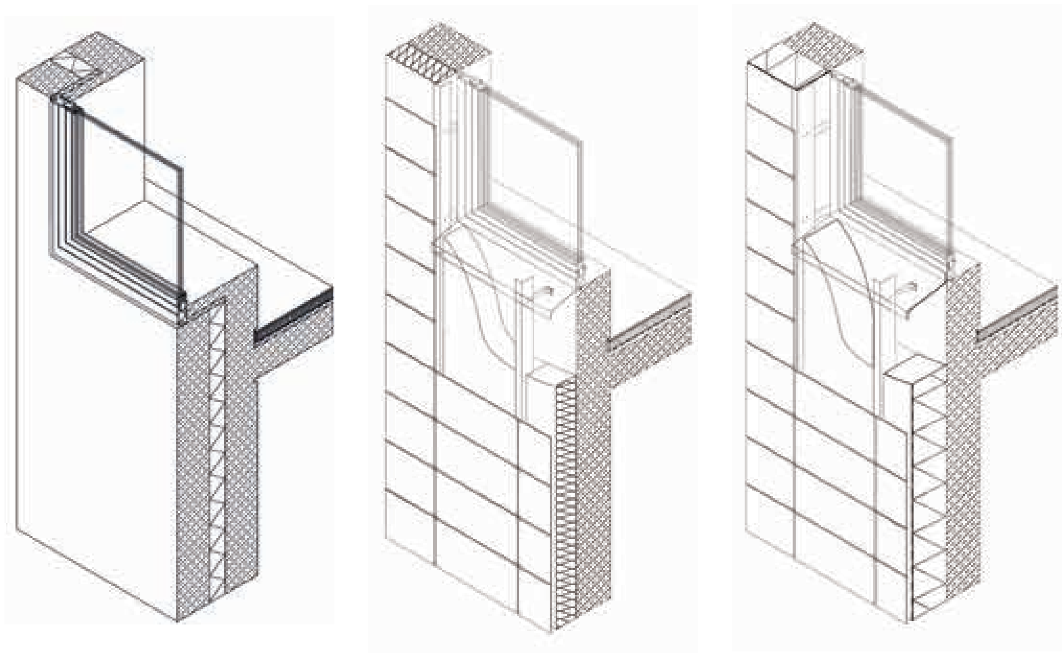


Figure 135
EE for PWF -WF 03



A B C

Figure 136

(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

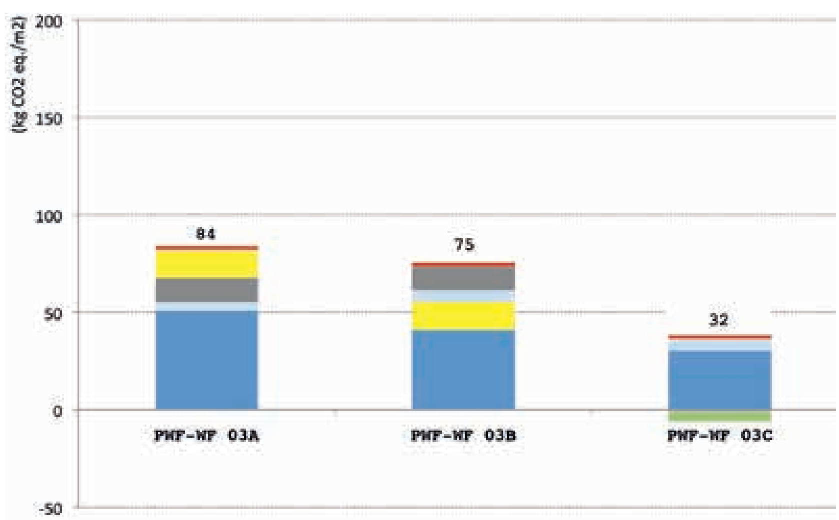


Figure 137

GWP for PWF -WF 03

§ 9.2.4 Punctured window façade- warm façade 04

PWF- WF 04			
Project	Semi-detached building in Bielefeld		
Calculated , optimised and re-designed	Nicole Rempel (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	15mm lime plaster, 300mm lime stone, concrete lintel, 30mm synthetic render, operable double pane IGU, PVC frame	15mm lime plaster, 300mm lime stone, concrete lintel, substructure, 120mm wood fibre insulation board, 0.2mm PE foil, wood cladding (larch), triple pane IGU, operable wood frame	15mm lime plaster, 240mm aerated concrete, concrete lintel, substructure, 40 mm wood fibre insulation board , 0.2mm PE - foil, wood cladding (larch), triple pane IGU, operable wood frame
Transparency share (%)	10	26	26
Heat conductivity (W/sqmK)	1.65	0.38	0.43
Weight (kg/sqm)	704	612	286
EE (MJ/sqm)	**1,300**	**928**	**810**
GWP (kg CO_2 eq./sqm)	**136**	**102**	**69**

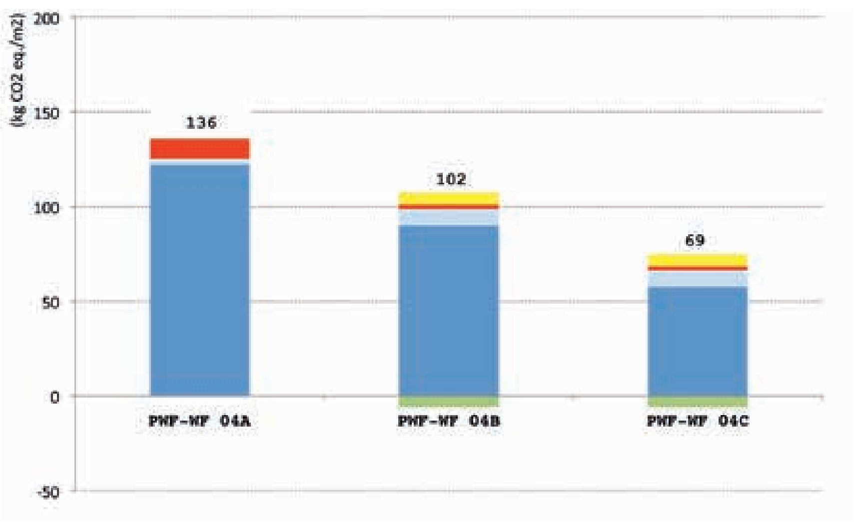
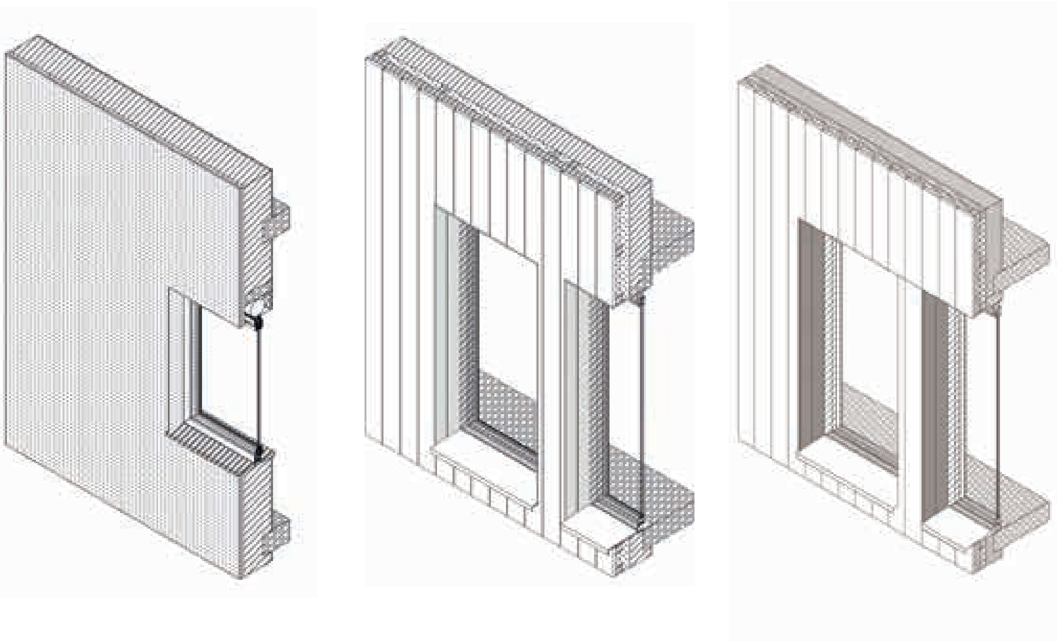


Figure 138
EE for PWF -WF 04



A B C

Figure 139
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

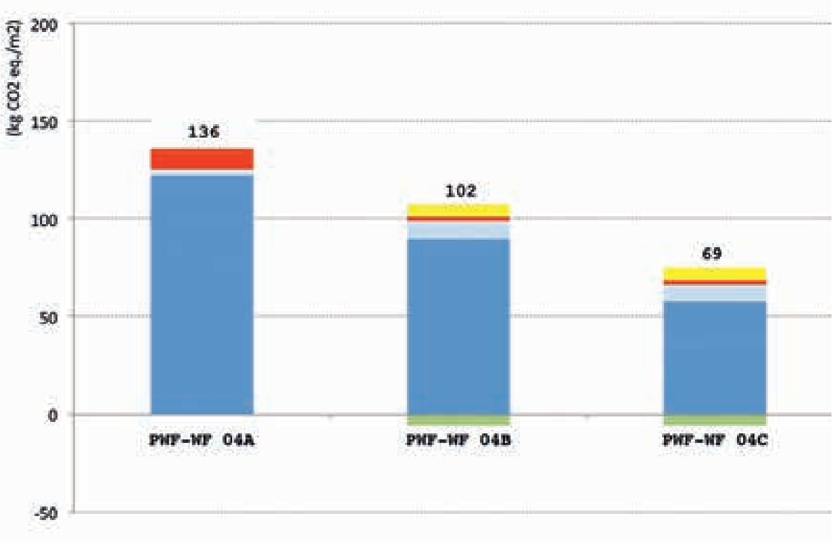


Figure 140
GWP for PWF -WF 04

§ 9.2.5 Punctured window façade- warm façade 05

PWF- WF 05			
Project	Semi-detached building in Bielefeld (1912), refurbished presumingly in the 80ies		
Calculated , optimised and re-designed	Karl Patrick Wessel (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	20mm plaster, 365mm brick, 30mm cement render, operable, single glazed window, wood window frame	20mm plaster, 365mm brick, 150m EIFS with mineral wool, operable, triple pane glazed IGU, PVC window frame	20mm plaster, 365mm brick, 100m EIFS with wood fibre board, humidity barrier PE, substructure, larch cladding, operable, triple pane IGU, wood window frame
Transparency share (%)	30	30	26
Heat conductivity (W/sqmK)	1.42	0.27	0.33
Weight (kg/sqm)	498	528	526
EE (MJ/sqm)	**957**	**1,458**	**1,249**
GWP (kg CO_2 eq./sqm)	**95**	**99**	**97**

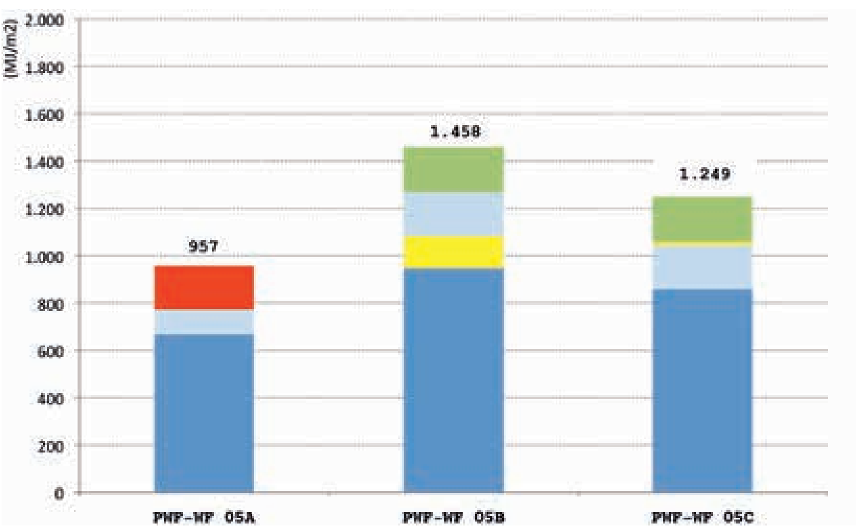
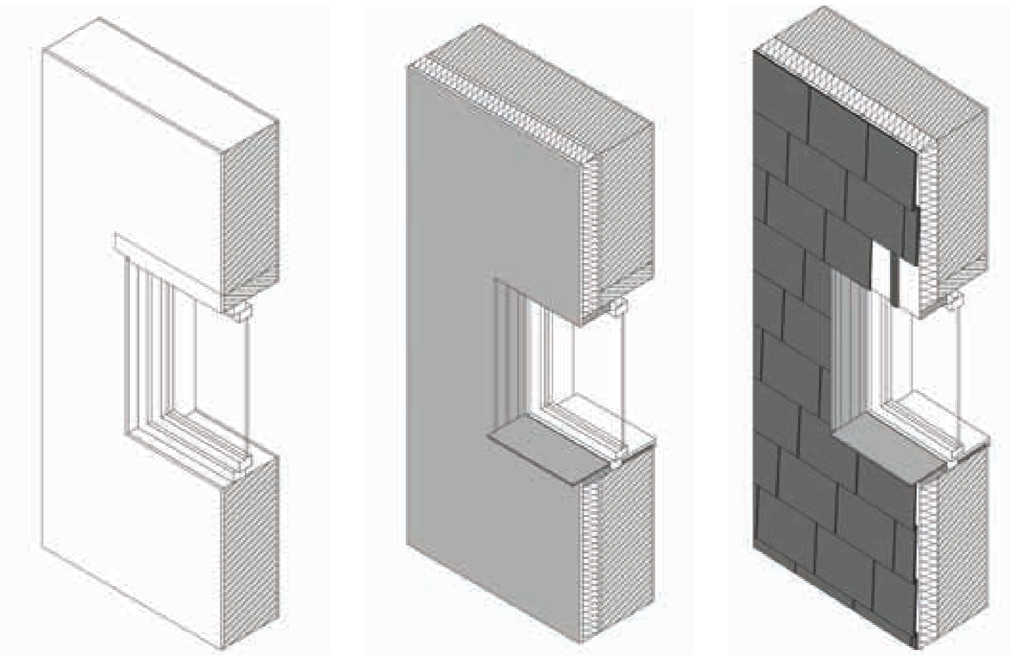


Figure 141
EE for PWF -WF 05



A B C

Figure 142
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade .PWF- EF 05 shows significantly slim window profiles

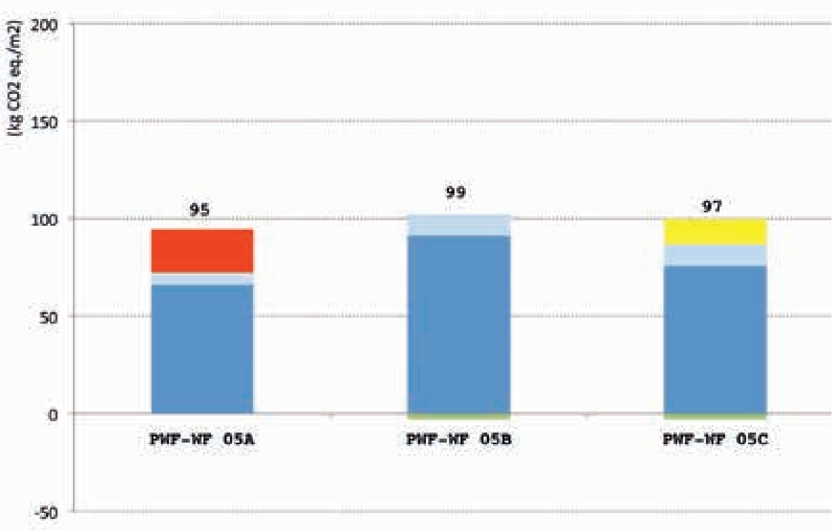


Figure 143
GWP for PWF -WF 05

§ 9.2.6 Punctured window façade- ventilated 06

PWF- V 06			
Project	Housing in Hagen,		
Calculated , optimised and re-designed	Lisa Heyen (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	12.5mm gypsum board, substructure wood, 50mm mineral wool, 19mm OSB, wooden structure, 200mm mineral wool, PE foil, cedar wood cladding (ventilated), operable double glazed IGU, aluminium window frame	12.5mm gypsum board, substructure wood, 50mm wood fibre wool, 19mm OSB, wooden structure, 200mm wood fibre board, hemp fleece, larch wood cladding, operable double glazed IGU, wood window frame	20mm OSB, substructure wood, 50mm wood fibre wool, 19mm OSB, wooden structure, 200mm wood fibre board, hemp fleece, larch wood cladding, operable double glazed IGU, wood window frame
Transparency share (%)	30	30	30
Heat conductivity (W/sqmK)	0.20	0.22	0.23
Weight (kg/sqm)	80	88	80
EE (MJ/sqm)	400	338	325
GWP (kg CO_2 eq./sqm)	30	20	20

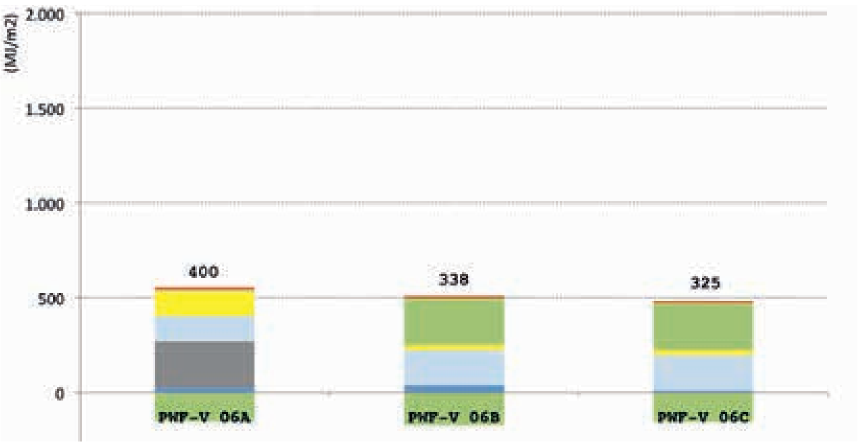


Figure 144
EE for PWF -V 06

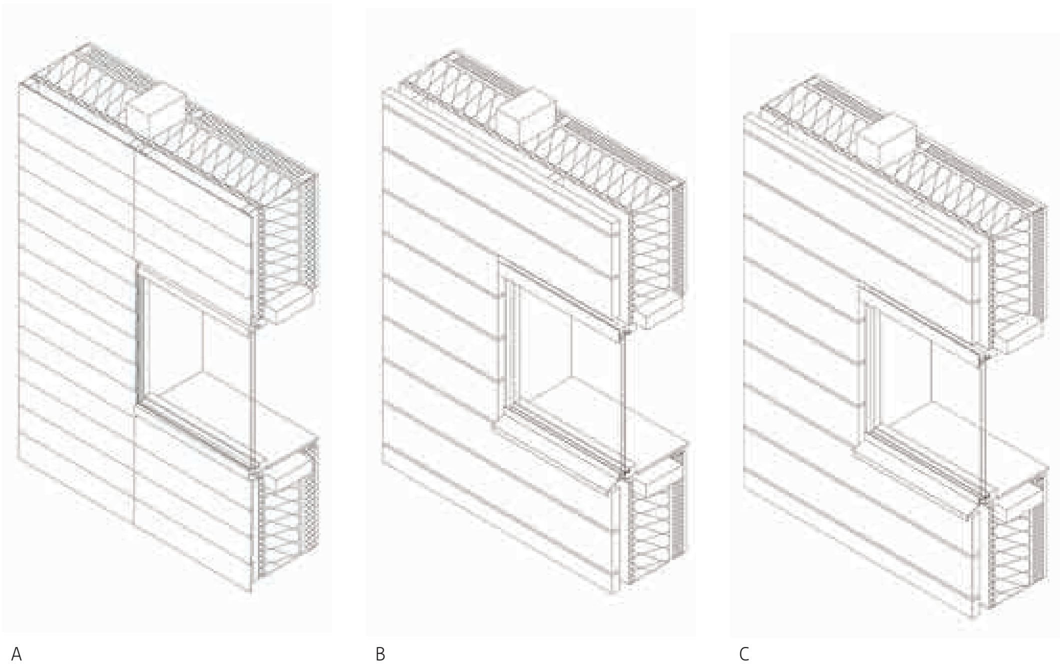


Figure 145
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade
From the existing to the EEO the construction remains the same only the materials are exchanged. Mineral wool is exchanged for hemp insulation. A wooden product replaces the aluminium window frame. In variant Design the vapour barrier is planned by two layers of OSB.

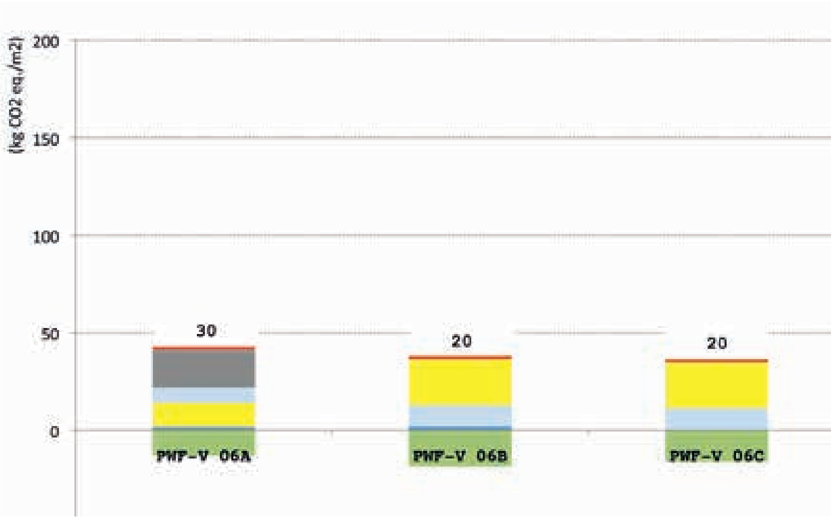


Figure 146
GWP for PWF -V 06

§ 9.2.7 Punctured window façade- ventilated 07

PWF- V 07			
Project	Konrad-Adenauer School in Langenberg		
Calculated , optimised and re-designed	Sabrina Mix (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	20mm plaster, 220mm concrete, wooden substructure, 100mm mineral wool, wooden substructure, HPL boards (ventilated), operable double pane IGU, alumin-ium window profile	20mm plaster, 300mm aerated concrete, wooden substructure, 100mm wood fibre board, 0.2 mm PE foil, wooden substructure, HPL boards (ventilated), triple pane glass IGU aluminium window profile	20mm plaster, 200mm OSB (magnum) boards, wooden substructure, 100mm wood fibre board, 0.2 mm PE foil, wooden substructure, HPL boards (ventilated), triple pane glass IGU wood window profile
Transparency share (%)	31	31	29
Heat conductivity (W/sqmK)	0.40	0.30	0.30
Weight (kg/sqm)	478	197	184
EE (MJ/sqm)	**847**	**765**	**81**
GWP (kg CO_2 eq./sqm)	**110**	**90**	**38**

Figure 147
EE for PWF -V 07

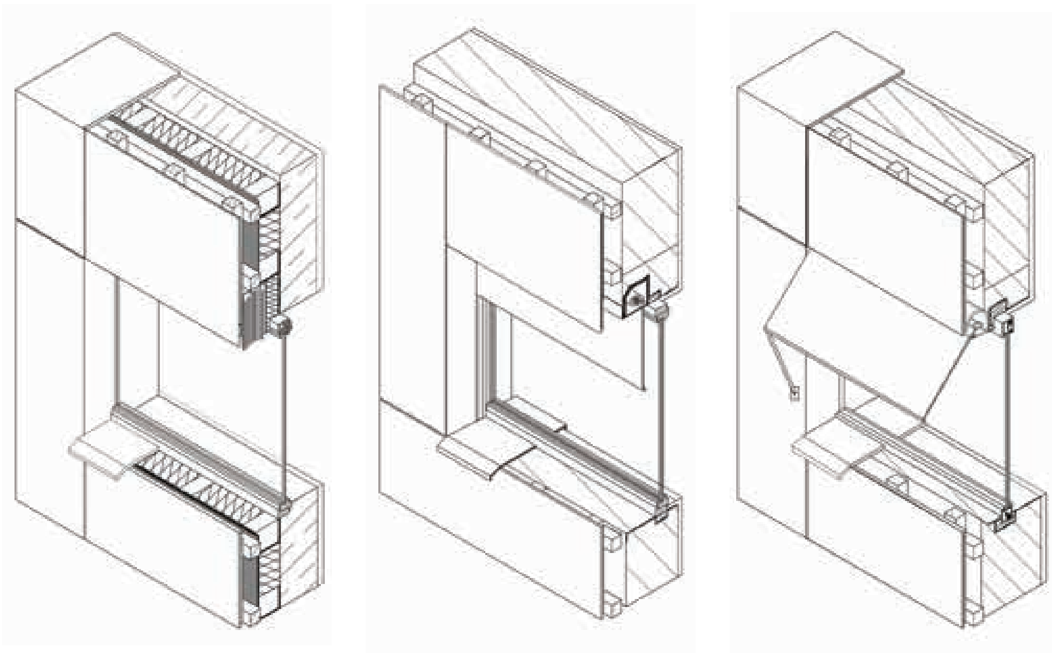


Figure 148
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

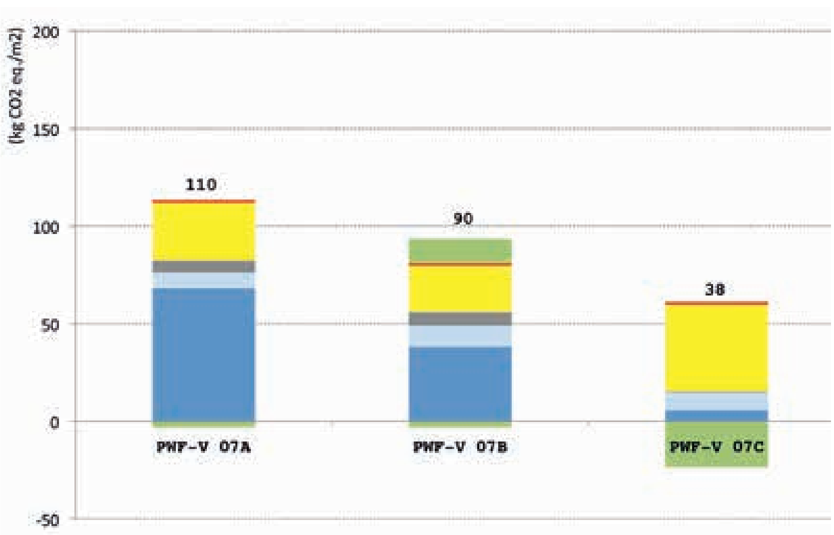


Figure 149
GWP for PWF -V 07

§ 9.2.8 Punctured window façade- ventilated 08

PWF- V 08			
Project	Frog Queen, Graz		
Calculated , optimised and re-designed	Carina Kisker (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	200mm concrete, aluminium substructure, 200mm mineral wool, 0.2mm PE foil, aluminium substructure, aluminium sheets (ventilated), operable double pane IGU, aluminium window profile	250mm aerated concrete, aluminium substructure, 50mm mineral wool, 0.2mm PE foil, aluminium substructure, aluminium sheets (ventilated), operable double pane IGU, aluminium window profile	250mm aerated concrete, aluminium substructure, 200mm PE bottles, 0.2mm PE foil, used HPL boards, operable double pane IGU, wood window profile
Transparency share (%)	25	25	25
Heat conductivity (W/sqmK)	0.23	0.33	0.38
Weight (kg/sqm)	400	119	120
EE (MJ/sqm)	**1,228**	**938**	**846**
GWP (kg CO_2 eq./sqm)	**133**	**78**	**57**

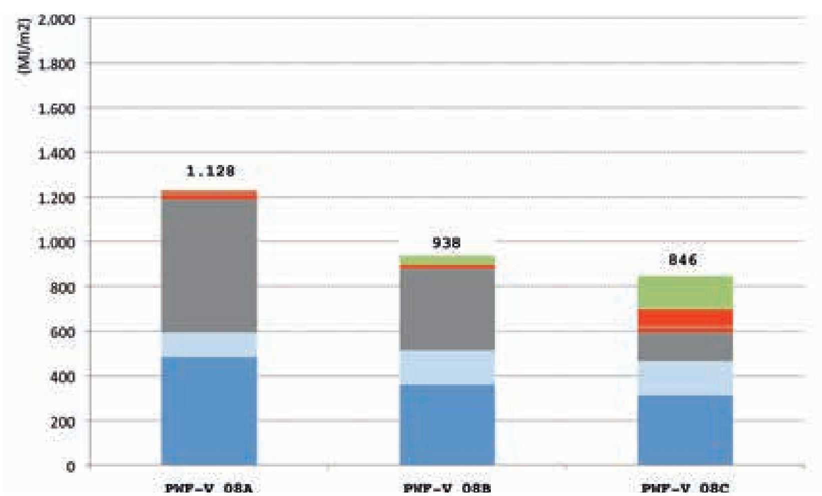
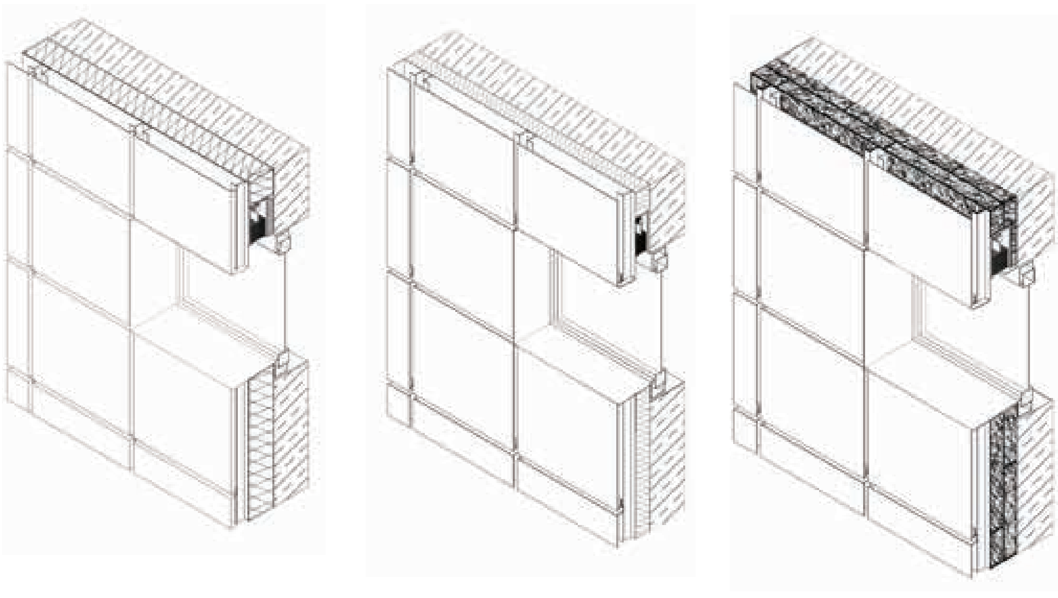


Figure 150
EE for PWF- V 08



A B C

Figure 151
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

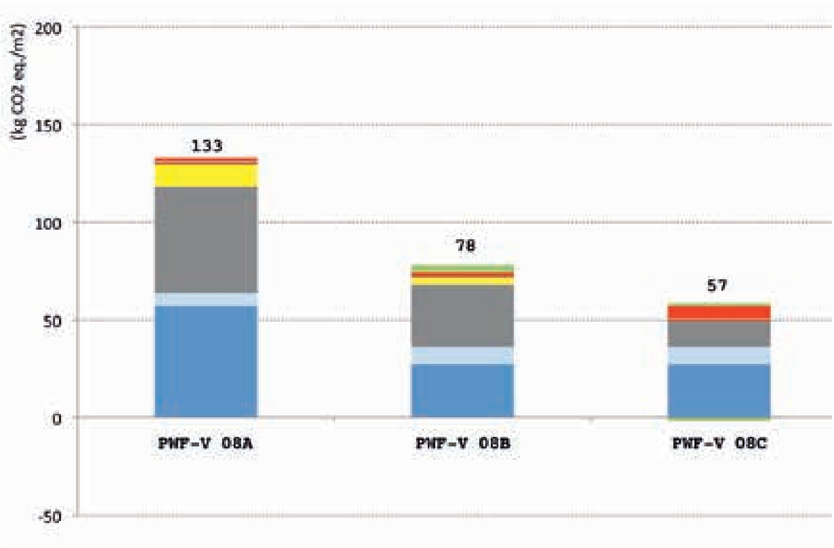


Figure 152
EE for PWF- V 08

§ 9.2.9 Punctured window façade- ventilated 09

PWF -V 09			
Project	Housing in London		
Calculated , optimised and re-designed	Lorena Altrogge (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	19mm rendering panel, 200mm wood frame construction filled with mineral wool, wood fibre board, wooden substructure, clay tiles, operable double pane IGU, aluminium frame	19mm rendering panel, 150mm wood frame construction filled with EPS, wood fibre board, wooden substructure, clay tiles, operable double pane IGU, PVC frame	19mm rendering panel, 250mm wood frame construction with wood fibre board, wooden substructure, clay tiles, operable double pane IGU, wood frame
Transparency share (%)	30	30	30
Heat conductivity (W/sqmK)	0.26	0.30	0.33
Weight (kg/sqm)	124	119	113
EE (MJ/sqm)	**605**	**705**	**547**
GWP (kg CO_2 eq./sqm)	**48**	**61**	**17**

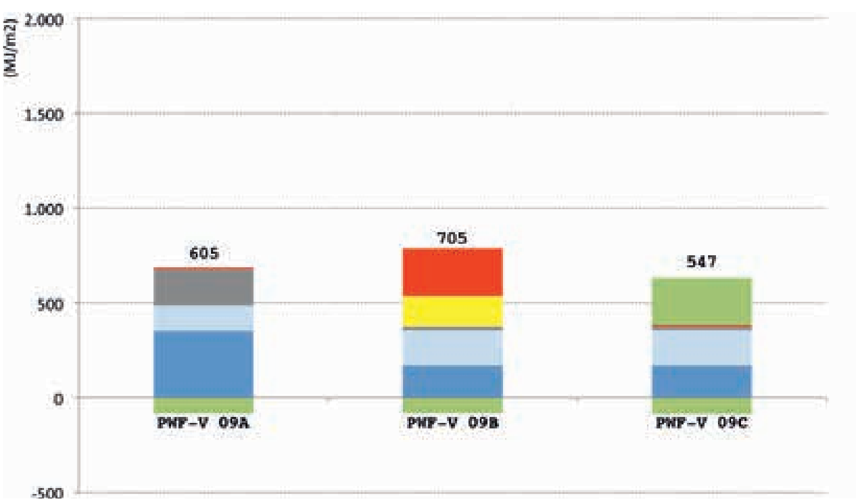


Figure 153
EE for PWF- V 09

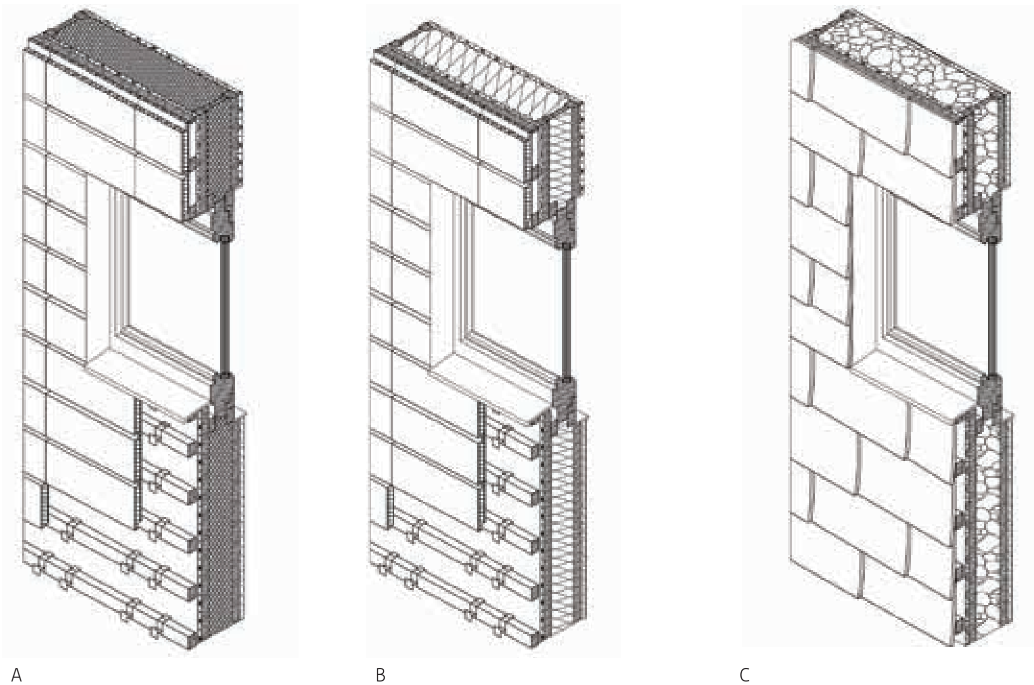


Figure 154
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

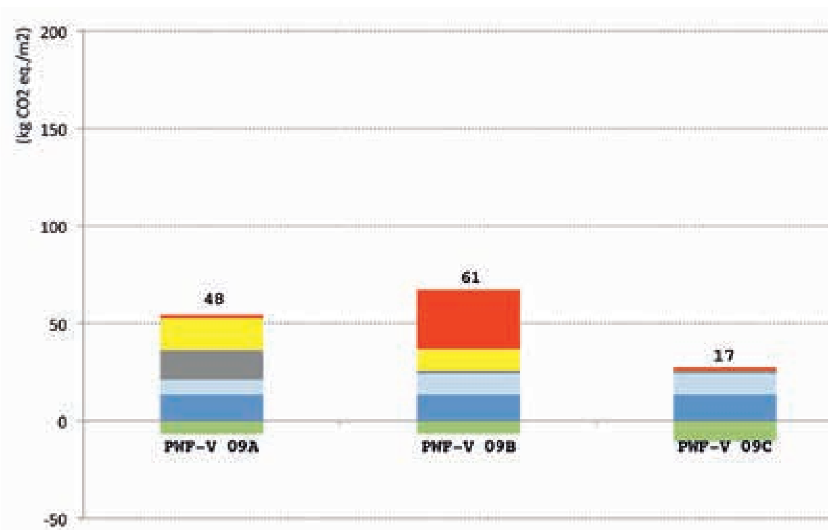


Figure 155
GWP for PWF- V 09

§ 9.2.10 Punctured window façade- ventilated 10

PWF- V 10			
Project	Fire and police station in Berlin		
Calculated , optimised and re-designed	Wadislaf Witlif (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	15mm lime plaster, 250mm concrete, 120mm mineral wool, 0.2mm PE foil, aluminium substructure, triple pane IGU, aluminium window frame	15mm lime plaster, 250mm concrete, 200mm wood fibre boards, 0.2mm PE foil, wood-aluminium sub-structure, triple pane IGU, wood window frame	15mm lime plaster, 250mm concrete, 120mm wood fibre boards, 0.2mm PE foil, PET bottles attached in a PA net to grow plants, tri-ple pane IGU, aluminium window frame
Transparency share (%)	38	38	38
Heat conductivity (W/sqmK)	0.37	0.32	0.49
Weight (kg/sqm)	497	500	470
EE (MJ/sqm)	**1,962**	**1,598**	**1,199**
GWP (kg CO_2 eq./sqm)	**186**	**158**	**136**

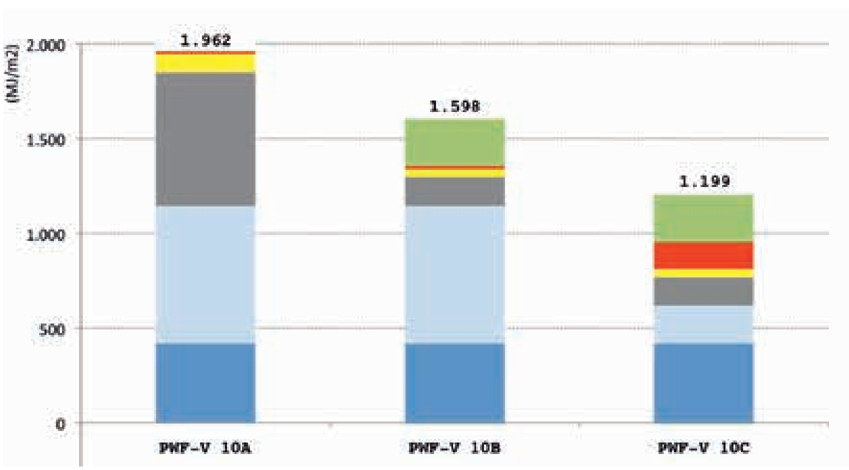


Figure 156

EE for PWF- V 10

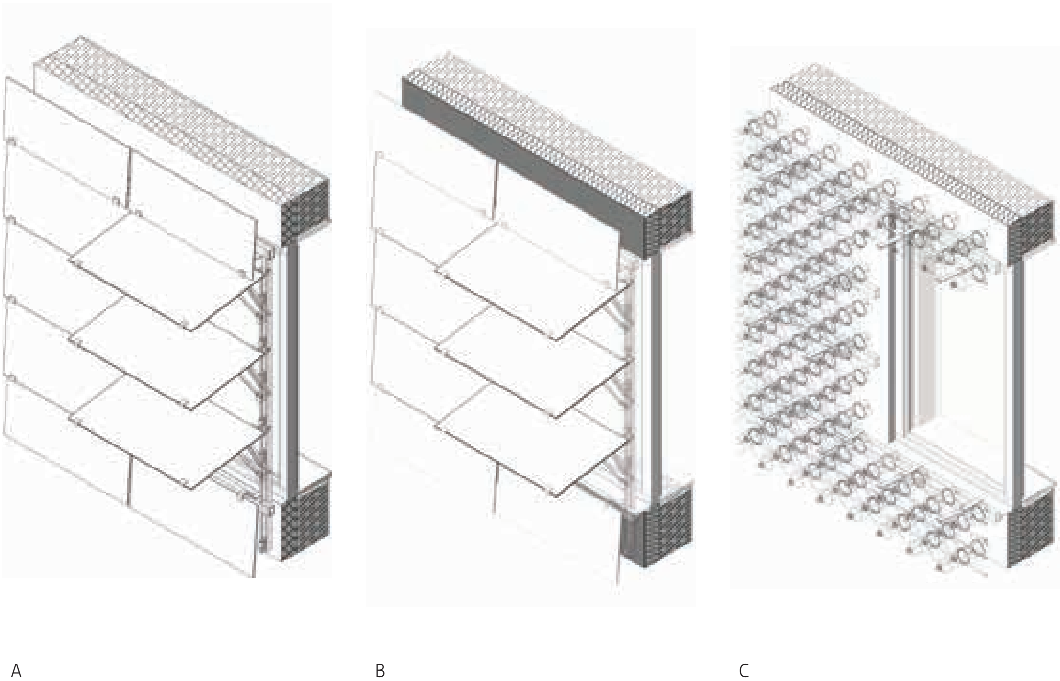


Figure 157
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

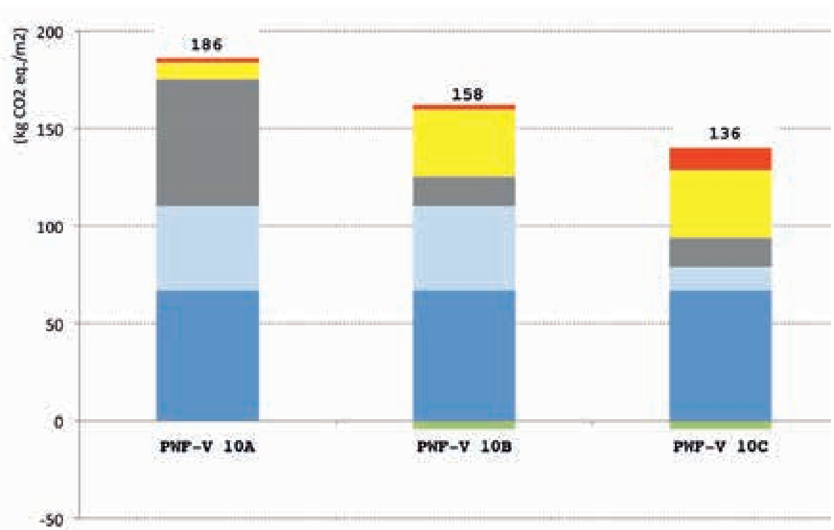


Figure 158
GWP for PWF- V 10

§ 9.2.11 Punctured window façade- ventilated 11

PWF- V 11			
Project	"Berliner Würfel" (Berlin dice)		
Calculated , optimised and re-designed	Maximilian Ernst (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	15mm plaster, 175mm lime stone, 60mm mineral wool, 100mm brick facing façade, hand rail and sun screen high grade steel, operable triple pane IGU, PVC window frame	50mm clay plaster, 200mm aerated concrete, 160 mm wood fibre board, 100mm brick facing façade, safety barrier glass, operable IGU wood window frame	Primary façade (not load-bearing) structure solid timber with glass and wood fibre fillings, secondary façade (load-bearing) laminated columns with steel connector, EFTE foil
Transparency share (%)	27	27	32
Heat conductivity (W/sqmK)	0.57	0.27	0.41
Weight (kg/sqm)	504	383	183
EE (MJ/sqm)	1,463	1,325	518
GWP (kg CO_2 eq./sqm)	137	46	9

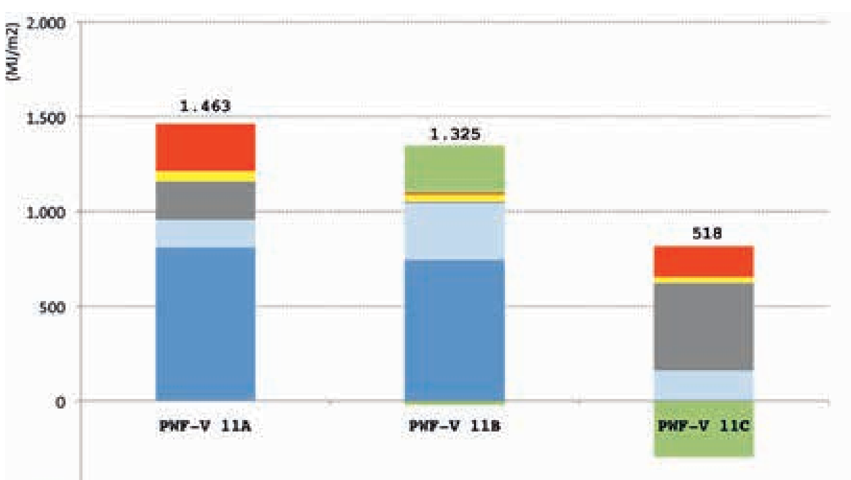
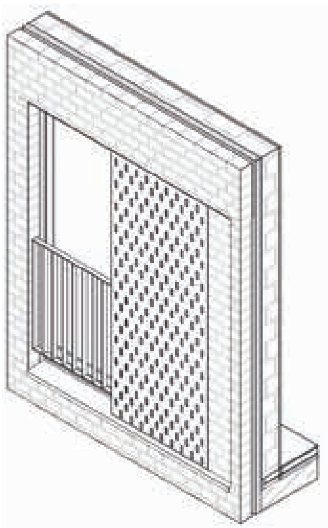
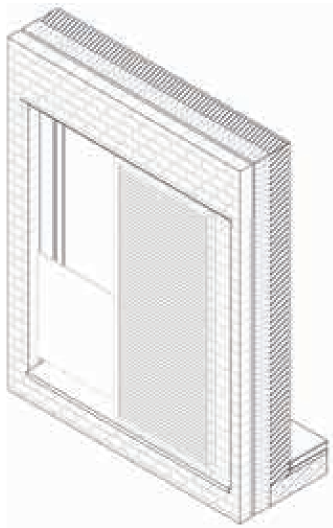


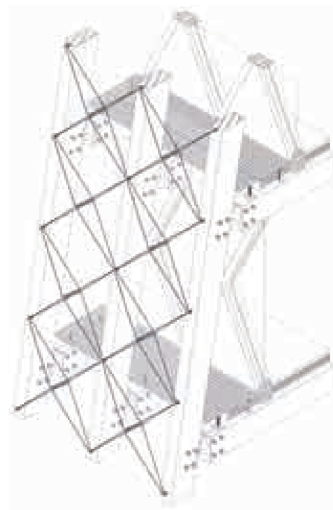
Figure 159
EE for PWF- V 11



A



B



C

Figure 160
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

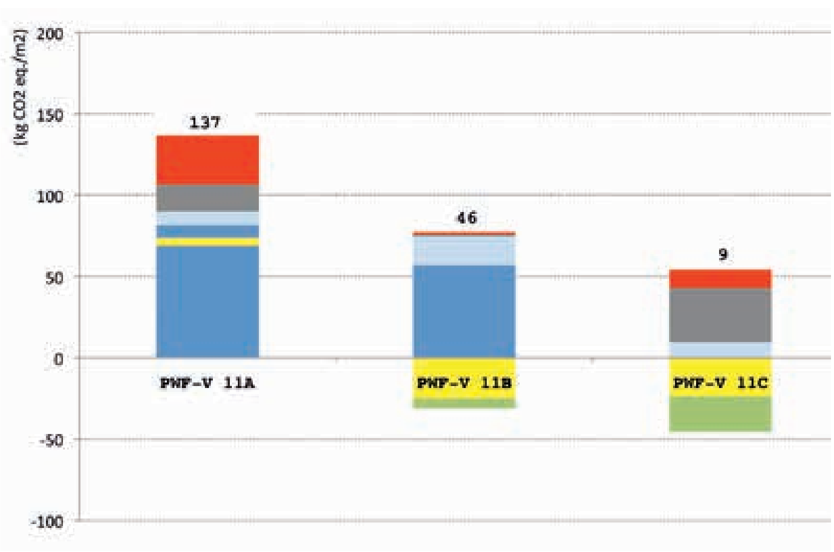


Figure 161
GWP for PWF- V 11

§ 9.2.12 Curtain wall- Mullion and transom façade 12

CW- MTF 12			
Project	Rosmarin Karree, Berlin		
Calculated , optimised and re-designed	Katharina Portmann (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Box window façade pf: floor-to-ceiling glazing, operable double pane IGU, wood frame sf: floor-to-ceiling glazing, VSG, attached with point fixing, vertical attachment by steel sword, horizontally attached and separated by aluminium sheet insulated with EPS, aluminium lamella for air exchange, steel roast	Box window façade pf: 160mm parapet in insulated wood frame, operable triple pane IGU, wood frame sf: floor-to-ceiling glazing, VSG, attached with point fixing, vertical attachment by steel sword, hori. attached and separated by alu. sheet insulated w. EPS, wood lamella for air exchange, wood roast	Box window façade pf: 160mm parapet from wood (stillage) frame with celluloses insulation, window operable triple pane IGU, wood frame sf: floor-to-ceiling glazing, VSG, attached w. point fixing, verti. attachment by steel sword, hori. attached & sepa-rated by alu. sheet insulated w. foam glass, wood lamella for air exchange, wood roast
Transparency share (%)	76	54	61
Heat conductivity (W/sqmK)	0.88	0.44	0.36
Weight (kg/sqm)	108	128	183
EE (MJ/sqm)	**2,343**	**2,024**	**1,391**
GWP (kg CO_2 eq./sqm)	**136**	**149**	**69**

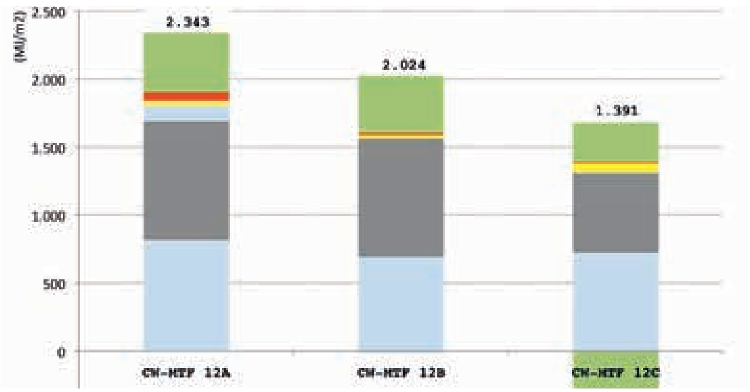
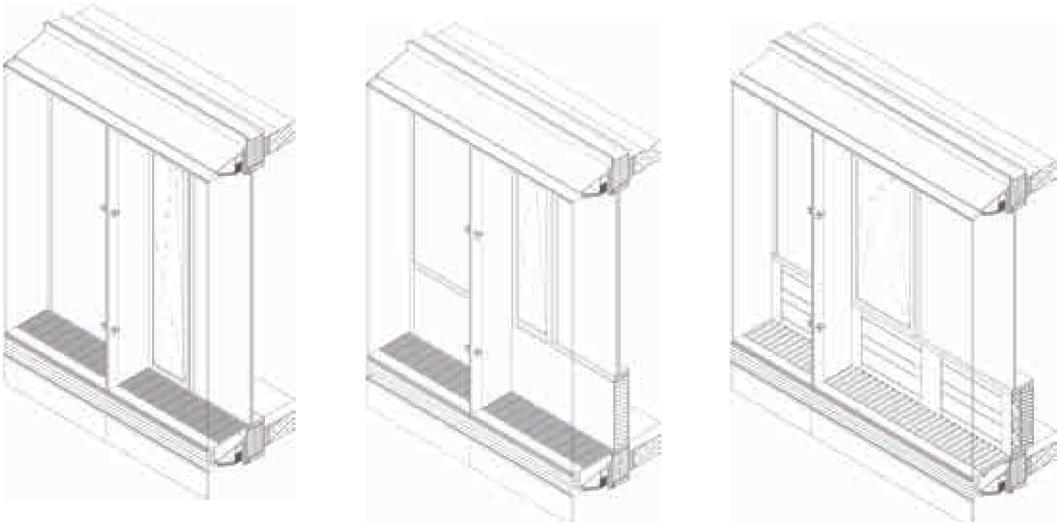


Figure 162
EE for CW- MTF 12



A B C

Figure 163
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

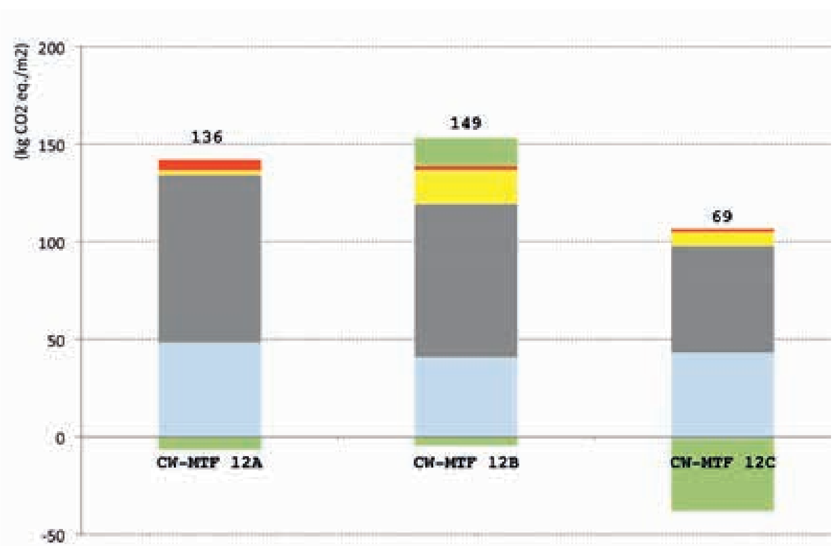


Figure 164
GWP for CW- MTF 12

§ 9.2.13 Curtain wall- Mullion and transom façade 13

CW -MTF 13			
Project	Office façade Webersbleiche, St. Gallen		
Calculated , optimised and re-designed	Katharina Görtz (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Aluminium frame, floor-to-ceiling triple pane glazing, edge insulation with EPS, ceramic board covered	Wood-aluminium frame, parapet with aluminium frame, metal sheet panel, non-operable triple pane IGU, edge insulation with EPS, ceramic board covered	Wood- aluminium frame, parapet with wood/OSB frame, cellulose insula-tion, triple pane IGU, edge insulation with EPS, ceramic board covered
Transparency share (%)	55	36	36
Heat conductivity (W/sqmK)	0.7	0.28	0.36
Weight (kg/sqm)	43	48	53
EE (MJ/sqm)	**875**	**946**	**453**
GWP (kg CO_2 eq./sqm)	**58**	**33**	**27**

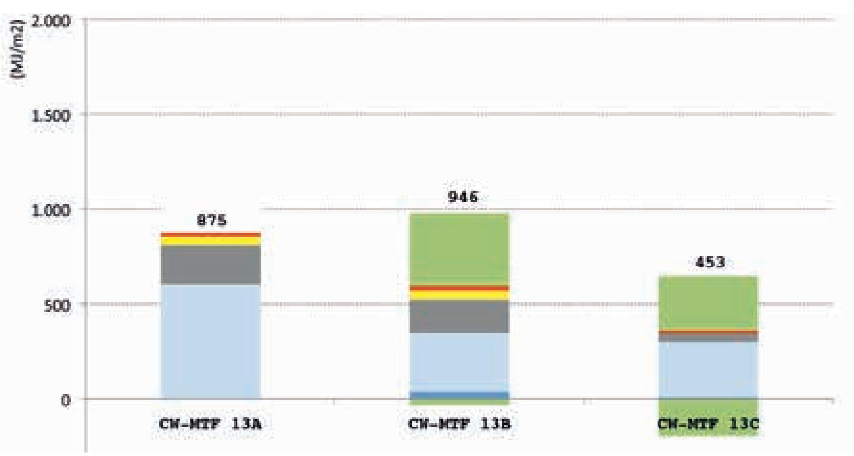
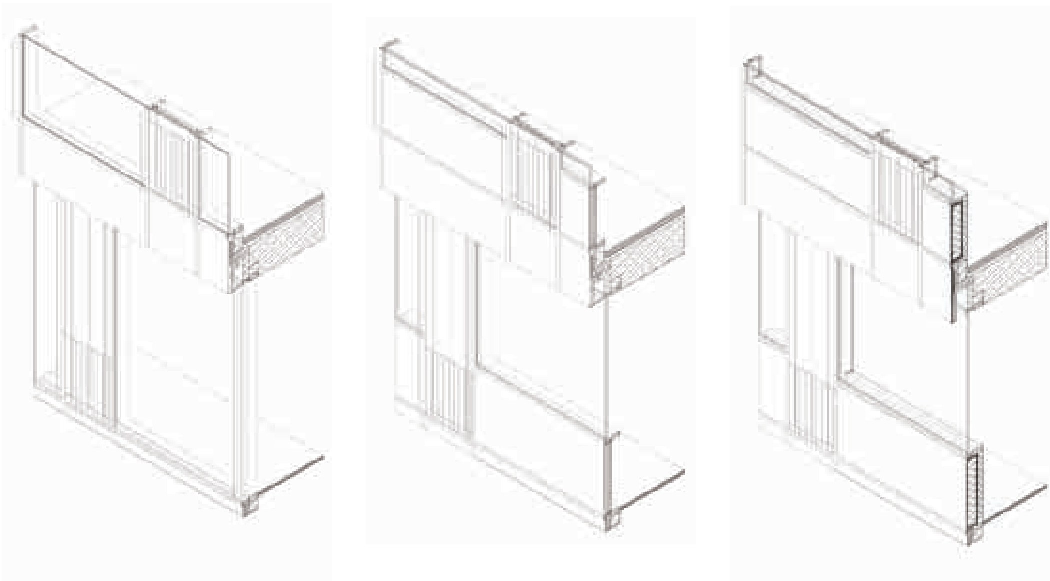


Figure 165
EE for CW- MTF 13



A B C

Figure 166
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

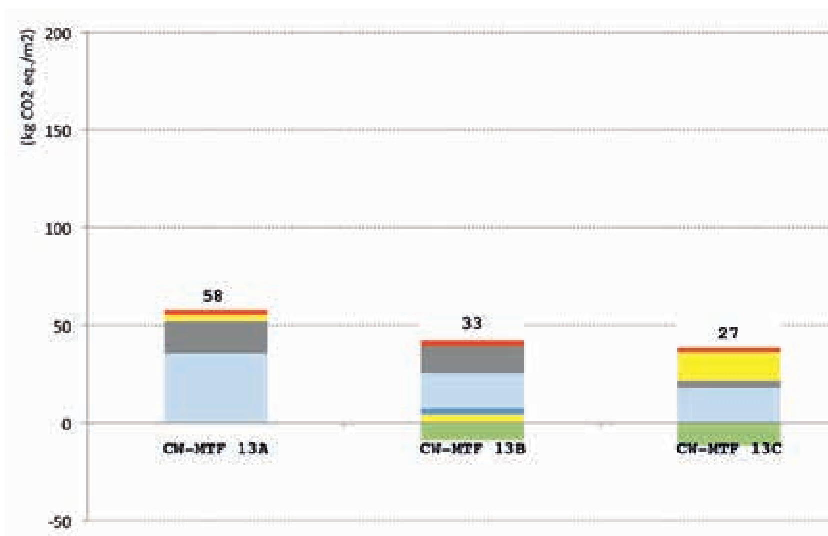


Figure 167
GWP for CW- MTF 13

§ 9.2.14 Curtain wall- Mullion and transom façade 14

CW-MTF 14			
Project	Office building, ARCA Frankfurt		
Calculated , optimised and re-designed	Tobias Planizter (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Double pane façade (Corridor façade) pf: aluminium frame, operable double pane IGU, insulated parapet with gypsum surface, 0.2mm PE foil behind it,clad with ventilated alu. sheet,operable PCV frame, double pane IGU, sf: aluminium frame, VSG, glass lamella for ventilation beneath the glazing,insulated edges with EPS and alu. cladding	Double pane façade (Corridor façade) pf: floor-to ceiling IGU with operable windows, wood frame sf: aluminium frame, VSG, insulated edges with EPS and aluminium cladding,outside is clad with glass lamella which provides ventilation below the ceiling substructure and metal sheet in cavity	Double pane façade (Corridor façade) pf: wood frame, floor-to ceiling IGU with operable window and wood frame sf: aluminium frame, VSG, insulated edges with EPS and aluminium cladding,outside is clad with a ventilated aluminium sheet substructure and metal sheet in cavity
Transparency share (%)	70	85	60 (including sun protection)
Heat conductivity (W/sqmK)	1.8	0.68	0.54
Weight (kg/sqm)	63	77	84
EE (MJ/sqm)	**1,863**	**1,887**	**1,989**
GWP (kg CO_2 eq./sqm)	**137**	**119**	**87**

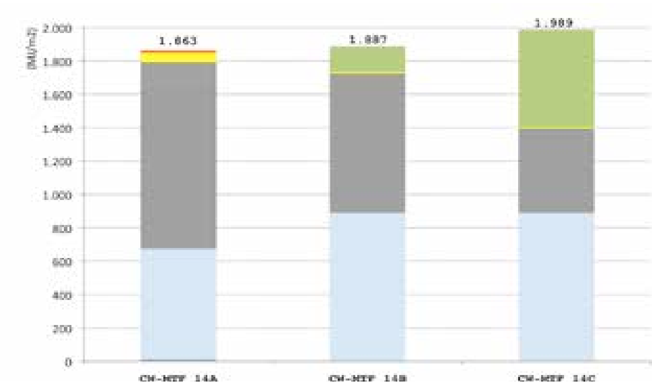
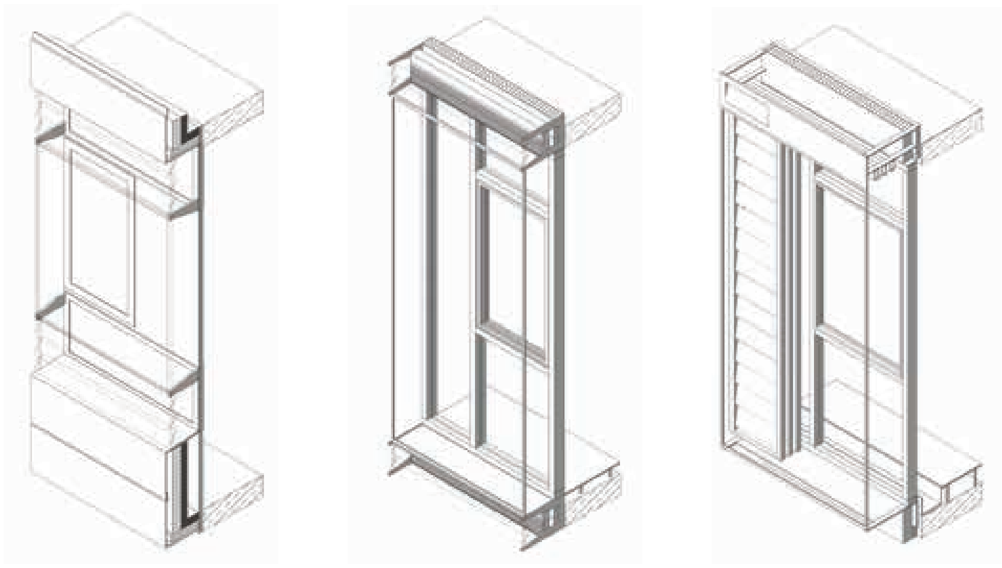


Figure 168
EE for CW- MTF 14



A B C

Figure 169
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

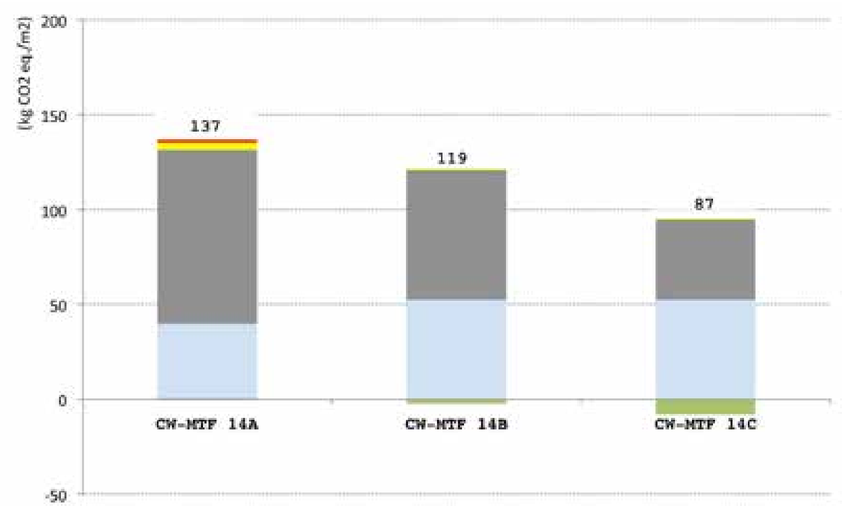


Figure 170
GWP for CW- MTF 14

§ 9.2.15 Curtain wall- Mullion and transom façade 15

CW- MTF 15			
Project	Rosmarin Karree, Berlin		
Calculated , optimised and re-designed	Eugen Friesen (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Double pane façade, (corridor-façade) pf: aluminium frame,double pane IGU, concrete lintel insulated with EPS, sf: Steel structure, floor-to-ceiling glazing with four glass lamella (20cm broad) located on top&bottom of the glazing, natural stone cladding on ceiling edge and vertically per element	Double pane façade, (corridor-façade) pf: wood frame,double pane IGU, concrete lintel insulated with EPS sf: Steel structure, floor-to-ceiling glazing with four glass lamella (20cm broad) located on top & bottom of the glazing, natural stone cladding on ceiling edge and vertically per element	Double pane façade, (corridor-façade) pf: wood frame,double pane IGU, concrete lintel insulated with EPS sf: Steel structure, PA ropes with membrane, natural stone cladding on ceiling edge and vertically per element
Transparency share (%)	85	85	80
Heat conductivity (W/sqmK)	1,1	0.85	0.75
Weight (kg/sqm)	135	139	118
EE (MJ/sqm)	**2,256**	**2,447**	**2,316**
GWP (kg CO_2 eq./sqm)	**169**	**152**	**148**

A B C

Figure 171
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

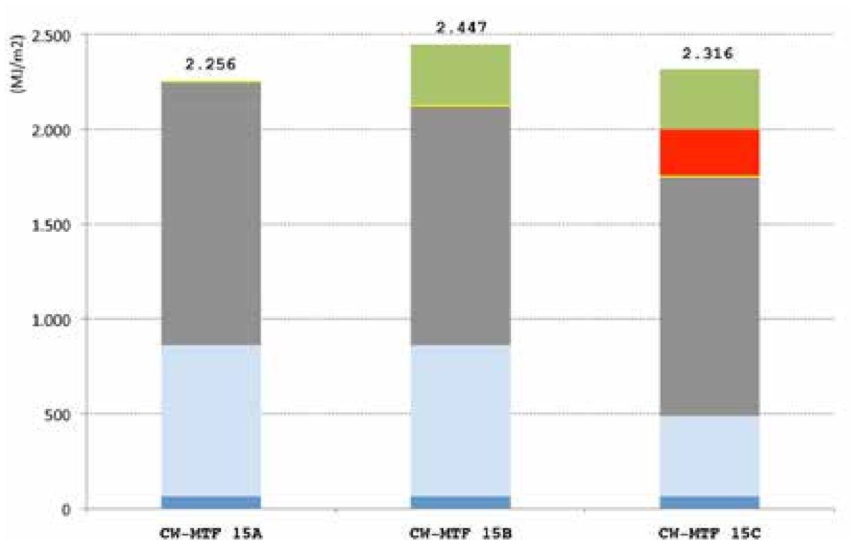


Figure 172
EE for CW- MTF 15

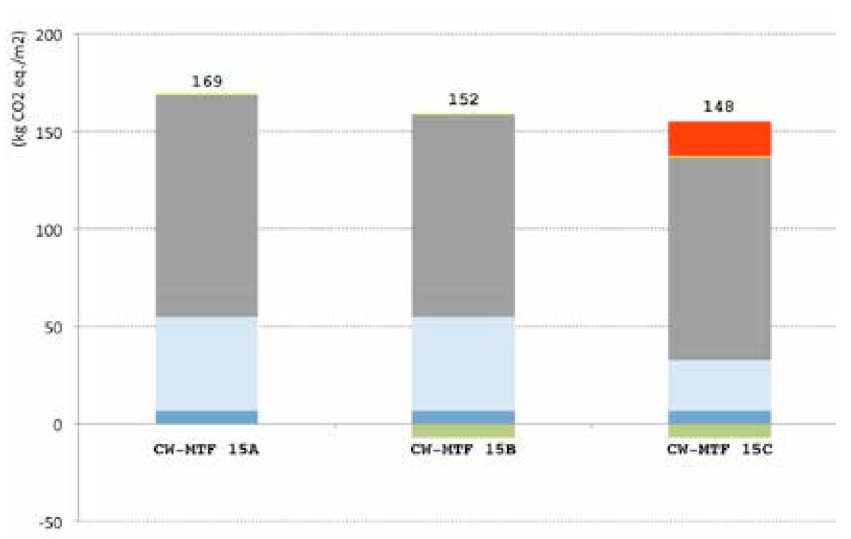


Figure 173
GWP for CW- MTF 15

§ 9.2.16 Curtain wall- Mullion and transom façade 16

CW- MTF 16			
Project	Idea Store in London		
Calculated , optimised and re-designed	Julia Weber (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Aluminium frame with wooden mullions, floor-to-ceiling glazing,double pane IGU	Aluminium frame with wooden transoms, floor-to-ceiling glazing, VIP behind 2/3 of the glazing, 1/3 double pane IGU	Wood frame with steel core, 1/3 floor-to-ceiling glazing, 2/3 insulated panels (vapour barrier PE, celluloses, foil PE), wooden substructure and larch cladding
Transparency share (%)	85	28	28
Heat conductivity (W/sqmK)	0.7	0.23	0.42
Weight (kg/sqm)	41	39	84
EE (MJ/sqm)	**562**	**537**	**420**
GWP (kg CO_2 eq./sqm)	**38**	**37**	**31**

Figure 174
EE for CW- MTF 16.

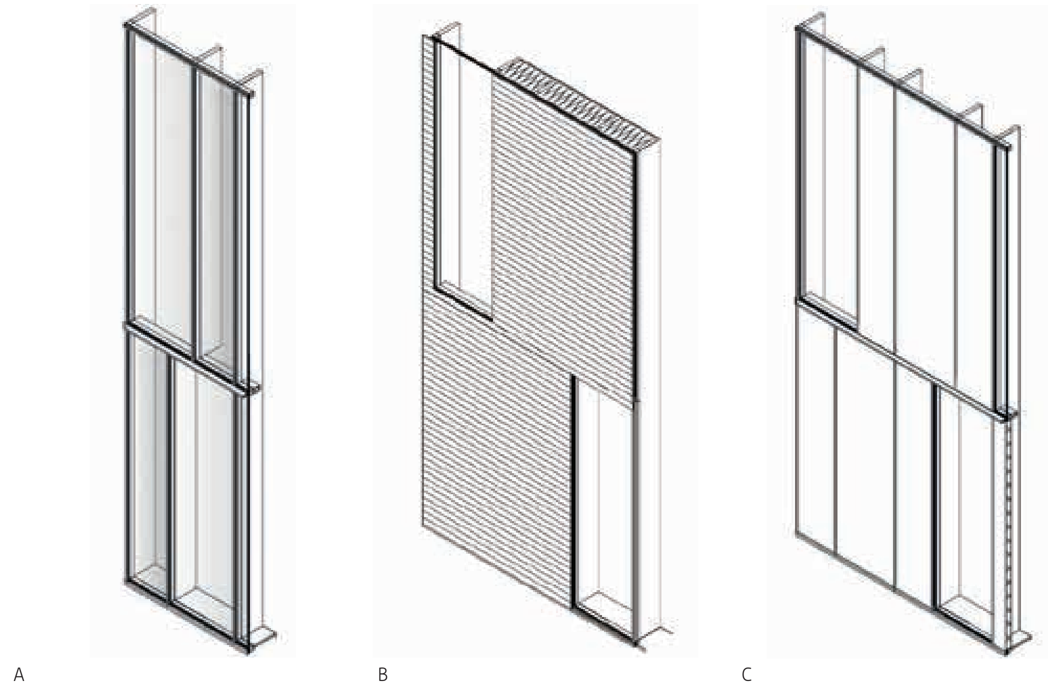


Figure 175
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

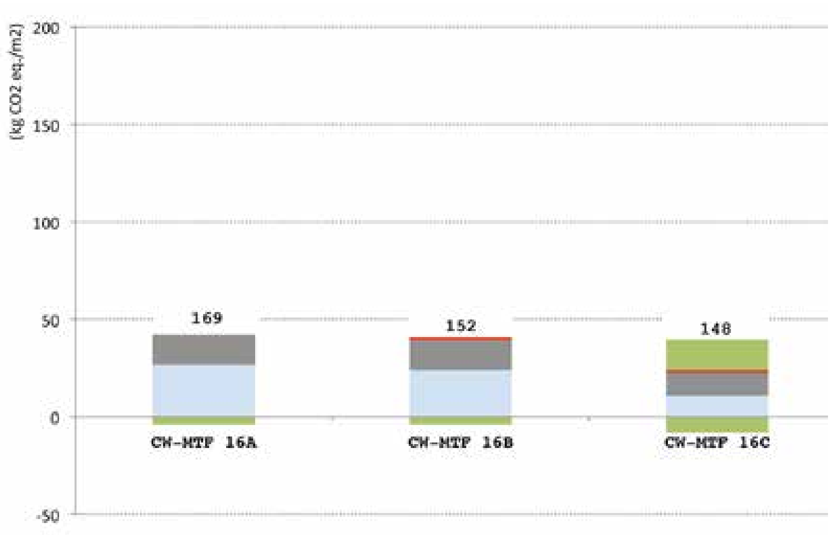


Figure 176
GWP for CW- MTF 12

§ 9.2.17 Curtain wall- Mullion and transom façade 17

CW- MTF 17			
Project	Lipperlandhalle; Lemgo		
Calculated , optimised and re-designed	Maren Krille (WS 11/12))		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Aluminium frame transoms, floor-to-ceiling glazing, double pane IGU	Wood frame with aluminium cover caps, floor-to-ceiling glazing, triple layered IGU, VIP filling	Wood frame with aluminium cover caps, floor-to-ceiling glazing, triple layered IGU, vacuumed sport balls as filling
Transparency share (%)	90	65	28
Heat conductivity (W/sqmK)	1.7	0.44	1.6
Weight (kg/sqm)	34	42	40
EE (MJ/sqm)	**939**	**580**	**548**
GWP (kg CO_2 eq./sqm)	**67**	**35**	**33**

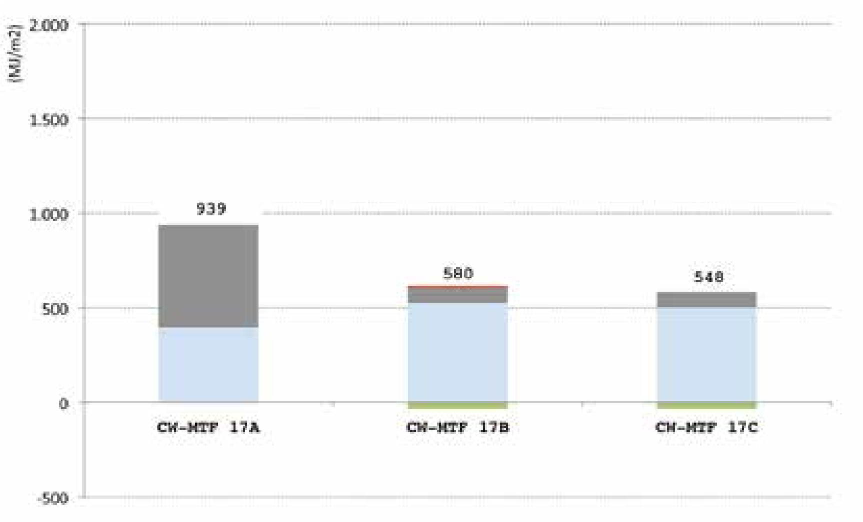
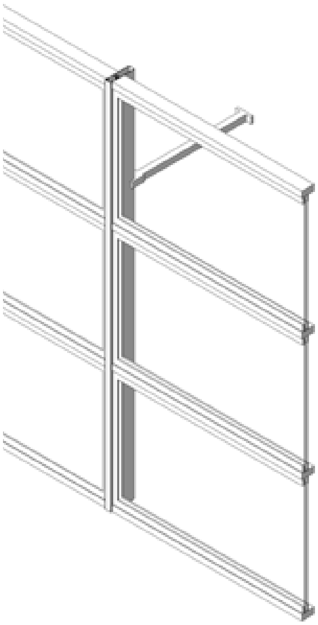
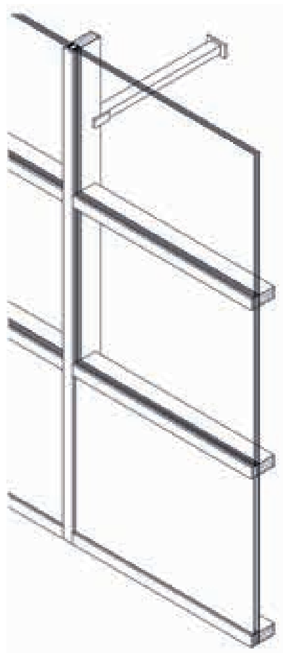


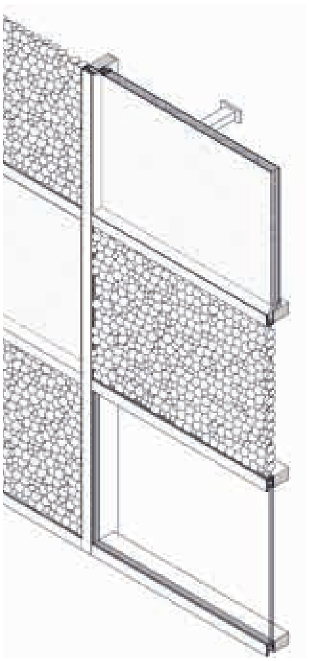
Figure 177
EE for CW- MTF 17



A



B



C

Figure 178
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

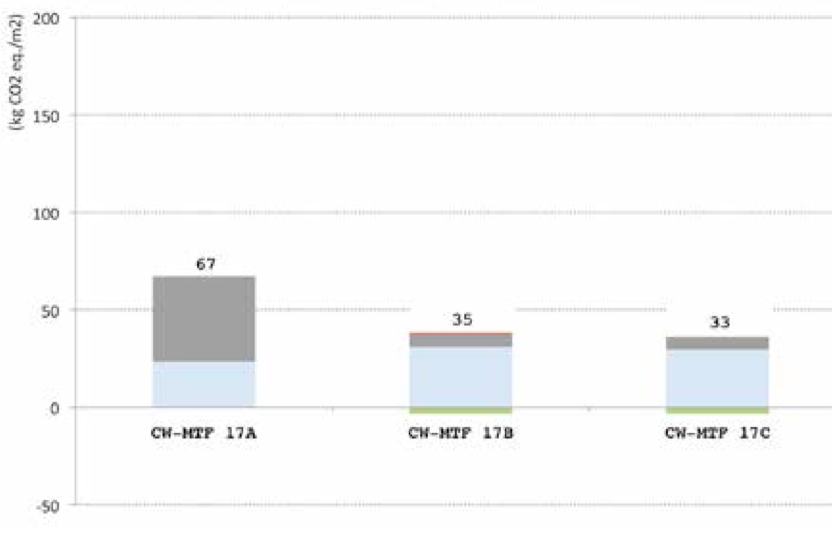


Figure 179
GWP for CW- MTF 17

§ 9.2.18 Curtain wall- Mullion and transom façade 18

CW- MTF 18			
Project	Laban Centre, London		
Calculated , optimised and re-designed	Andreas Kremer (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	Double façade which has one layer in window areas pf: Steel frame, double pane IGU sf: polycarbonate boards cavity is a clad insulation bar from EPS window with aluminium frame and double pane IGU	Double façade which has one layer in window areas pf: wood frame construction, wood fibre insulation sf: polycarbonate boards cavity is a clad insulation bar from EPS window with aluminium frame and triple layered IGU	Double façade which has one layer in window areas pf: wood frame, floor-to-ceiling glass filling, triple glazed IGU sf: pmma and glass lamella cavity is a clad insulation bar from EPS, aluminium grillage, window,aluminium frame and triple layered IGU
Transparency share (%)	29	29	29
Heat conductivity (W/sqmK)	1.38	0.24	0.9
Weight (kg/sqm)	90	123	66
EE (MJ/sqm)	**1,954**	**1,032**	**953**
GWP (kg CO_2 eq./sqm)	**137**	**127**	**57**

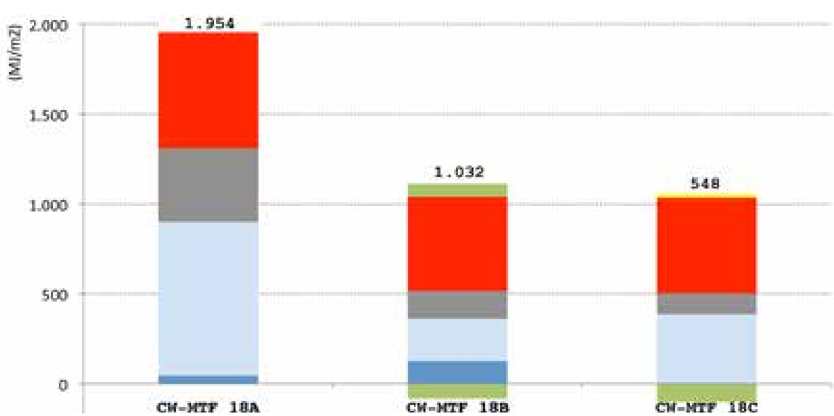
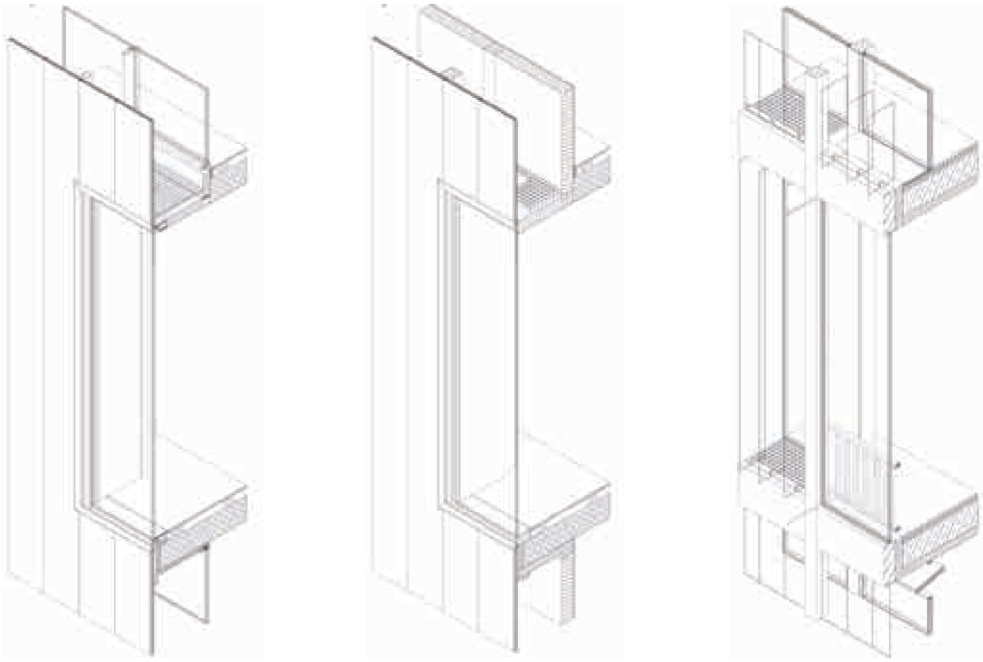


Figure 180

EE for CW- MTF 18



A B C

Figure 181
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

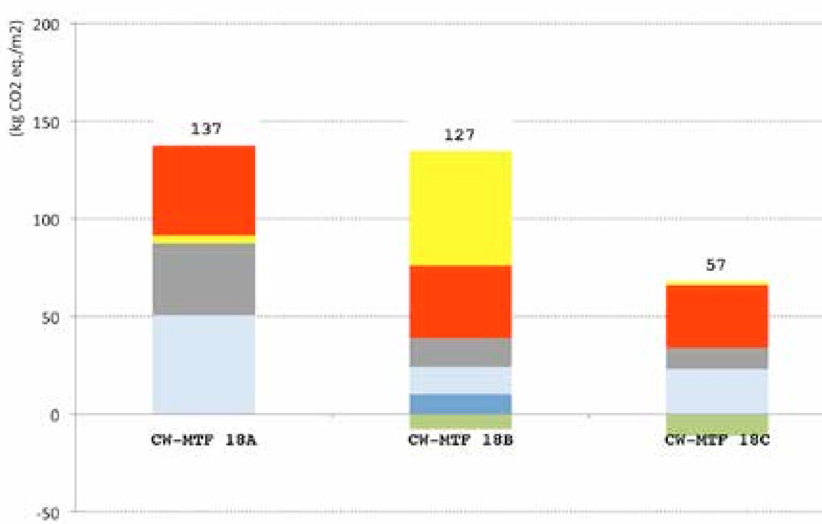


Figure 182
GWP for CW- MTF 18

§ 9.2.19 Curtain wall- System façade 19

CW-SF 19			
Project	Cubus Seestern office building, Düsseldorf		
Calculated , optimised and re-designed	Kerstin Kramme (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	pf :Prefab aluminium frames with double pane IGU, floor-to-ceiling sf: floor-to-ceiling laminated safety glass attached with point fixing	Parapet: wood panel with mineral wool, aluminium cladding Window area, pf: wood frame, double pane IGU sf: steel substructure, laminated safety glass	Paper construction filled with cork waste covered with adhesive foil, insulated ceiling edge (mineral wool) covered with aluminium sheet pf: wood frame, double pane IGU,sf: wood frame, laminated safety glass
Transparency share (%)	55	38	34
Heat conductivity (W/sqmK)	0.9	0.43	0.34
Weight (kg/sqm)	60	65	68
EE (MJ/sqm)	1,259	1,017	836
GWP (kg CO_2 eq./sqm)	85	48	10

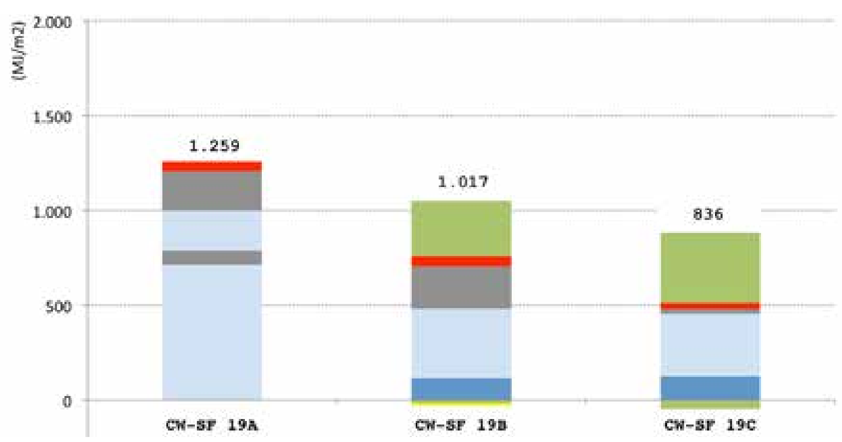
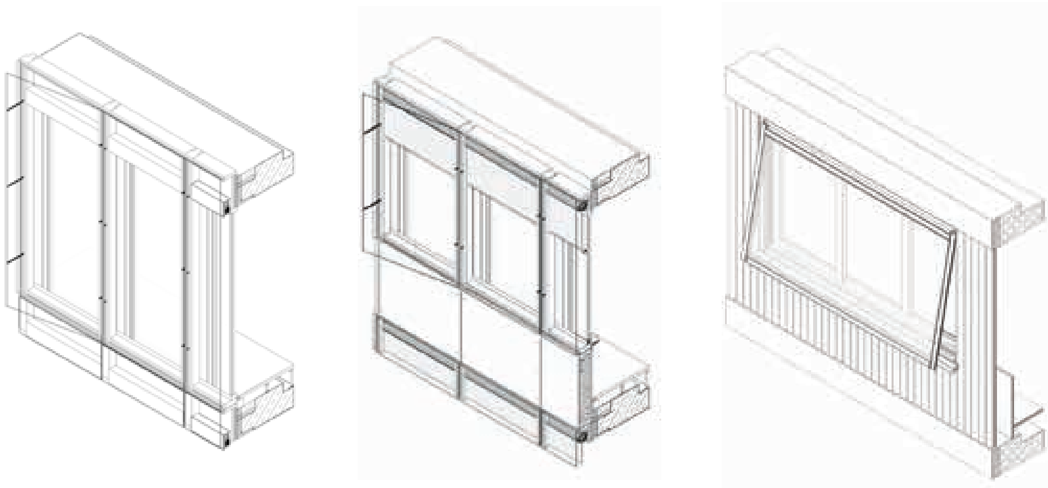


Figure 183
EE for CW- SF 19



A B C

Figure 184
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

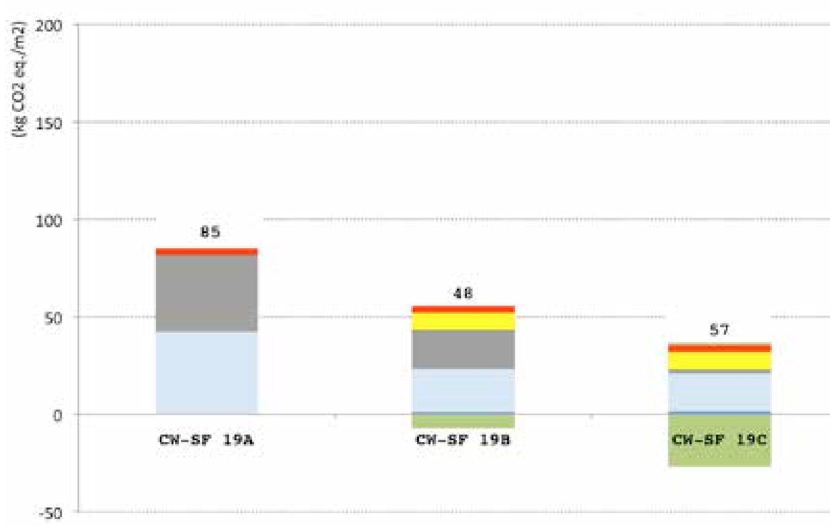


Figure 185
EE for CW- SF 19

§ 9.2.20 Curtain wall- System façade 20

CW- SF20			
Project	Düsseldorfer Stadttor		
Calculated , optimised and re-designed	Eduard Rempel (WS 11/12)		
Supervised by	Linda Hildebrand, Lutz Artmann		
Variation name	Existing façade	Optimisation	Design
Construction	pf: wood frame with floor-to-ceiling double pane IGU, insulated ceiling edge (EPS) covered with aluminium box which holds the sun shading system, 1.40m cavity sf: VSG attached by point fixing	pf: wood frame with floor-to-ceiling double pane IGU, insulated ceiling edge (EPS) covered with aluminium box which holds the sun shading system, 0.70m cavity sf: VSG attached by point fixing	pf: wood frame with floor-to-ceiling double pane IGU, insulated ceiling edge (EPS) covered with aluminium box which holds the sun shading system 0.70m cavity sf: aluminium rope sub-structure, membrane
Transparency share (%)	90	75	60
Heat conductivity (W/sqmK)	1.1	0.75	0.64
Weight (kg/sqm)	83	75	50
EE (MJ/sqm)	**1,426**	**1,354**	**1,008**
GWP (kg CO_2 eq./sqm)	**71**	**66**	**49**

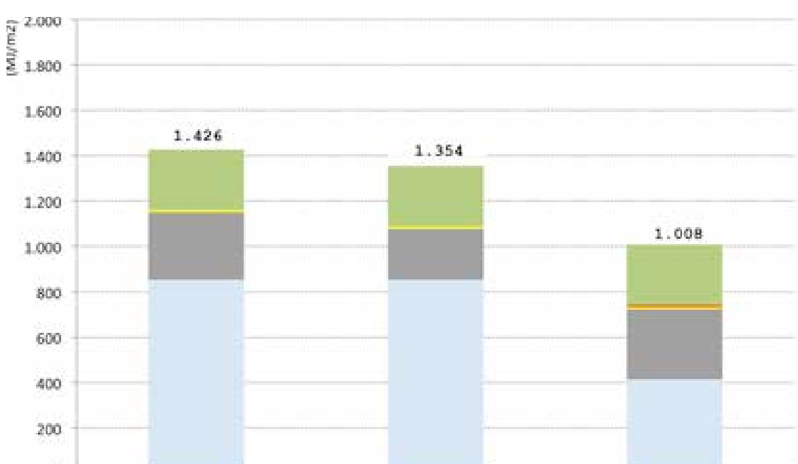
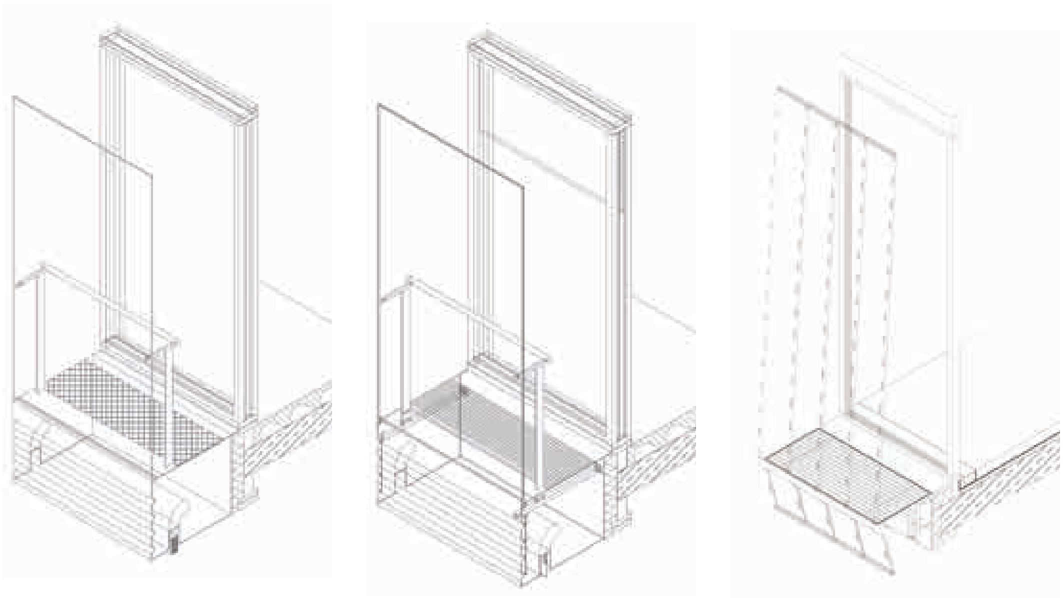


Figure 186
EE for CW- SF 20



A

B

C

Figure 187
(A) Existing façade, (B) Optimised façade, (C) Redesigned façade

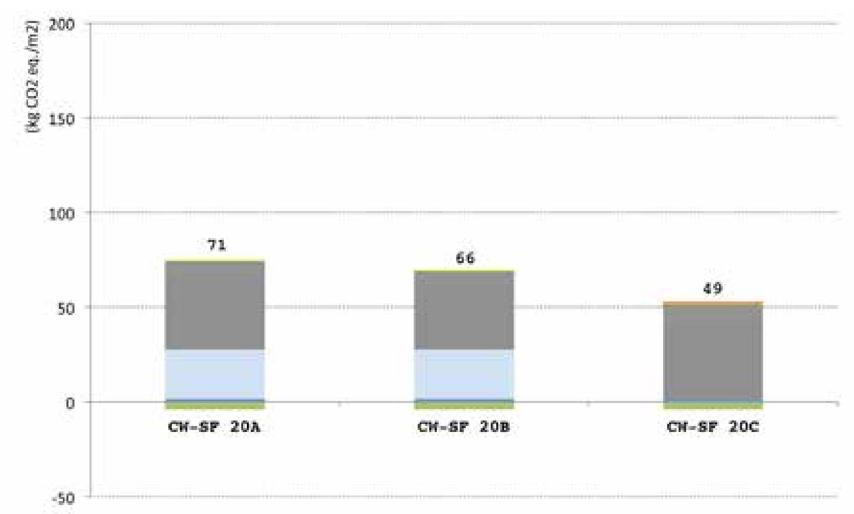


Figure 188
EE for CW- SF 20

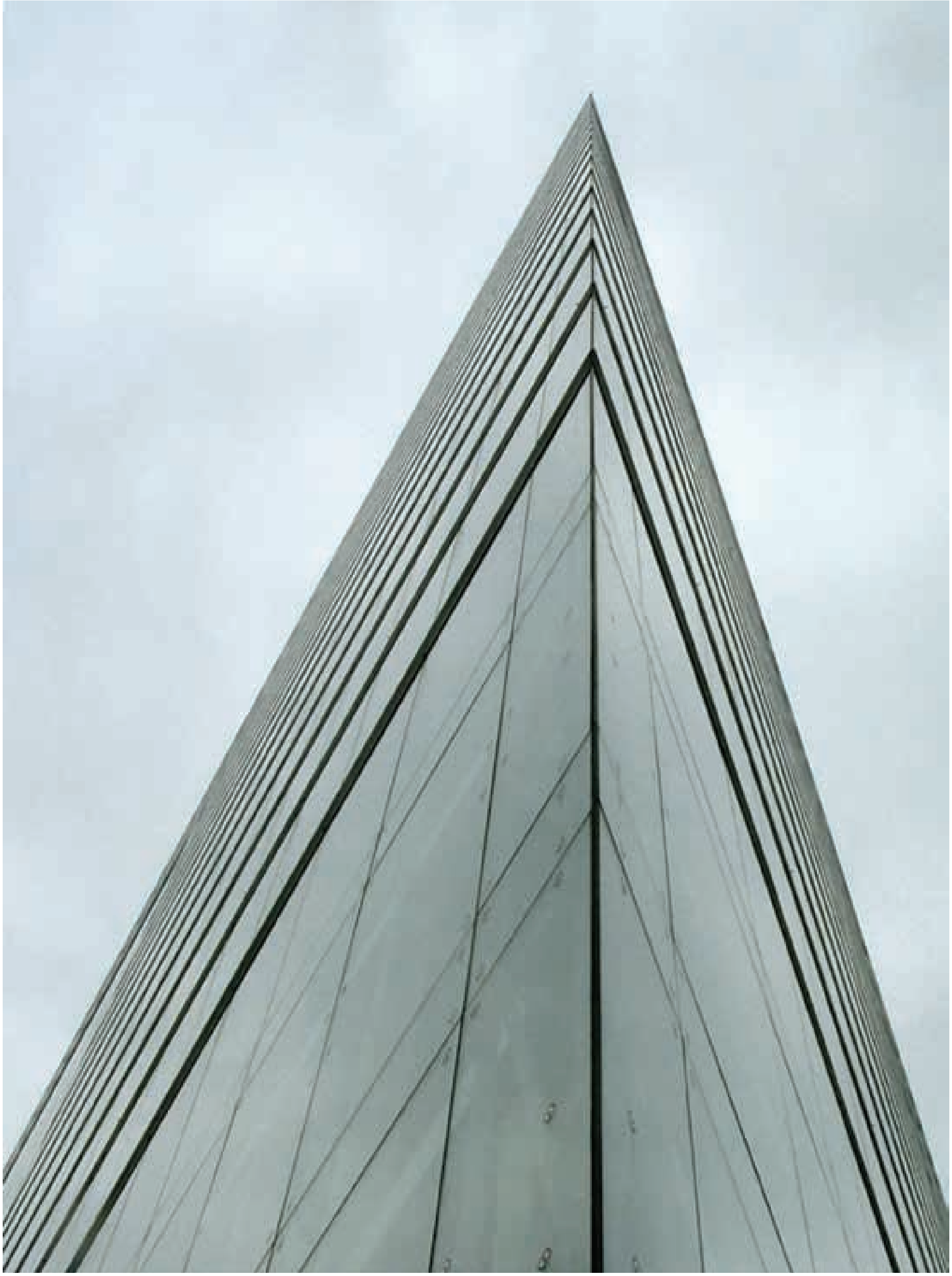


Figure 189
Stadttor Düsseldorf (CS SF-20)

§ 9.3 Analysis

The evaluation was motivated by the following sub-questions:

What are the characteristics of embodied energy and global warming potential in façades? Does the type of façade define the environmental impact? How can embodied energy in façades be optimised?

According to the method used in chapter 7, this sub-question will be further divided into more specific questions which will be answered based on the evaluation's outcome. The topics '9.3.1 Characteristics of EE and GWP in façades' will be discussed in one paragraph and the '9.3.2 Optimisation potential' in another.

§ 9.3.1 Characteristic of EE and GWP in façades

The characteristics of EE and GWP in façades and the interdependencies of façade type and ecological impact will be specified with the following sub-question. Each will be answered in one paragraph.

What is the range of the evaluation? What are the causes for extreme (low and high) values? (§ 9.3.1.1)
Does the value range show similarities to other studies? (§ 9.3.1.2)
Can façade type be identified according to EE and GWP? (§ 9.3.1.3)
What percentage do material groups have? What impact does the glass share have on the total EE/GWP? (§ 7.3.1.44)

§ 9.3.1.1 Evaluation results

The EE evaluation shows a range of 81 to 2,447 MJ/sqm (Figure 190). The average value for one square meter façade is 1,090 MJ. 16 façade have values within a +/-20% tolerance frame which accounts for one quarter of the case studies.

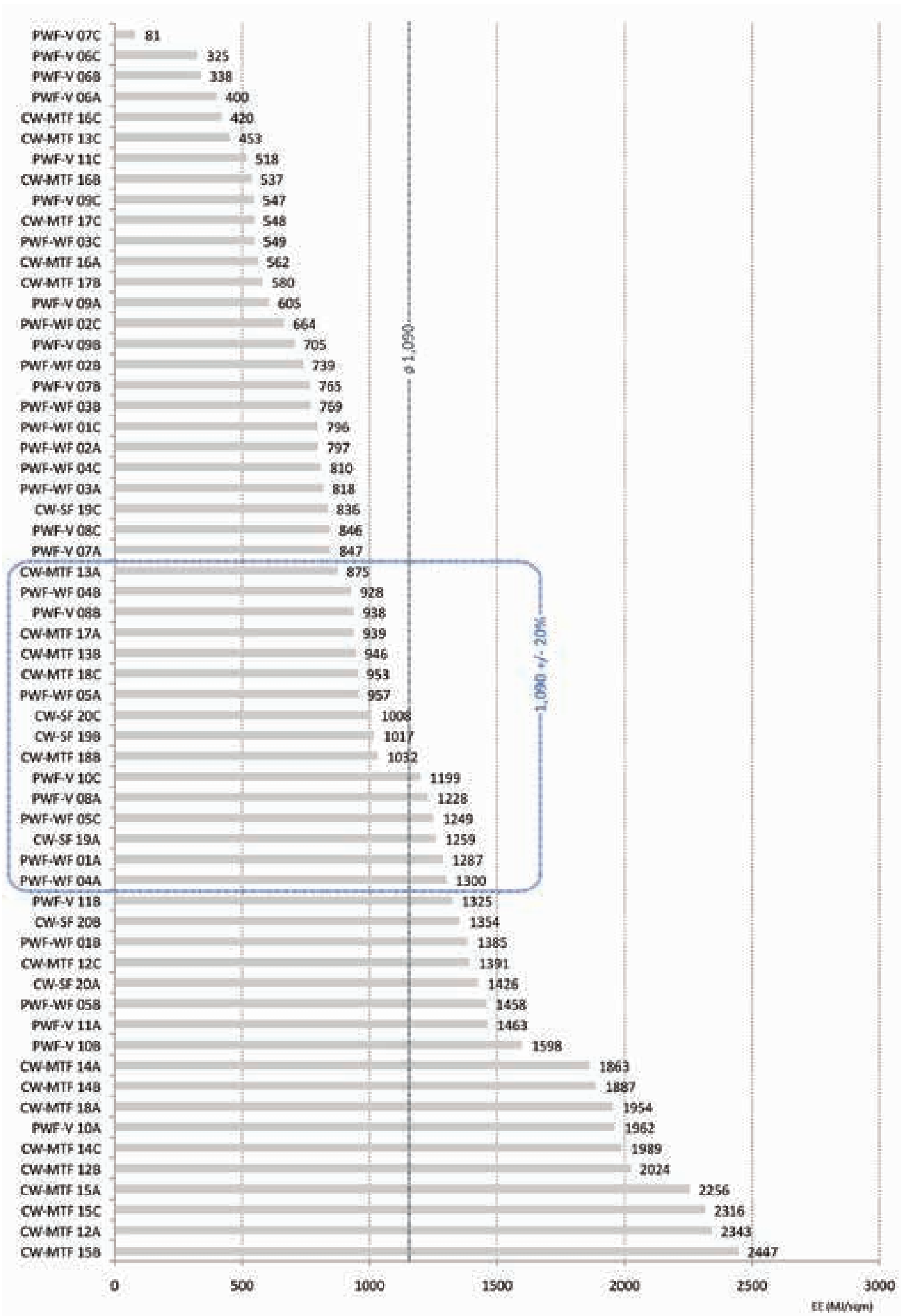


Figure 190

EE hierarchy for façades

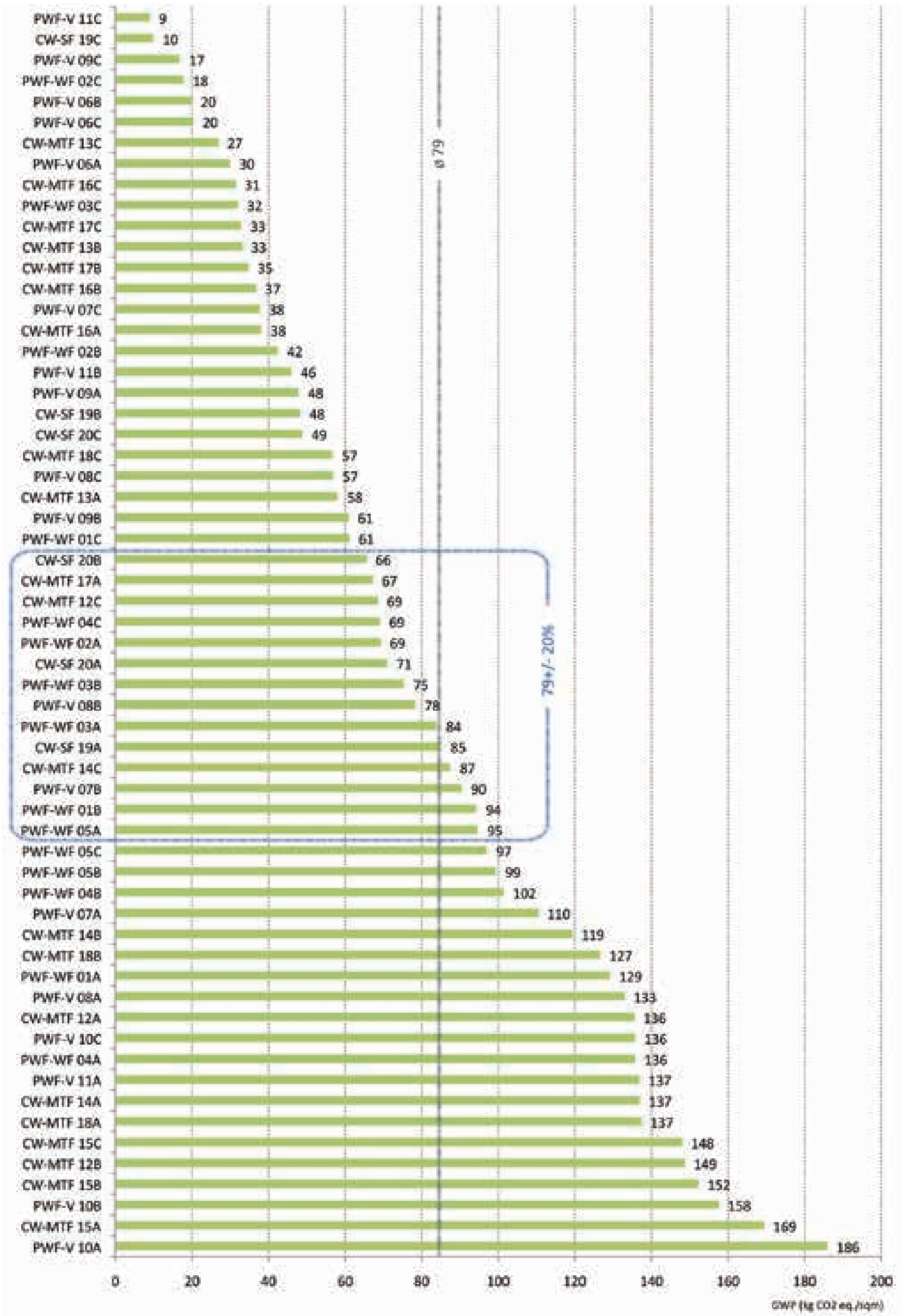


Figure 191

GWP hierarchy for façades

GWP varies from 63 to 95 kg CO_2 eq./sqm (Figure 191) and averages at 79 kg CO2 eq./sqm. 14 case studies vary in the +/-20% tolerance frame, which is similar to EE: A ventilated punctured wall façade shows the lowest amount for both indicators. The case study PWF-V 07C embodies the lowest amount of EE with 81 MJ/sqm, followed by PWF-06 (all variations C/B/A). All of them belong to the punctured wall types. The structure of PWF-V 07C consists of a magnum board (200mm OSB) with a ventilated façade covered with HPL boards. The high wood share causes low amounts of EE. The GWP for this façade shows values which at 37.8 kg CO_2 eq./sqm are significantly lower than average.

PWF-V 06 shows low values for all three variants. The basic construction is a wood framework filled with mineral wool in (A) which is replaced in (B) and (C) by wood fibre wool and hemp insulation. In all variants the façade is covered with a ventilated wood layer. In this façade the maximum of renewable materials is installed in the façade.

The façade with the lowest amount of GWP is named after its variant A PWF-11C but belongs to the type of curtain wall façades. To keep the same functionality, the load-bearing structure lies within the thermal barrier and is part of the assessment. Considering only the outside skin, the façade has the lowest weight due to the glued laminated timber and the weather barrier from a double-layered pre-stressed foil. Attachment is provided by point fixation.

The highest values for EE are demonstrated in the case study CW-MTF 15A. The GWP value is also very high showing the second highest value. This double-layered façade includes a floor to ceiling in both layers. The primary façade is made of aluminium and the edges are covered with natural stone. The grate in between the two layers contributes essentially to the weight and the indicator.

§ 9.3.1.2 References to other studies

It is prerequisite for a façade study to include the same function in order to provide comparability. Façade studies suitable to check the plausibility of the here conducted results need to consider at least the same life phases (production and end of life), provision of at least a similar functional performance (transmission below 0.5 W/sqmK and a transparent part of at least 15%) and the same indicator. The considered time needs to be considered as well. A rough adaption to a certain considered time is possible if calculation details are given.

Only very few published façade studies meet these requirements. The Baustoffatlas, for example, shows a small range of façades and their ecological dimension (Figure 192), but neither the thermal quality (none of the examples includes insulation) nor the transparency ratio are included. Only the production phase is shown as it is the main impact. ures 169 shows a range from 220 to 1.100 MJ/sqm and -50 to 90 kg CO_2 eq./sqm.

Glas								
Profilglas, einfach*	532	59	28	0	0,15	0,0095	0,014	50–80
Profilglas, U-Profil 498 × 41 mm, Glasdicke 6 mm Aluminiumrahmen, Silikonfuge, 40 mm								
ESG*	531	62	28	0	0,15	0,0093	0,013	50–80
ESG, 6 mm Klemmpressprofil Aluminium, EPDM-Dichtung, 40 mm								
Wärmeschutzglas U_g = 1,1*	547	65	29	0	0,16	0,0097	0,013	50
Zweischeiben-Wärmeschutzglas, Argonfüllung, 24 mm Klemmpressprofil Aluminium, EPDM-Dichtung, 40 mm								
Wärmeschutzglas U_g = 0,7*	837	70	40	0	0,20	0,014	0,018	50
Dreischeiben-Wärmeschutzglas, Argonfüllung, 36 mm Klemmpressprofil Aluminium, EPDM-Dichtung, 40 mm								
Doppelfassade*	2162	353	131	0	0,76	0,041	0,055	50
ESG, 6 mm Tragkonstruktion Aluminium, 250 mm Zweischeiben-Wärmeschutzglas, Argonfüllung, 24 mm								

Figure 192
Façades and their ecological component published in the Energy Manual (Hegger et al., 2007)

The report published by the German Association of Natural Stone shows the highest similarities to the evaluation here. In the study, a concrete wall clad with natural stone is compared to a glass façade (although no windows are included for the natural stone variant).The results for production, maintenance and end of life are displayed separately. The natural stone (without fenestration) shows 1,150 MJ/sqm and 140 kg CO_2 eq./sqm, the glass façade 1,400 MJ/sqm and 110 kg CO_2 eq./sqm (the denomination used here it would account to the group of curtain wall /mullion and transom façade).

The average values are close enough to published results. The differences to the average values are traceable and the plausibility control is considered completed.

§ 9.3.1.3 Façade types and EE/GWP

The façades have been distinguished by type in two main groups, punctured wall façades and curtain walls. The following discusses the dependencies of façade typology and ecological impact. Furthermore, façade features that contribute to an extreme result will be analysed.

A Relevant construction features for curtain walls

15 out of 27 CW case studies are double layered. Four of them have both, single and double leaves and eight are single layered. The highest 14 case studies have two layers and eight out of the ten lowest examples have one layer which shows that the number of façade layers has a noticeable impact. From a material perspective, single layered façades perform significantly better than double layered.

The construction for the void is most commonly metal based. A larger distance from primary to secondary façade results in high ecological impact. With lower distance, EE and GWP can be reduced.
The secondary skin most often consists of glass installed within a metal substructure. The high amounts of EE and GWP embodied in the material (glass and aluminium or steel) cause high results for the secondary façade.

A light construction offers an alternative. Ideally, both components, surface and structure, use as little material as possible. A solution for the surface is the application of textiles and foils. As shown in CW-SF 20 the replacement of glass by a foil and its respective construction shows an ecological potential. Values could be reduced from 1,350 to 1,010 MJ/sqm.

Comparing a double layered façade with glass to an example with synthetic twin wall sheet (CW-MTF 18) does not seem to offer a high improvement potential. As only one façade from this kind is evaluated here, the validity of this thesis is limited and could be investigated in further research.

B Relevant construction features for punctured wall façades

The average EE for the PWF is 915 MJ/sqm. The highest amount of EE is shown in case study PWF-V 10 for (A) and (B). Sauerbruch Hutton's Firestation façade has a concrete wall and a metal substructure to attach the glass shingles which give the building its colourful look. The student decided to exchange the aluminium window frame for a wooden one and to replace the mineral wool with wood fibre insulation. This reduces the EE from 1,960 to 1,600 MJ/sqm but it still accounts for the second highest example. The third highest value is shown by PWF-V 11A with 1,460 MJ/sqm. The ceiling window wing with its PVC frame account for a significant share.

The lowest examples for EE can be found in PWF-V 07C and 06C. Not recognisable from the outside, the main construction is made of a timber frame. The lowest amount of EE is 81 MJ/sqm, which is less than one tenth of the average value, followed by 325 MJ/sqm, which is about one third of the average EE. Their GWP performance is slightly weaker; 07C has the eighth lowest and 06C the fifth lowest performance.

Figure 193
Rendering of PWF-V 11C, the case study with the lowest embodied GWP due to a wood construction with a light secondary façade.

The best GWP performance can be found in PWF-11C. The student made fundamental changes to the original design and developed a double layered façade which technically belongs to the type of curtain walls. Even considering both types, this case study shows the best results. It is a double layered façade with a timber construction as primary façade and a foil as outside barrier. The foil is tensioned with a rope construction which needs very little material and contributes only slightly to the ecological assessment. The high wood share and the light outside layer end up in the lowest GWP results.

The construction of the opaque parts impacts PWF similar to CW. A simplified evaluation has been conducted in order to investigate the relevance of layers and its materialisation further. The frame work is the same as for the façades shown in 7.2, except for transparent areas. The minimal heat transmission is 0.24 W/sqmK or better (calculated with the web-based tool on www.u-wert.net). 86 solid façades without fenestration are evaluated. (A detailed description of the construction can be found in Table 44 on page 401-404.) The solid façades are organised in the four categories solid second layer, cold façade, warm façade - single-layered and warm façade - multi-layered.

- Solid second layer (abbr.: SSL)

The primary, load-bearing layer is made from limestone, brick or concrete, the secondary façade is made from limestone - or brick-clinker - and from concrete. The second layer has a thickness of 115mm and is solid. A typical construction for this category includes 175mm limestone, 160mm mineral wool, 115mm clinker.

- Cold façade (CF)

A cold façade consists of a load-bearing layer, insulation, a substructure and cladding. Air can ventilate behind the cladding material which leaves the façade cold.
In this evaluation the load-bearing layer is made of concrete. Technically, other materials like lime stone or brick could be used as well. For the sake of comprehensiveness the choice is limited to concrete because this construction also allows for heavy cladding materials.

- Warm façade - mono-layered (WF mono)

The layers of a warm façade are equivalent to the ones for cold façades. The cladding and the insulation are connected so air flows happen outside the system. The main material has a low heat transmission and no additional layer is necessary. (Render and plaster are not counted as an individual layer).

- Warm façade - multi-layered (WF multi)

This type also belongs to the warm façades with the exception that additional layers are needed. A load-bearing layer with an EIFS is a typical construction.

The evaluation contains 86 façades (44 SSL, 30 CF, two WF mono and eleven WF multi).
The ten highest examples belong to the group of SSL. The five lowest have a cold façade with wood fibre insulation. A similar trend can be observed for GWP; the eight highest examples belong to SSL, the five lowest to CL (the examples with the lowest values are the same for EE and GWP). (Table 44 page 401-405 contains detailed information. It shows the results for EE.)

Figure 194 shows the EE for the four solid façade types. The range spans from 213 - to 1,839 MJ/sqm (the previous main façade evaluation ranges from 80-2,500 MJ/sqm). Looking only at the average amount (the black dot), the façades with a solid secondary layer show the highest amount of EE, followed by the cold façades. The monolithic warm façades embody slightly less energy. The lowest amount can be recognised by the multi-layered warm façades.

The SSL show a high variation in values. The lowest amounts can be found for concrete sandwiches. Despite high emissions due to the cement production, the GWP shows the lowest values for this construction as well (SSL 41 /42:180mm concrete, 120 /160mm glass wool, 100mm concrete, the concrete is considered with 0.008 vol.% steel reinforcement). In this assessment concrete is only combined with glass wool and EPS. The values would improve even more when considering wood fibre insulation. Within the SSL category, the highest value with 1,839 MJ/sqm is shown by a masonry construction (SSL 40: 15mm lime cement render, 175mm brick, 120mm polyurethane, 115mm clinker). Both masonry layers account for 80% of the sum. 12% result from the insulation.

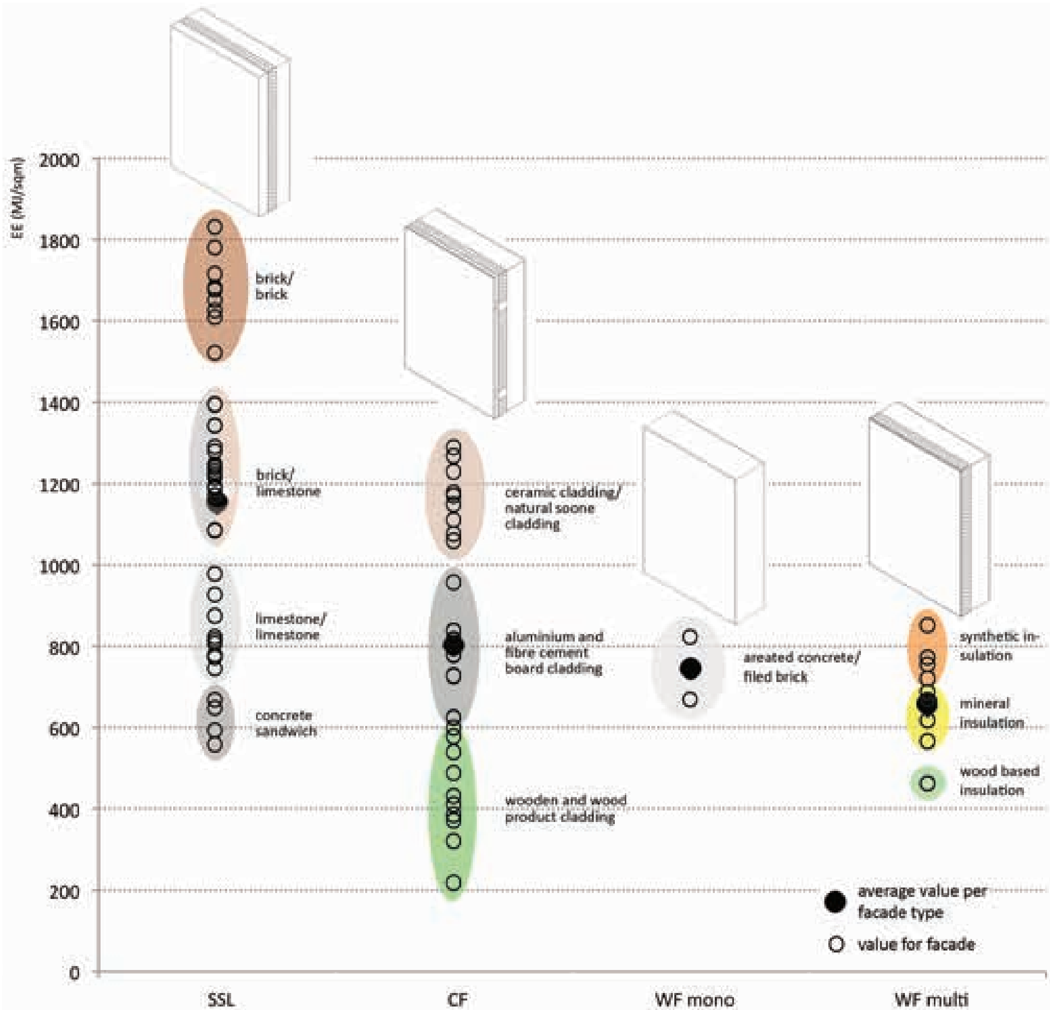


Figure 194

Solid façade types and their EE

A hierarchy for the constructions in group SSL can be identified. As shown in Figure 194, the examples with brick as load-bearing layer and secondary layer result in the highest values. Even with the use of wood fibre insulation this tendency cannot be improved. The combination of brick and limestone performs slightly better, followed by the construction of two layers of limestone. The concrete sandwiches show the lowest EE in this group.

For the group of cold façades, the concrete construction constitutes a base line which enables a comparison of different cladding materials and evaluation of the role insulation material plays. The construction consists of the load-bearing layer, insulation, sub-structure and cladding material. For natural stone and ceramic cladding, 3 kg/sqm aluminium sub-structure is assumed; for the aluminium and fibre cement board cladding it is 2.1 kg /sqm. The wood based materials have a wooden sub-structure in the evaluation.
Ceramic and natural stone cladding account for the highest amounts of EE and GWP. Aluminium and fibre cement board claddings show similar results and show medium values within this CF group. The lowest values can be observed with wood based products. The two cases studies differ in the thickness of the insulation; one has 140mm, the other 180mm wood fibre insulation. Both show a similar result (459.2 and 459.4 MJ/sqm) because the production and end of life effort cancel each other out.
Compared to an EIFS, a better EoL scenario could be assumed due to the possibilities to deconstruct the insulation. This helps, especially in the case of the synthetic based insulation materials. The difference between treatment as building rubble and recycling accounts for approximately 100 MJ/sqm which is a recognisable difference.

The average value for the monolithic warm façade lies only slightly below the ones of CF. Aerated concrete and insulating brick are evaluated here. They do not show a significant derivation.

In order to compare insulation material, the load-bearing layer is the same for all examples in WF multi (175mm limestone). The result is equivalent to the ones discussed under § 5.3; the wood insulation performs best, followed by mineral and synthetic materials that embody the highest amount of EE.

This brief evaluation shows the relevance of layers and emphasizes the relevance of their functional context; a solid second layer will most commonly embody higher amounts of EE, such as for example a ventilated façade. Thus, the installation of this type of construction needs to be an absolutely mandatory and relevant part of the concept.

The results of this abstract will be discussed in the very last paragraph under § 9.3.2 "Optimisation potential"..

C Relevant construction features for both curtain walls and punctured walls

Coming back to the main façade evaluation, the relevance of the glass area will be discussed as an aspect that is relevant for both façade groups, curtain walls and punctured wall façades.

Figure 196 shows the EE for both façade groups. The glass share of each case study is indicated by the light blue right end of the bar. For all case studies, the average EE for the glass alone is 37%. Looking at each façade type separately, the curtain walls show an average percentage of almost one half of the total EE (49%) and punctured wall façades nearly a third (28%). (For GWP it is 53%, for CW 25% for PWF.)

Figure 195
Solarlux façade outside layer

The structural fixation of the glass area is related to the glass area itself. When the window area also functions as thermal and humidity barrier, the glass is held in a frame. For a secondary façade this is not necessarily the case.

The factors that impact the ecological indicator for the glass fixation are:

- Window area
- Operable window or fixed glazing
- Frame material

Naturally, with increasing window area, the fixation ratio grows. A fixed glazing consists of only one frame; whereas an operable window requires a fixed frame and a movable wing. According to Ökobau.dat, the fixed frame is a little bit lighter than the operable wing. This is true for aluminium (0.98 kg/m and 1.02 kg/m), for PCV (2.80 kg/m and 3.10 kg/m) and for wood (1.43 kg/m and 1.51 kg/m).

The type of fixation is defined by the functional requirements of the building envelope layer. A primary façade usually provides the thermal barrier (along with other features like fire safety, noise barrier, humidity barrier). The application of an insulated frame offers an all-in-one solution. A secondary façade can have lower requirements and a frame is not essentially necessary. A point fixation offers a very material efficient solution and has the ecological benefit of using very little material with high structural performance. Framing only parts such as the horizontal edges is a solution if no structural performance but operability is required.

The fixation is mostly made with metal or synthetic material which both embody high amounts of EE and GWP; decreasing the construction is quite effective. A frame can weigh up to 5 kg/sqm which accounts for approximately 200 MJ/sqm while point fixation at only 150-300 gr/sqm can embody significantly less at approximately 8MJ/sqm.

Figure 196 shows the EE for CW in the upper and PWF in the lower part. Both façade types show a high variation in values. A superiority of one façade type over the other cannot be observed.

Within the façade types, different construction features are responsible for the extent of their ecological impact.

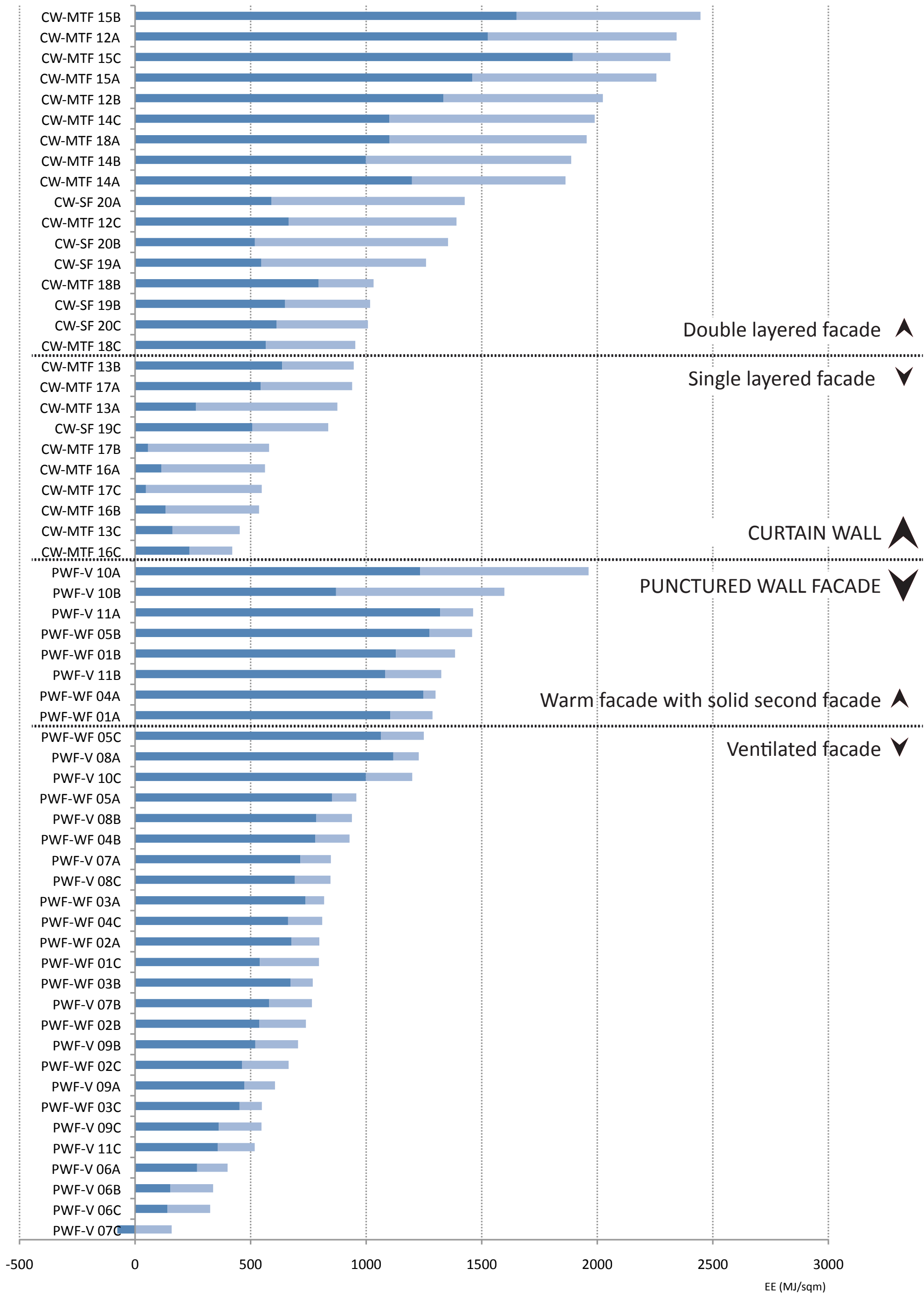


Figure 196

EE for curtain walls and punctured wall façades.

§ 9.3.1.4 EE/GWP distribution for materials groups

The material analyses tracks the impact of material groups and aims at identifying materials or construction attributes that make an essential contribution to a beneficial or disadvantageous environmental performance.

Figure 197 shows the weight of the façade of each case study and indicates the role of the material group. In Figure 198 the EE is displayed in the same order of case studies. The shift from weight to EE is significant. While the curtain wall façades in the upper part are lighter compared to the punctured wall, the differences in EE from CW to PWF have become less significant. Comparing the two figures, the high impact of glass and metals is obvious. They initiate the shift so that the results of the façade types are intermixed.

Insulation material is recognisable in most of the case studies. The mullion transom façade with an insulated frame does not display the insulation share separately.

The two main façade types can be distinguished by their share of glass and the ratio of mineral material. All curtain wall façades have a significant glass share. It can account for up to 90% (CW-MTF 17). Figure 199 shows the average material distribution for the two main façade typologies. The average glass share of CW case studies is 46% while it is 21% for PWF. Additionally, the metal share increases significantly from weight to EE figure.

The main material group for PWF's is mineral material. This can be observed in both figures, weight and EE.

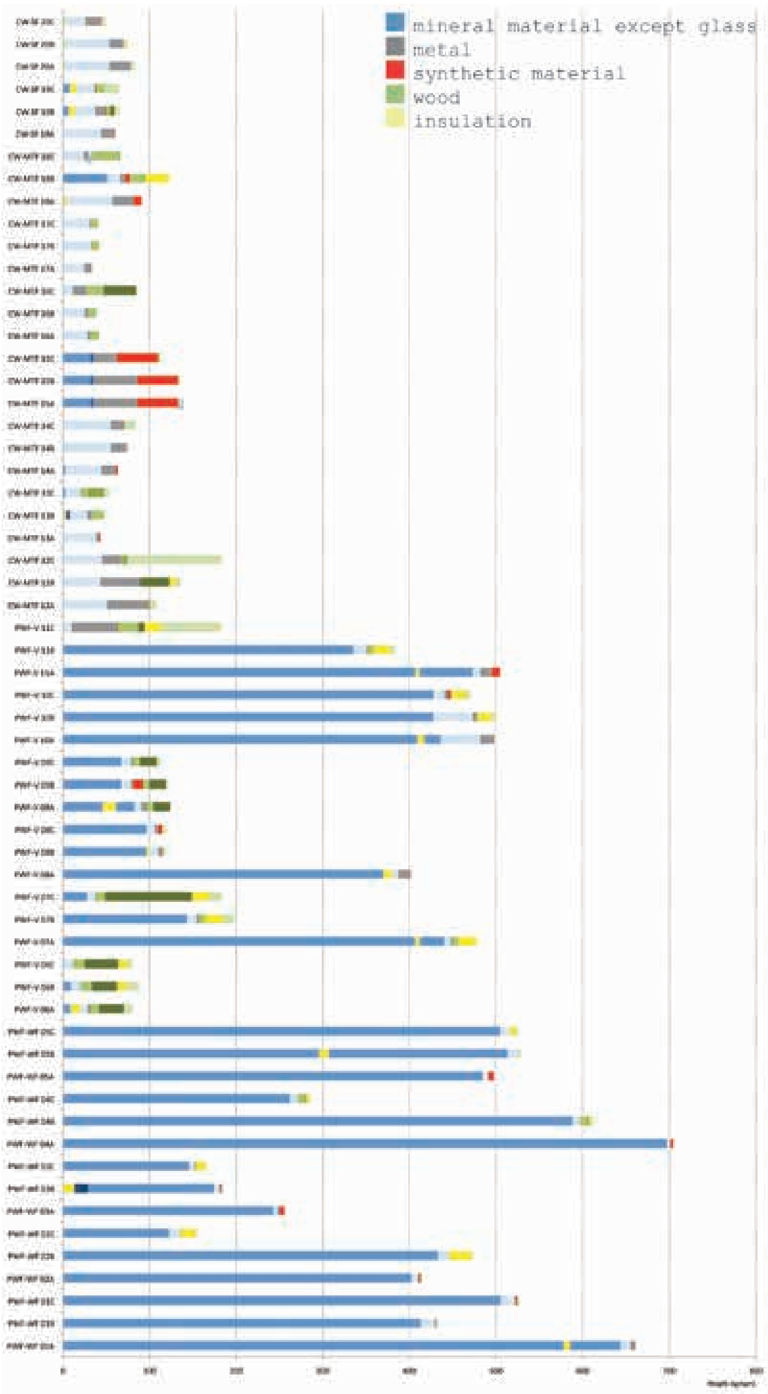


Figure 197

Weight of façades. The curtain wall have a significant lower weight than the punctured walls. Exceptions are recognizable for timber frame construction (especially PWF-V 06)

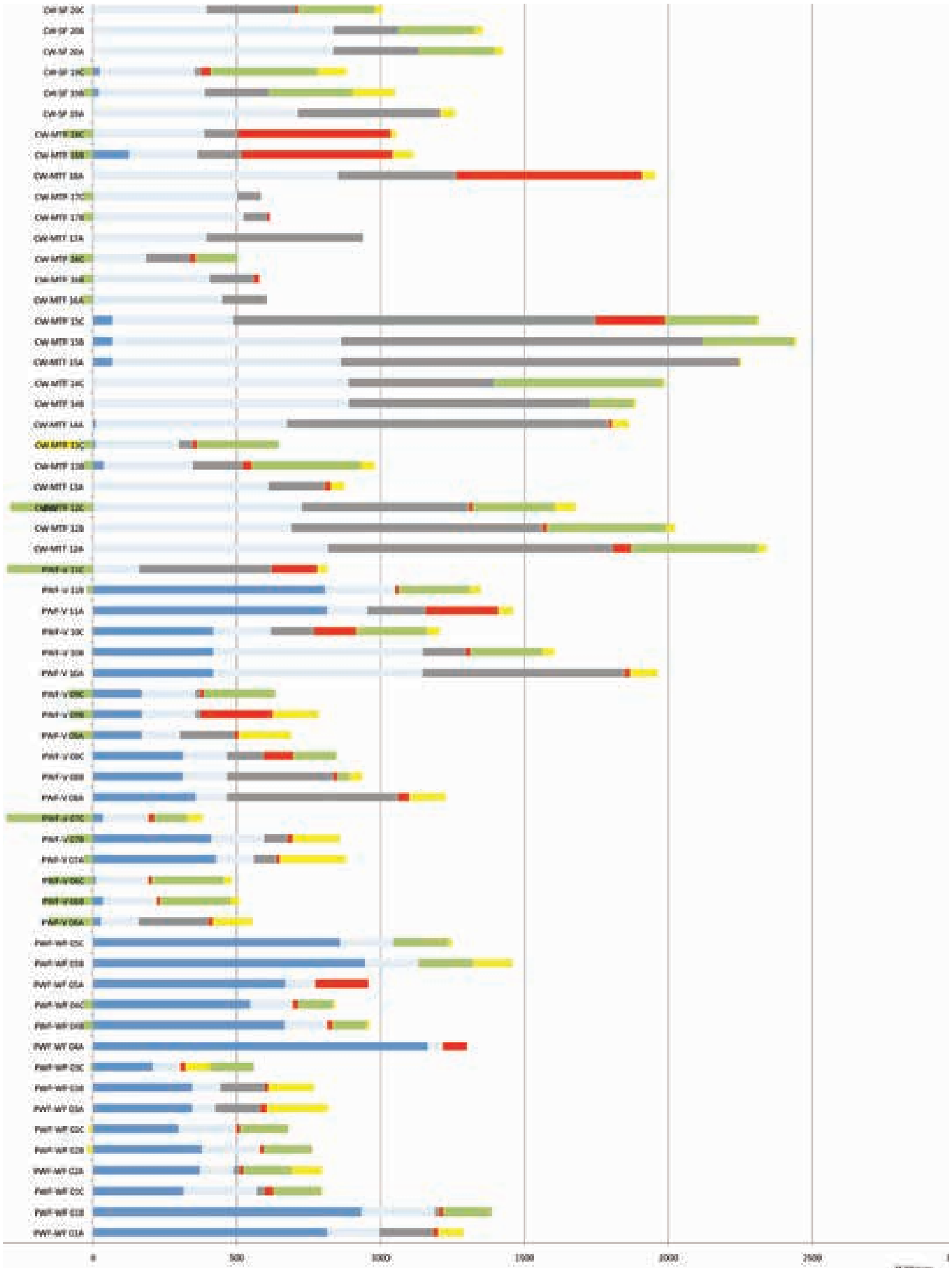


Figure 198
EE material distribution

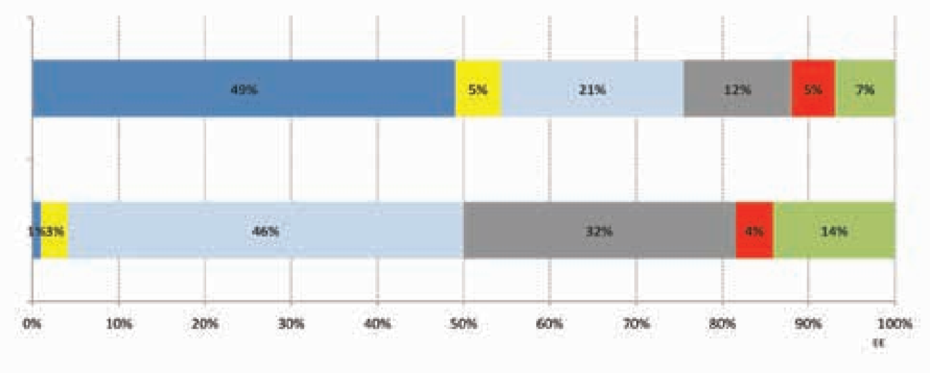


Figure 199
EE of average material distribution. The upper bar shows the average for PWF, the bottom one for CW. PWF is dominated by mineral material. The glass and metal share is significantly higher for CW compared to PWF.

It can be figured that the glazing share has an essential impact on the result. Due to the relatively high EE of the material it should be carefully installed in the building. Irrelevant for an identification of optimisation potential is the observation that the material distribution indicates the façade typology.

§ 9.3.2 Optimisation potential

Chapter 7 states that the façade contributes significantly to the environmental performance of the building substance. 9.3.1 contained topics which are relevant to understand the ecological performance of a building element.
In this paragraph, these topics will be discussed regarding their potential to optimise the ecological footprint of façades.

The ecological dimension of façades (regarding the material performance) is defined by various aspects. The functional context and the effects the construction has on operational energy need to be taken into consideration. This is the background why only dependencies are presented here, and no complete hierarchies.

§ 9.3.2.1 Façade type

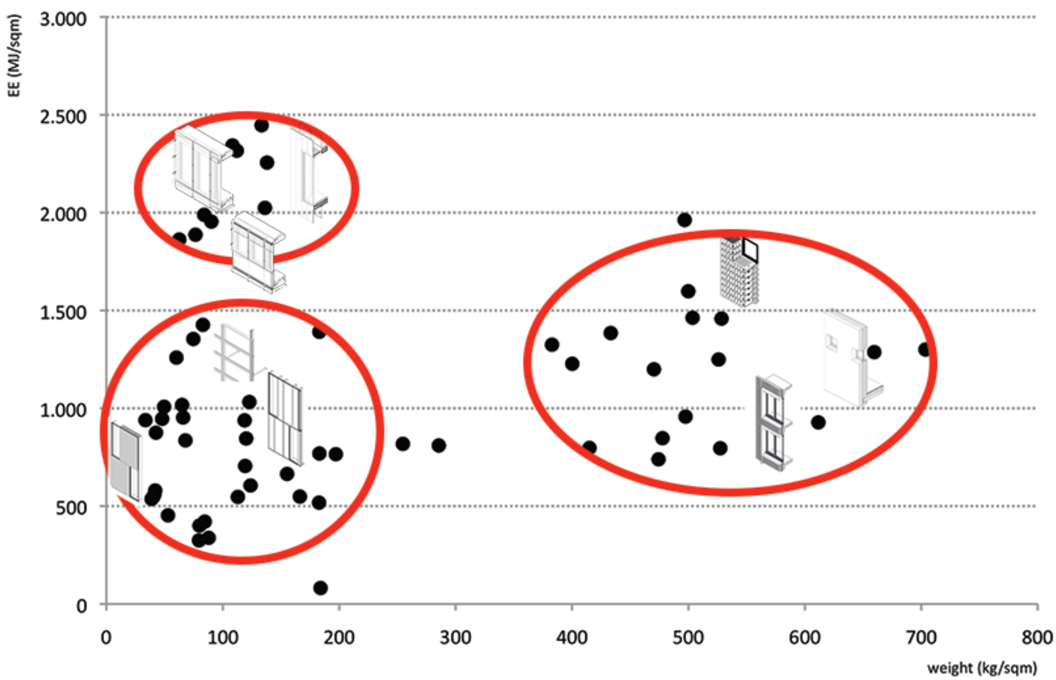


Figure 200

EE and weight in façades. Façades within one typology show similar results and can be grouped according to both indicators.

Figure 200 shows façade types and their EE. Fuzzy circles can be identified. Curtain walls with one layer show a good environmental performance, solid punctured wall systems are in the middle and twin façades present the highest amount of EE. This simplified summary indicates tendencies and does not exclude exceptions. However, it expresses the effect of the second layer for curtain walls as described earlier. Punctured wall façades are heavier and have a broad range of values.

Main impact can be made by the choice of façade type, but the area within one bubble expresses the range of possibilities that follow after this decision.

§ 9.3.2.2 Façade construction

Façade construction is distinguished in skeleton and solid. Punctured wall façades are most commonly made of solid constructions. A skeleton construction is also possible for a PWF (see example shown in case study PWF 06) but is less common.

Comparing skeleton and solid construction, the first shows ecological benefits due to the limited use of resources. The weight of a construction can be much lighter. An exception can be made with products from renewable resources. A solid wood construction offers an optimal ecological performance, as shown in case study PWF-V 07, where variant (A) with 847 MJ/sqm could be optimized to (C) 81 MJ/sqm by replacing the original concrete structure with a magnum wood board. (The mineral wool was replaced with wood fibre insulation, which helped to additionally decrease the result.) A high wood share helps to decrease EE and GWP. Safety regulations limit this method though. Hybrid constructions with concrete are an alternative and offer both, safety and an ecologically friendly solution.

Beyond the use of renewable material, the reduction of material is a valid approach. Material optimisation can also be realised by using only one layer or by adding a very light second layer. A light-weight surface enables a light-weight sub-structure which emphasises the relevance of the fixation of building elements. Frames embody more energy and emissions than point fixation, and offer an optimisation potential.

§ 9.3.2.3 Façade deconstruction

The construction type affects the amount of recyclable material. As discussed under § 9.3.1.3, the warm and cold façades show significant ecological differences. Ventilated façades offer better recycling scenarios than warm façades with an EIFS since their weather barrier is loosely connected. Each material can be described according to its ideal EoL procedure. This has a special relevance for synthetic insulation materials (which embody high amounts of EE during production) as their EoL scenario shows a high potential for recycling.

§ 9.3.2.4 Transparent and opaque areas

The ratio of transparent and opaque area can be an indicator for the ecological impact. Although glass façades do not have a very good ecological reputation, differentiated consideration is necessary.

Looking at one square meter façade area, opaque areas can range from 100-1,900 MJ. The glass layer itself embodies approximately 524 MJ (17,9 MJ/kg for P and EoL, 12mm glass thickness). The frame ratio is the decisive parameter. Aluminium, steel and PVC frames will easily double the amount of EE. For transparent areas with this type of frames the statement is true that with increasing window area the amount of EE and GWP grows.

The use of timber frames can help to limit this extent of ecological impact. A hybrid profile from aluminium and timber is good solution if a wood frame on the outside is technically difficult to realise due to high maintenance requirements. Here, the physical and ecological qualities are well exploited.

A second aspect is the number of layers. As shown in.Figure 196, the double-layered glass façades result in significantly higher values than the single-layered ones. As described earlier (page 342 ff), the size of the void and respectively the construction affect the ecological results significantly. If a second layer is necessary, the structural construction should use as little material as possible. Given that the secondary façade is not the thermal barrier, foil construction perform ecologically better than glass façades.

§ 9.3.2.5 Materialisation

The choice of material is an essential impact category. A good balance between functionality and ecological dimension is absolutely necessary.

Renewable materials perform best in all assessments. The solid wood construction with wood fibre insulation, a wooden sub-structure, a wood cladding and a wood window frame will show negative figures for EE and GWP. Not having an ecological friendly reputation, the concrete wall shows a good performance, however, followed by lime stone and brick, which show weaker results.

For heat protection, wood fibre insulation shows a valuable potential to decrease EE and GWP, but this is only possible if the wall thickness can be extended. While synthetic - based insulation shows better thermal barrier capacities and can therefore be used at a slimmer thickness, the wood fibre insulation board uses more material to perform equally, but still has the lower ecological impact.

Ceramic cladding and natural stone are very heavy materials and require a massive sub-structure. The materials themselves embody a lot of energy and emissions. Cement based boards perform better, similar to aluminium sheets. The best values are presented by timber based products.

The highest amounts can be found in façade constructions with a high metal and a high glass share. Two layers (primary and secondary façade) of floor-to-ceiling glazing, both in an aluminium frame with a void greater that 200mm will show the highest possible results.

§ 9.4 Conclusion for chapter 9

Throughout the last sub-chapter, the relevance of different façade design aspects has been outlined.

It has been stated that the following parameters affect the ecological extent:

- Façade construction
- Façade deconstruction
- Opaque and transparent area
- Materialisation

Especially the second layer, transparent or solid, has a potential to improve the ecological performance as it adds a substantial amount of EE and GWP. Mono-layered façades show advantages compared to multi-layered façades.

The complex nature of façades is defined by their functional requirements. For an ecological evaluation both parts have to be considered. One façade solution cannot be judged over the other. Only similar façade variants can be discussed when one aspect is isolated. Like a high financial investment, EE can be perceived as a currency that expresses the value of a construction. For example, the high EE in a masonry construction can be perceived as potential that supports a maximum usage phase by prolonging its function.

PART 3 Findings and their integration into the architectural planning process

10 Improvement methods

How can the information about embodied energy in the building context affect the design process? How can knowledge about embodied energy be translated into strategies for the design process?

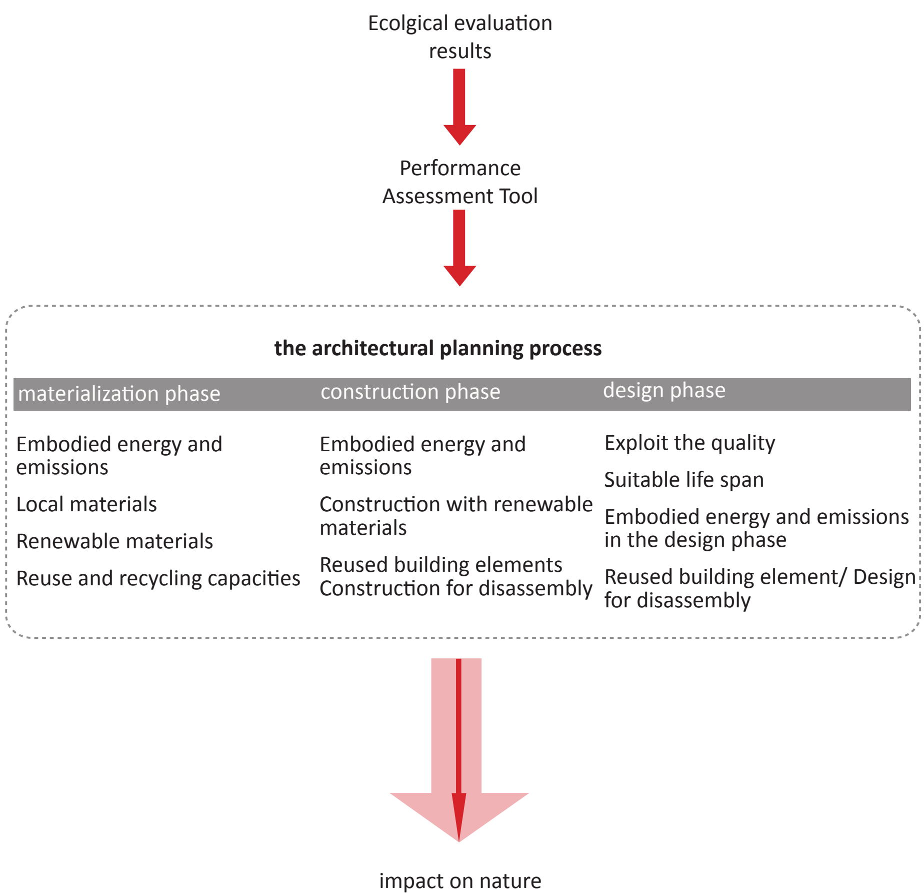


Figure 201
Content and application of chapter 10

This thesis aims at investigating LCA and converting those findings into a format that architects can use as a basis for decision making. This chapter deals with the transfer from theoretical results to a practical approach which can be integrated into the architectural planning process.

Ecological considerations are an additional concern to existing requirements. To address total energy performance, the first part of this chapter examines the effects of different usage and construction scenarios on the two types of energy, embodied and operational energy. For this purpose the Performance Assessment Tool was developed and it is applied to illustrate the difference in relevance according to the scenario. The second part focuses on the transfer of findings to the planning process. It is based on the analysis of chapters §5, 7 and 9. From the material, building element and building level findings are transferred into the planning process in order to affect the ecological scope of a building.

§ 10.1 Embodied and operational energy - Performance Assessment Tool

The total amount of energy needed to produce, operate and demolish a building depends essentially on the life span and on the type of construction. This paragraph evaluates different life span scenarios regarding the relationship of operational and embodied energy. For this purpose the Performance Assessment Tool (PAT) was developed between Thomas Auer, Ulrich Knaack and the author. The purpose of PAT is to illustrate the relevance and potential each energy category has for the different scenarios.

The concept of PAT will be explained in the basic graph. The EE values are taken from the building evaluation (or else explained in the text).

Operational energy is based on literature search and is mostly taken from Energy Design for Tomorrow (Daniels & Hammann, 2008). Operational energy is based on assumptions that relate to the specific scenario.

Deviations are possible for specific projects. The strength of the graph is to characterise the relevance rather than giving detailed figures. It operates with assumptions; hence the tool contains certain vagueness.

§ 10.1.1 Basic concept

The PAT graph shows the relationship of operational and embodied energy for different time scenarios. The y-axis displays the amount of energy for both types. The positive part of the axis expresses EE in blue. The operational energy is shown on the negative side of the y-axis in purple. The numbers for OE are not negative they are displayed as positive numbers. Both, EE and OE increases with distance to the x-axis.

The x-axis shows time span in years. The building is erected in year zero. The energy amount is shown per year. With progress in time the yearly operational energy remains the same,while the embodied energy is being divided by the number of years, thus lowering the mean value with every year.

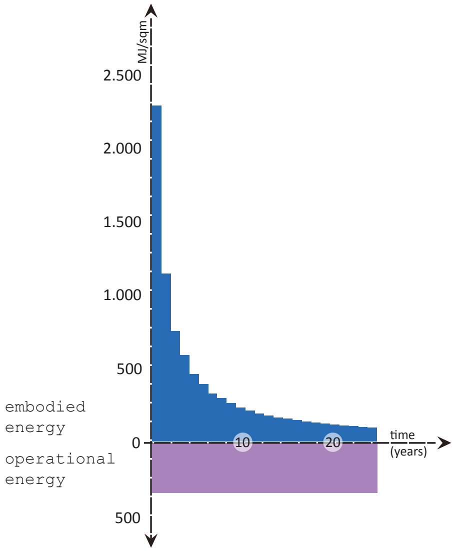


Figure 202
PAT basic: 25 years for a building using 100 kWh/sqm OE

§ 10.1.2 Demolition followed by new construction versus refurbishment

A building that does meet the current functional requirements can either be demolished and replaced by a new construction or improved with refurbishment measures. Primarily, this is a question of functionality. A refurbishment route only makes sense if it results in a satisfactory condition. Here, the ecological dimension of both scenarios is displayed.

Figure 203 shows the energy performance for the first case, demolition with new construction. Looking at this scenario against the backdrop of EE, the existing material can no longer be accounted for the material used in the new building since it is destroyed in the demolition. Thus, new EE has to be factored in and set into relation to the operational energy.

Since the existing building was demolished, and with it its EE, that EE can be added to the new building's expenditure. As a result, this building can be seen as performing worse than a new building for which no existing building was demolished.

Most new buildings operate with considerably less energy so that their overall performance is positive when considered over a long life cycle. Furthermore, this approach to a building's assessment does not include functional and technical aspects, which are an important factor in the decision for or against complete demolition. If, for example, the ceiling height or capacity of the structure does not serve the purpose anymore, the EE can only be a secondary factor in the decision about the demolition and the tool is used to factor in EE. Retrospectively it is however possible to look at the building and consider how different, possibly energetically more expansive decisions in the design of the original building would have affected the current repurposing. Part of the examination of embodied energy is, apart from the actual energy for the production and transport of materials, the possibility of giving materials another "life" by assigning it a subsequent use. This potential can be assessed from an energetic point of view. Different ratings are allocated to the material depending on its recycling potential and its ability to be returned to its original quality. In light of this, minimising the different kinds of material used in construction is preferred.

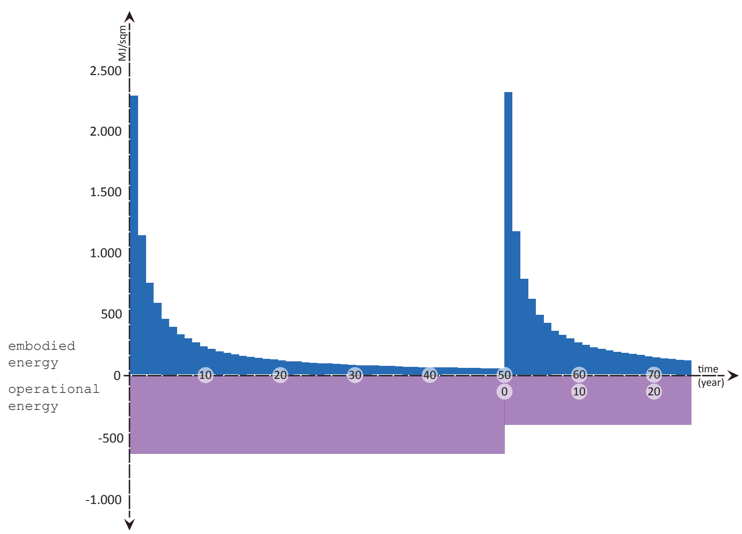


Figure 203

Demolition and new construction

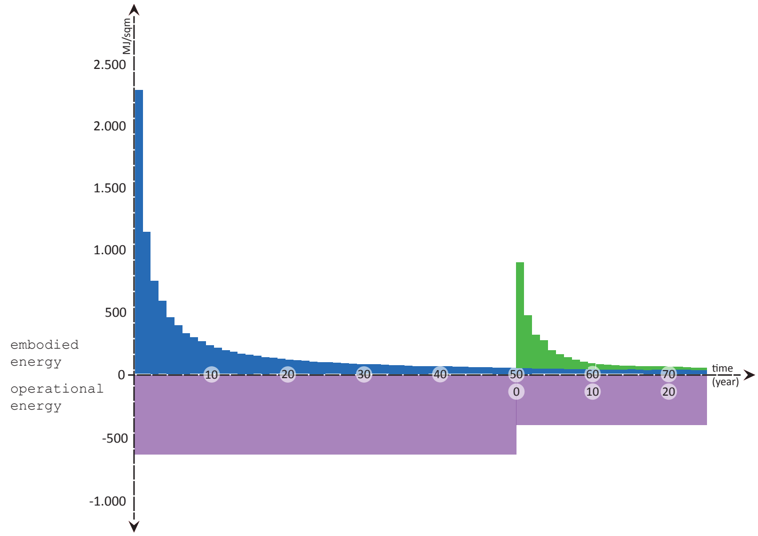


Figure 204
Existing building and its refurbishment

Figure 204 shows the performance for a refurbishment scenario. The EE values for the refurbishment measure are based on a research for a housing association in Germany. It is assumed that the refurbishment measures are transferable from housing to office building. (The scenario includes new windows, a new roof, EIFS and new interior surfaces and is assumed with 1000 MJ/sqm.)

For the scenario of refurbishment, the embodied energy of the existing building is to be taken as the basis for the analysis, to which the additional input is added. The EE that is added through new materials and new construction then has to be spread over the lifetime of the newly refurbished building. Since most cases of refurbishment use the existing structure, and since the amount of newly invested materials is limited, the introduced embodied energy tends to be lower too. This causes a reduction in the operational energy as an improvement of the efficiency of the building.
When considering a major refurbishment where major building parts are replaced or when the function of the building is being changed altogether, the pattern of analysis can be applied so that the base embodied energy of the existing building remains as the embodied energy of the new building. The EE in the new materials and construction is then added. Since less energy is expended in comparison to a new building, a holistic energy assessment displays those savings, thus rating the building with an overall energy advantage.

§ 10.1.3 Temporary buildings

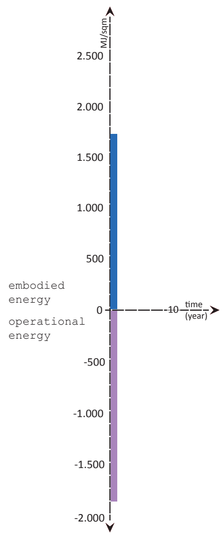


Figure 205
Temporary buildings show the high energy amount for operation

Temporary buildings, such as exhibition buildings, call for the evaluation of overall input of energy. Heavy buildings, i.e. buildings of weight or expansive constructions requiring intensive energy input, receive an unfavourable rating despite their potentially low operational energy. This can be explained by the limited use to which the energy is apportioned. Hence, it is more reasonable to opt for simpler buildings, which will have a less favourable operational energy but require less embodied energy. Furthermore, the recyclability of the materials should be considered when choosing buildings in this category.

§ 10.1.4 Light buildings

Figure 206 shows a light construction with low passive performance. Due to a lack of accumulation mass, the HVAC system has to balance the indoor comfort, which leads to relatively high amounts of operational energy.

PAT does not inform on the type on construction. With 1,200 MJ/sqm it is alternatively possible to construct a building following a hybrid concrete- wood method. As a result, both accumulation mass and relatively good EE performance are secured. For the described scenario the performance energy would be significantly lower.

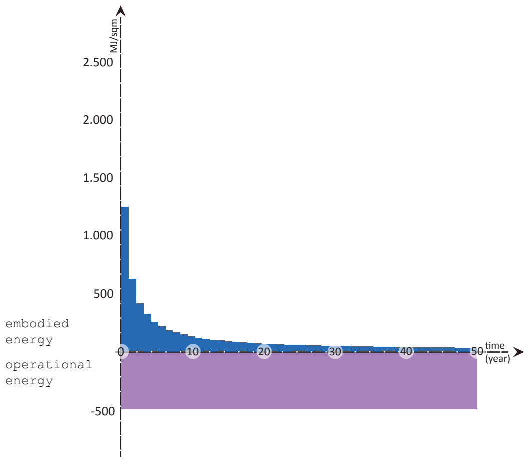


Figure 206
Wood construction illustrates a slightly higher amount of operational energy due to less accumulation capacities

§ 10.1.5 Conclusion (EE/GWP and operational energy- Performance Assessment Tool)

By analysing different scenarios the following can be concluded:

EE (per year) decreases with time

EE is of major significance for temporary buildings

When offering the same functionality, refurbishment shows significantly better environmental performance than newly built constructions.

§ 10.2 LCA and the architectural planning process

LCA is a widely accepted method to trace the ecological impact of services or products. It includes very detailed information about processes which leads to complex data management. (Millet, Bistagnino et. al., 2007)) Over the last 20 years a range of databases for building material became easily available and is now increasingly relevant in architectural practise. Architects are more and more familiar with the concept of LCA and accept its significance but are not yet able to include it the planning process. Educated designers can use databases and LCA software to assess the impact of different scenarios by an ecological comparison. This requires specification and offers a niche for new specialists. Like a climate engineer or an acoustic professional, the LCA expert can guide architects and planners through the decision making process. LCA is new a skill that the architect does not necessarily have to be capable off but he/she does need to understands the basic concept and apply it at different stages.

The architectural planning process is rather complex as it is unique to the designer. It is therefore difficult to characterise. Yet, all of them start either with an idea, an enthusiasm for composition or a material, or with a demand. Most of the time, it is the latter; a need for a building required by a client. If he/she gets lucky the architect can answer this need with his fascination for a material or type of construction. The design phase most commonly develops from large to small scale. Against this background, the planning process is here simplified into design, construction and materialisation phases. In §5.3, 7.3 and 9.3 the evaluation of building material, complete buildings and façades have been analysed and findings have been derived. Aspects will be discussed according to theses phases starting from the detail (materialisation) and developing to an abstract level (design phase). Materialisation deals with material choice, construction with the addition and connection of materials, and the design phase is concerned with qualities. Recommendations will be given and explained in strategies. This format has been chosen in order to provide guidance in a compact format. Strategies are applied in the planning process instead of demonstrating a final result. Strategies contain interdependencies that are generally true but can vary in an particular planning situation and need to be checked carefully.

The strategies are based on the ideal of closed loop construction. This means, that material needs to cycle within their functional context, and landfill needs to be avoided. Consequently, reuse and recycling are preferred as compared to using renewable material. All topics are related to EE and GWP which define a hierarchy.

The strategies are organised in topics. Most of them have been discussed earlier. The goal is to condense the information and communicate only the essentials for the sake of comprehensiveness.

§ 10.2.1 Synthesis overview

A synthesis of ecological findings and the planning process will be been given in the description of strategies in this subchapter. This part contains an overview of the strategies.Figure 208 to Figure 210 show these according to the planning stage (design, construction and materialisation). Explanation for each strategy follows after this overview.

A Explanation of the overview graph

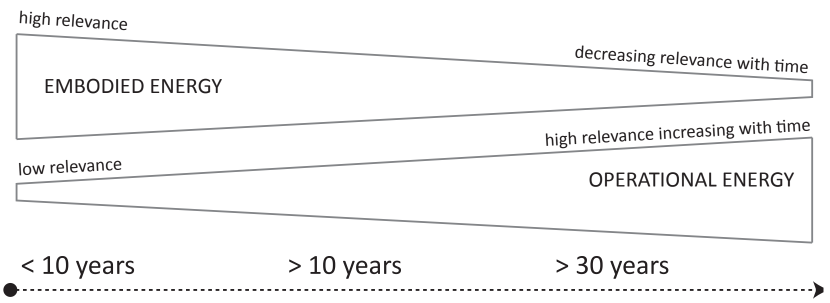


Figure 207
The overview graph (Figure 208 to Figure 210) expresses the relationship between the usage span and the type of energy. It is based on the finding that embodied energy decreases with time whereas operational energy increases.

The relevance for a strategy varies according to different usage scenarios. Embodied energy for temporary buildings contributes a significant share while its relevance decreases with time. For buildings with nearly zero energy to operate, the embodied energy is the parameter to impact the ecological scope. High effort (high EE/GWP) should be reflected in high quality, for example a long usage phase.

The strategies are organised according to the phases, while each phase is displayed in a separate figure. The usage span scenarios are shown horizontally on the very top; starting with less than 10, less than 30, and more than 30 years. A strategy is positioned under the particular usage span scenario for which the strategy is most relevant. Each strategy is framed by a sideways trapezium with one long and one short parallel edge. The longer edge indicates high relevance; the short edge shows the decreasing significance for the usage span scenario. Strategies are never irrelevant but their impact diminishes.

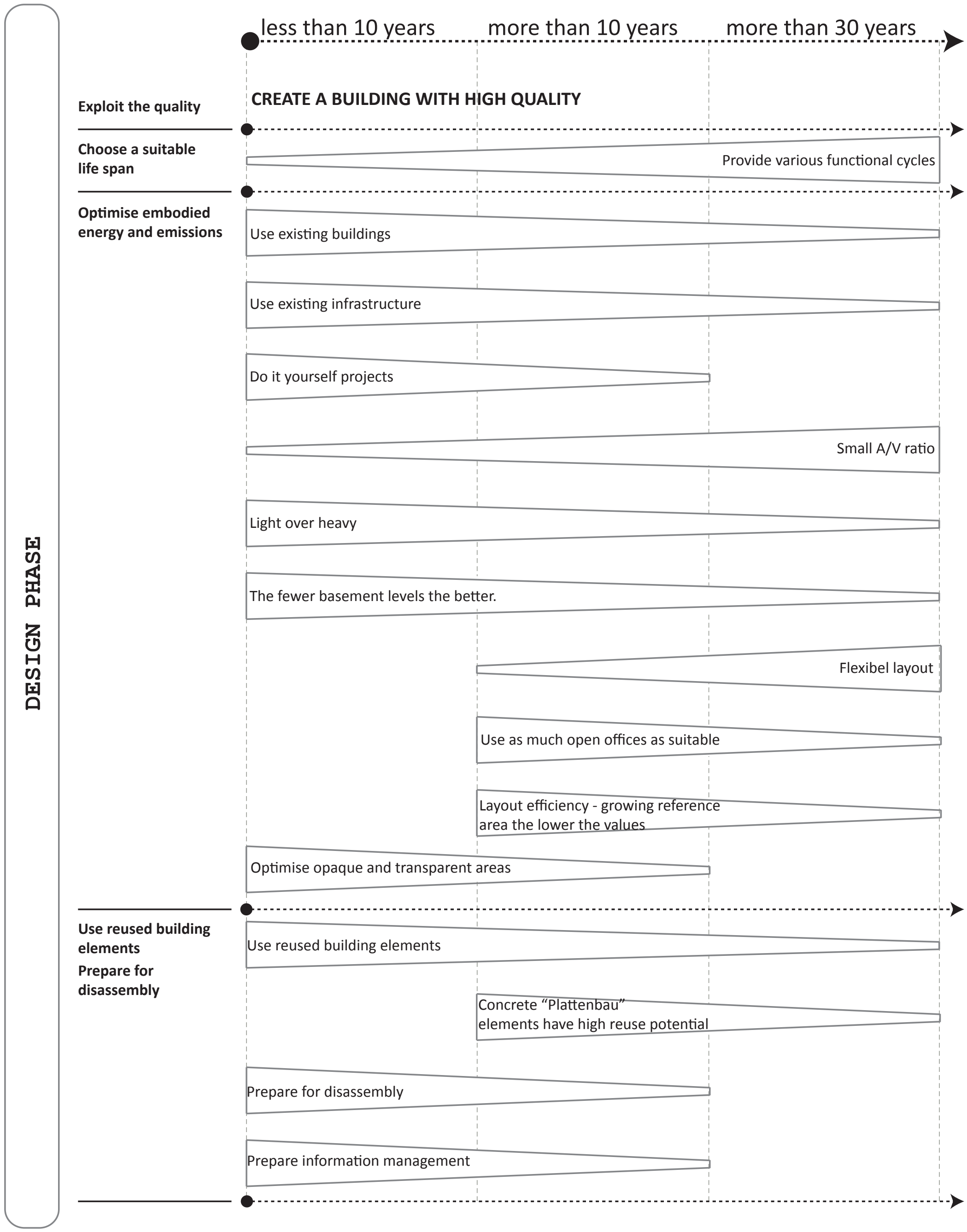


Figure 208
Overview of strategies for the design phase

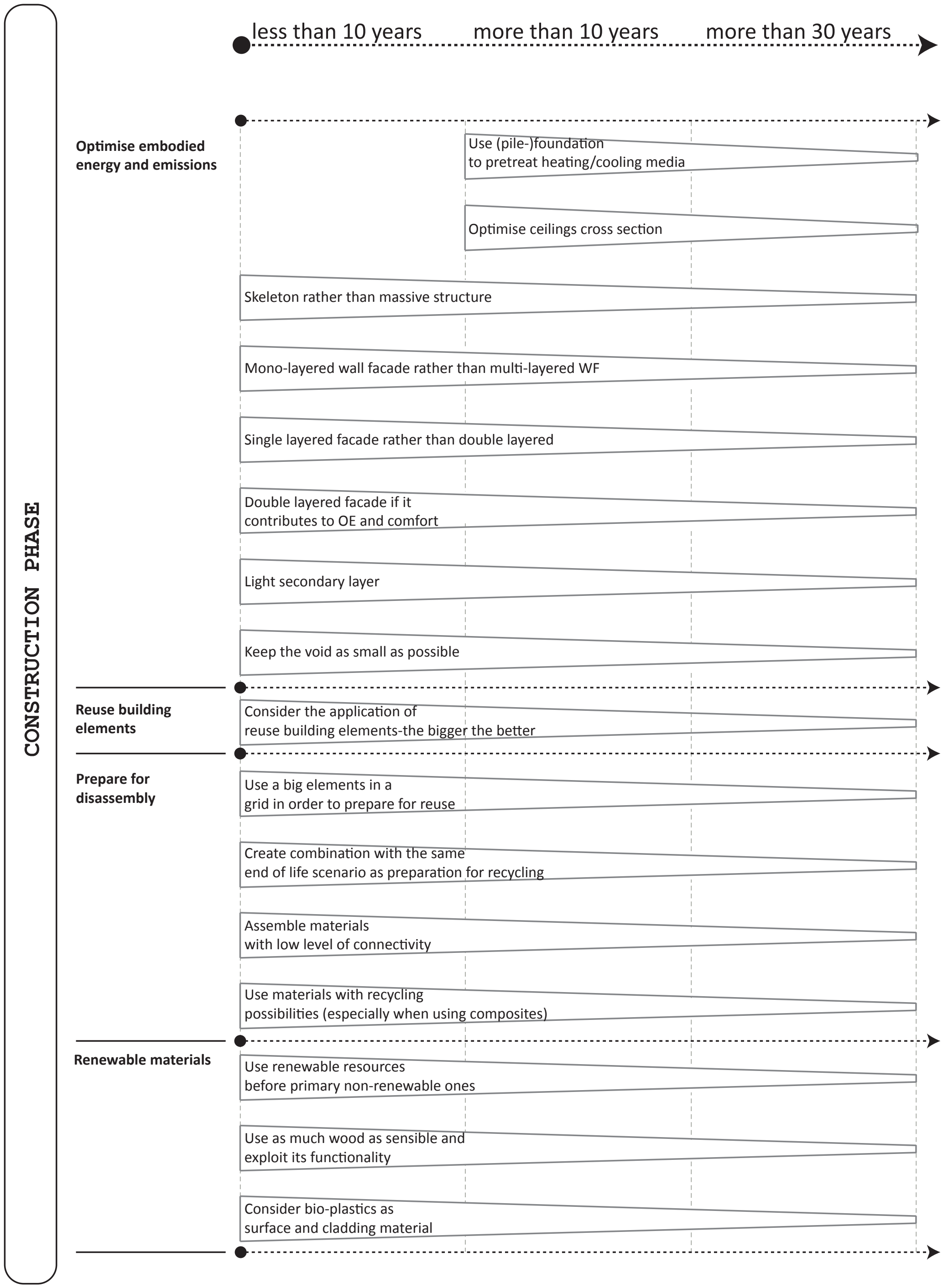


Figure 209

Overview of strategies for the construction phase

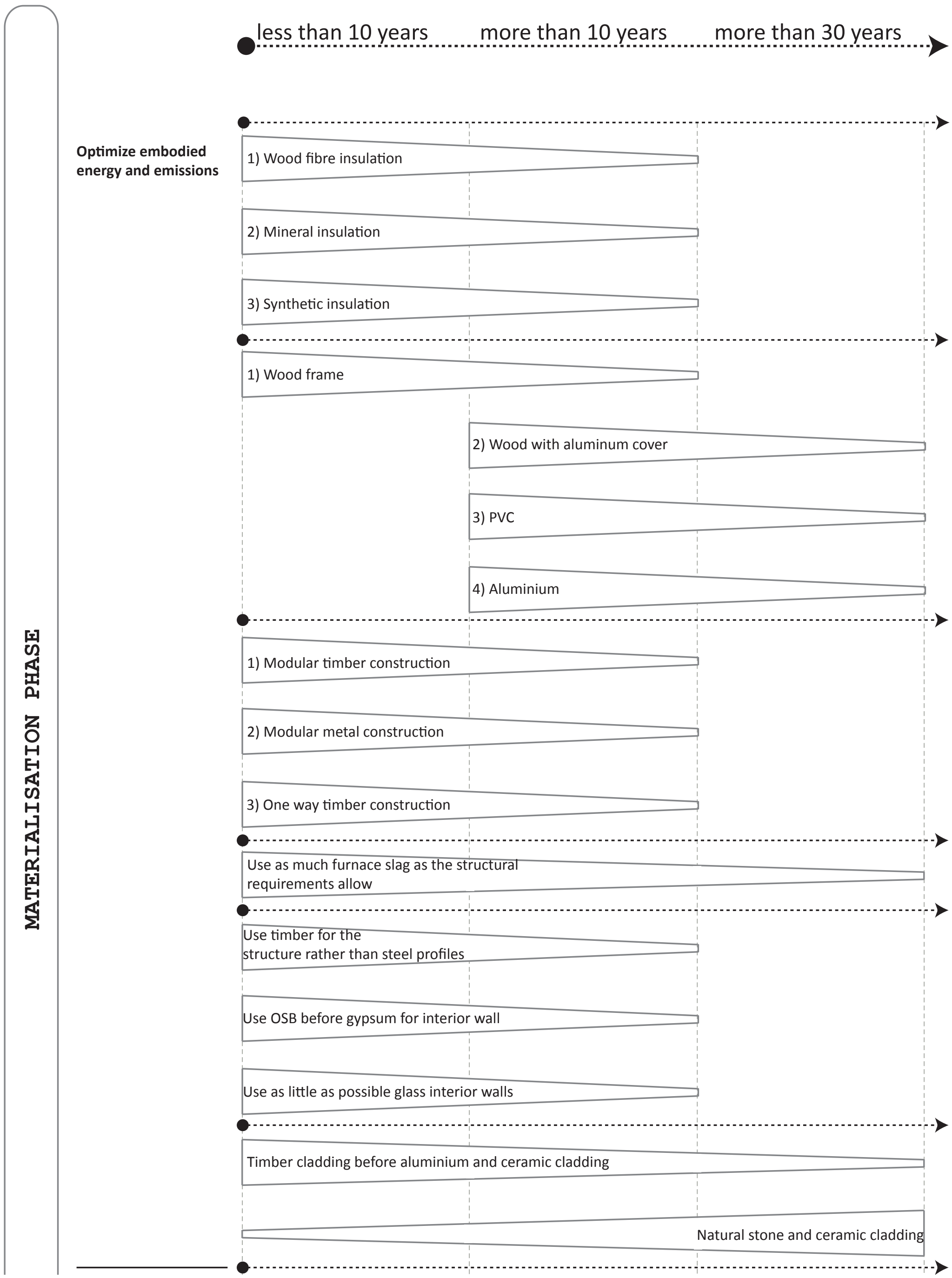


Figure 210

Overview of strategies for the material phase

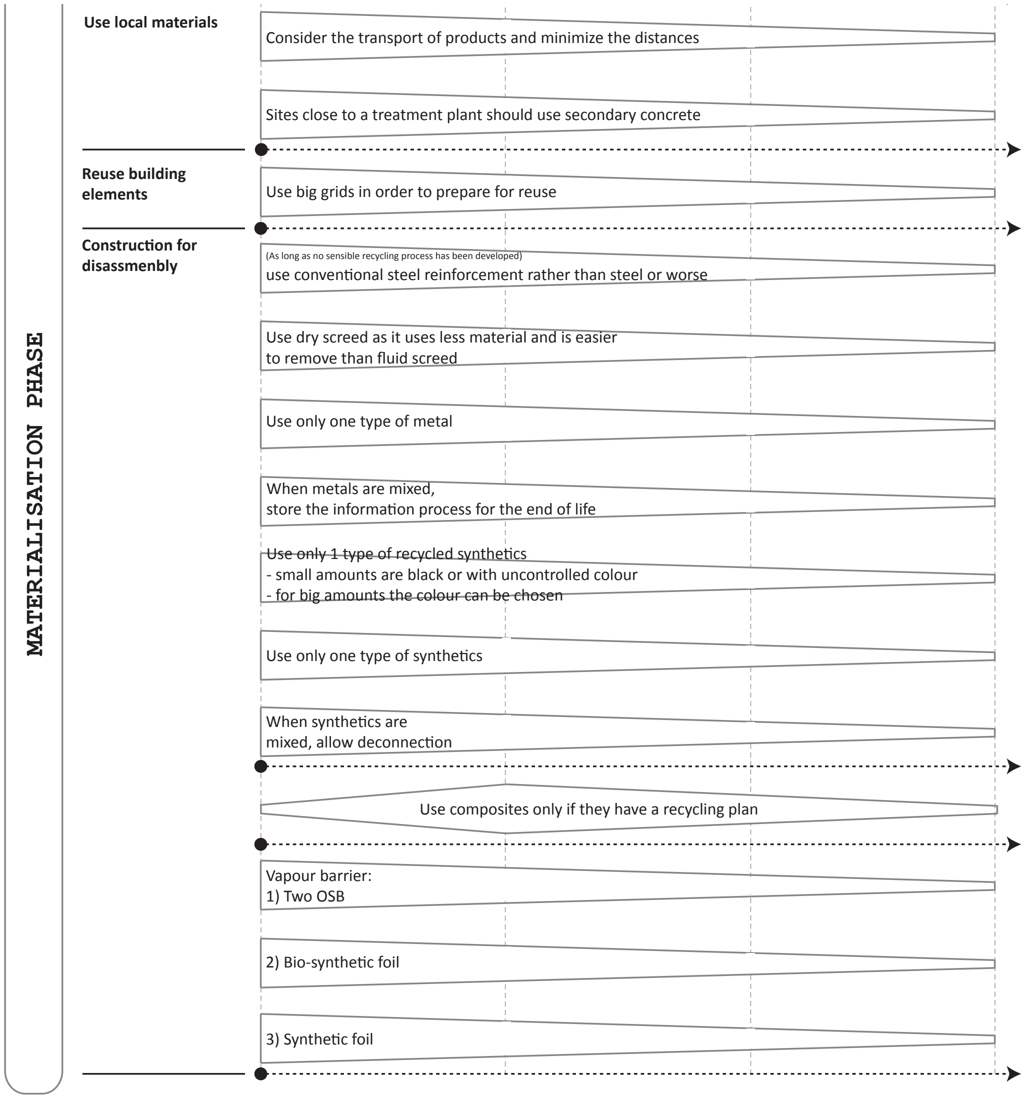


Figure 211

Summary of the material findings

§ 10.2.2 Design phase

The amount of material related to a building or building element is defined in the design phase. Impact can be made at this point of planning which makes this phase rather important for the extent of ecological impact (see figure 20, page 90).

Most of the strategies presented here are not unknown; from the sustainable perspective they are becoming increasingly more relevant and the ecological dimension of each strategy is mentioned.

§ 10.2.2.1 Exploit the potential

When planning a building, the designer defines the amount of resources and emissions related to the project. This burden on nature can be compared to a financial loan; with a higher burden the requirements for the outcome grow. For an architectural planning process this means a high amount of embodied energy and emissions has to be justified by high quality. Whether a value is high or low can be judged by comparison or, if available, by benchmarks. Quality on the other hand is an abstract term in the building context and contains various aspects. It has to be specified for each project. The idea is to use more material than minimally necessary in order to provide extra quality. Quality can refer to very different aspects, such as the integration into an urban context by installing a more complex geometry than the ideal A/V ratio, or the atmosphere of an interior by using a surface material that bounds a medium amount of EE but the lowest possible. These are soft criteria and can hardly be measured by figures. They are addressed in the concept and can differ for each project. When judging one design over another, it needs to be checked whether a measurement has been analysed and optimised regarding the EE and GWP on one hand, and performance or quality on the other. If that has not been done and the arguments for a more complex cubature (or similar) have been invented afterwards to promote the design (green washing) then the design does not meet sustainable standards.

Comfort is equally important for a quality building. It is indirectly measurable by the operational energy that is needed to provide indoor thermal quality. Double layered façades can passively contribute to both, a high level of comfort and an optimised operational performance. The installation of a high embodied energy façade can make sense when it positively impacts the operational energy.

The core of this aspect is to emphasise both sides; the scope of ecological impact and the quality that is developed with it. In other words:

Sustainable design connects creating a high level of built quality with low environmental impact.

§ 10.2.2.2 Suitable life span

The suitability of life span is a matter of perspective. The investor might consider the depreciation period, a tenant the duration he/she is using the building or the architect the warranty period for defects. The ecological advisor should foresee the total potential for the maximum usage life span including its different usage cycles. The definition of suitable life span is the basis on which planning decisions are made that refer to the different requirements. It also supports the usage of a necessary material amount by avoiding the installation of superfluous products.

The life span can be organised by the relationship of the two energy components. The three categories are “less than 10”, “less than 30” and “more than 30 years” can be distinguished. Over the first 30 years of a building, the embodied energy per year undergoes essential developments. While the first years show relatively high EE values, they drastically fall in the first 10 years and become rather flat after 30 years. A typical building with a temporary life span could be an exhibition booth or temporary facilities such as the pubs set up intermittently at the River Spree, for example. As shown in § 10.1.4 embodied energy is particularly relevant for this scenario.

The suitable life span impacts the general direction. It is one of the first parameters that need to be specified in order to find the appropriate design, construction and materialisation strategy.

§ 10.2.2.3 Embodied energy and emissions in the design phase

The simplest way to reduce EE and GWP in the production phase is to use as minimal material as possible. This affects different design parameters and can be applied in various respects.

A Existing buildings

The most resource-efficient way to provide the function of a building is to use an existing one. Most certainly, the effort to erect a new construction will be significantly higher than refurbishment measures (compare §10.1.2/3). This is especially relevant for buildings with high EE. It is sensible to utilise existing buildings in order to exploit their potential and to prevent the great amounts of building rubble that would result from a demolition.

Buildings with a solid façade most commonly embody significant amounts of EE. Most of the time, façades are load-bearing which limits the impact possibilities and therefore the added EE. It challenges the designer to use the existing façade and transfer this into contemporary context.

Using an existing building requires a prior evaluation regarding current standards. The existing must offer a certain functional standard; otherwise the consideration for further use does not make sense.

The functional aspects for the evaluation of a building remain the same. By integrating ecological aspects into the planning process, this option increases in relevance and designers need to be more aware about this potential to significantly decrease the environmental load.

B Existing infrastructure

The use of an existing infrastructure is promoted by a similar argumentation to the one in the previous abstract (the use of the existent saves primary resources.) Infrastructure in this case means energy and water supply, waste water as well as site development.

Neither the mechanical installation in or outside the building, nor the site development were considered in the evaluation conducted here due to the lack of representative LCA data and the required planning depth.

The infrastructure is a burden to nature not only because it disturbs the original soil structure but also because of the use of resources. This strongly recommends the densification of existing structures. Efficient infrastructure, traffic and energy supply can be provided that way.

Only considering energy and water supply; self-sufficient housing or less extreme decentralised energy supply systems offer minimum material use and the conservation of the soil structure.

C Do it yourself

"Do it yourself" (DIY), has become very popular for all sorts of products. Instructions are available online, designed to be applied at home with simple tools and adapted to a human scale (often without professional machines). Sometimes they are based on waste products or local resources. This low tech approach leads to low amounts of operational energy and low transportation energy as it is replaced by man-made work. This concept is very suitable for regions in which labour is cheaper than high-tech building elements. A DIY building project that creates a high level of quality corresponds very much with the ideal sustainable design.

Figure 212
Ithuba Science Lab, Gauteng South Africa

D Area to volume ratio

The building envelope contributes essentially to the amount of EE. Besides the type of façade, the amount of surface area also plays a major role. A large building surface area results in high EE and GWP. Hence, in this respect the area to volume ratio can also be used to indicate the surface efficiency. Complex geometries with large overhangs show higher EE than compact cubature. The shape of the building envelope has to be designed with regards to parameters that passively impact the operational energy. Most commonly, a compact cubature will affect the operational energy positively if the area for exchange of in- and outside conditions is minimised.

E Weight

LCA works mass based and light-weight solutions show advantages over heavy ones. This is also very relevant in the design phase (not only in the materialisation and the construction phase) as the choice for a light material such as foil or textile initially shapes the design and requires a different structure and organisation than a conventional construction method.

F Basement levels

An underground basement level requires excavation in addition to the embodied energy in the materials. This has not been considered in this evaluation as no basement levels were part of the office designs. In the SNARC method, the excavation is an essential part and is included with 100MJ per cubic meter soil. This would mean that for the excavation for an office building as shown in the evaluation, 8,500 cbm would have to be removed. Adding the slope, this approximately accounts for 70 MJ/sqm GFA. And this considers only the moved soil and not the materials to erect the underground level.

Basement levels with waterproofing require a higher constructive effort than the same measures above ground.

The effort to excavate and the relatively resource-intensive construction result in the recommendation to use above-ground levels over underground ones.

G Flexible layout

A flexible layout adapts to different usage scenarios. The load-bearing structure needs to be separated from the interior walls. Skeleton structures provide high spans which allows for different organisation of the interior walls. Since the interior walls do not need to carry loads, they are installed as lightweight constructions. Popular examples are lofts which were built for industry purposes but are now used as office buildings or residential dwellings.

Here, the topic “Flexible layout” is organised under “Embodied energy and emissions” because a flexible layout entails that only the necessary (light) interior walls are demolished and no unnecessary waste from solid walls occurs. This topic would also fit under “Exploit the quality” or could be a sub-item for “Existing buildings”. Due to its relevance it is placed within a single topic.

H Open offices

Using only few walls to organise a huge work space provides opportunity for a communicative atmosphere and a pleasant interior impression. The impact of the interior in the evaluation (chapter 7) showed a share of up to 50%. Not only the material (gypsum walls perform better than glass ones) but also the area impacts the result. The open office solution includes only necessary interior walls, which leads to minimised resource consumption.

I Layout efficiency

With a higher number of reference area, efficiency improves and the relative values decrease. Although this is only a mathematical model, it reminds us of the area potential and underlines the necessity to exploit this by filling it with sensible functions.

§ 10.2.2.4 Reused building element/ Design for disassembly

According to the Cradle to Cradle theory, mankind needs to close the technical cycle in order to prevent potentially useful resources ending up in landfill and to decrease primary resource consumption. In the building context this means to include used buildings, building elements or materials, and an effort to provide the usage cycle after the current project; ideally for the same function.

A Reused building elements

The use of reused elements becomes more attractive with decreasing effort to de-construct and maintain the element. Big elements have less connection area and can more easily be disassembled than small ones since the labour for disassembling small pieces will be significantly higher. The principle behind this is the same for existing buildings; for both is true: the less effort for the upcoming usage phase, the better. Transport and handling on the construction site limit the dimension.

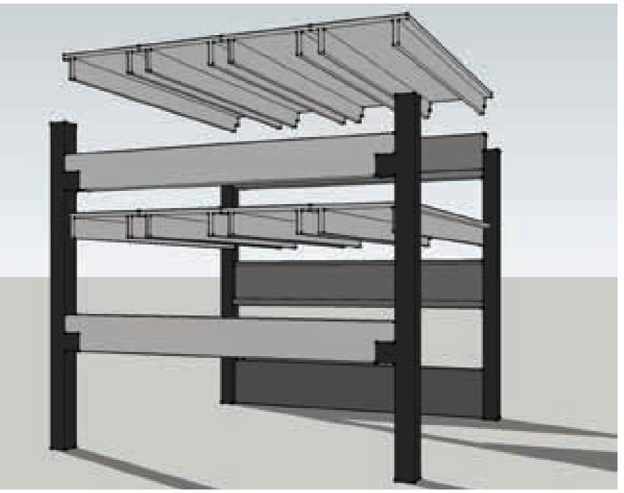


Figure 213
Scheme of 1980 Plattenbau as part of a Bachelorthesis at the Detmolder Schule. The title is Reuse potential of prefabricated concrete elements using the example of the Bielefelderstraße 66 (a former faculty building)

Prefabricated concrete elements installed in the 1970s have good potential for reuse. Prof. Mettke from Cottbus states that over 1.3 million dwellings in Germany from prefabricated concrete elements (Plattenbau) are unused due to structural change (2008). She evaluated the reuse potential and states that up to 70% of a building can be de-constructed, examined and installed in another building cycle. This bears a potential that needs to be considered at the very beginning of a design phase. The elements only work in their existing grid which fundamentally impacts the geometry.

The influence of reused building elements on the design needs to be incorporated, and an opinion about the design expression from the 60ies has to be developed.

B Design for disassembly

A closed loop prepares for a usage phase after the current one. The information management plan needs to be formulated during the design phase in order to prepare companies to disassemble buildings most efficiently.

C Information management

Material purity is an essential factor for high quality recycling. Not only do the connections have to be designed for the recycling scenario but also the information on the individual material has to be accessible. This can be provided centrally by material management systems or decentrally by an information chip (several institutions and companies are developing RFID chips that work on metal).

Stirring the material flow in the design phase is crucial for the next usage cycle. Considering recycling, the ideal would be if a single material would be used for the entire building. The mono-material that solves all functional requirements and is not polluted with any other material that would weaken the recycling process is an extremely fascinating concept. The recycling idea supports the research on mono-material research.

§ 10.2.3 Construction phase

Both phases; materialisation and construction phase, deal with products while the materialisation phase only considers the material, and the construction phase deals with the connection and combination of materials.

§ 10.2.3.1 Embodied energy and emissions in construction

A Foundation

A stripe foundation embodies less material and embodied energy than a plate foundation. For a seven storey building, the impact is rather insignificant. For a flat building, the use of strip foundation compared to a plate one will show more relevance.

Especially pile foundations bear the potential to contain more functionality than merely generating stability. The massive construction element also works as accumulator and can pre-temperate media to cool or heat the building.

B Ceiling

Concrete ceilings offer a potential for improving the EE performance by optimising the ceiling's thickness. The change of condition from liquid in production to rigid after bonding enables the designer to use concrete very efficiently. This requires more complex constructions of the form work, but the material can be reduced significantly. Ripped ceiling panels are a good example for that. Slabs with a hollow part (for example Hollow core slabs, Air Deck or BubbleDeck) use material very efficiently.

C Vertical load bearing structure

The skeleton structure shows significant advantages over solid walls. The mass and volume difference results in less EE and GWP for the skeleton structure. Over time, layout changes can be expected which support this argumentation. The passive performance to store heat and thereby contributing to a high indoor air quality and an efficient OE needs to be considered as well.

Following the LCA logic, a solid wood construction would perform better than a skeleton. If only a skeleton is functionally necessary, the minimal use of resources (even renewable) should be the focus.

D Façade

The façade is a building element with high ecological potential and should be planned carefully. The type and material choice impact the overall EE amount. Material choices already have been discussed. This paragraph gives recommendations for different construction types.

Single layer façades embody less embodied energy and emissions compared to double layer façades. This is true for solid (load-bearing) and curtain walls. If a double façade is used, the void should be as small as possible. Cleaning must be allowed but the construction should be as minimal as possible. The installation of such façade types might be recommendable if the façade comprises decentralised HVAC units, decreases the OE and generates a high level of comfort, or if the façade is part of the climate concept.

The highest amounts can be found in façade constructions with a high metal and a high glass share. Two layers (primary and secondary façade) of floor-to-ceiling glazing, both in an aluminium frame with a void greater that 200cm, will show the highest possible results.

The secondary skin shows potential for both types (PWF and CW). For the PWF it is not possible to judge a solid layer over a rear-ventilated one. This is material related. A solid brick accounts for the highest values, directly followed by ceramic and natural cladding. A solid limestone layer is approximately equivalent to an aluminium and fibre cement cladding. A wooden construction with wooden cladding performs best.

For curtain walls, foil and textile skins offer a low EE solution. Depending on the particular case, synthetic boards might be an alternative as well. The reduced weight enables optimisation of the ecological performance of the surface and the substructure.

Mono layer warm façades perform very well in the assessment. They do not only show low values for the embodied energy, but also do not prospect any problematic end of life like the multi-layer warm façades do.

§ 10.2.3.2 Reused building elements

The application of reused building elements is an opportunity to protect primary resources. Online platforms can provide information on reused building elements according to the area (e.g. superuse.org). The challenge is to guarantee structural performance (most of the time), and use them according to legislation. The sufficient functional performance is prerequisite. For temporary buildings, exception might be made. Generally, the elements need to be tested which has to be in balance with the testing effort and the benefit that can be gained. Unlike material recycling, the building elements have a certain size; a comparison between reused and primary building elements will always favour the reused one. (In contrast to recycling where the savings might account for transportation energy.) From the ecological perspective, the installation of reused building elements should be supported.

The larger the building element, the higher its reusability. A masonry wall consists of relatively small parts compared to a prefabricated concrete wall. The reuse capacity of the latter is very good. Here, the panels need to be separated while this procedure for small-scale masonry wall does not work. Most likely the masonry wall will be crushed and the small parts will become part of a less qualitative cycle.

On the other hand it means that brick buildings need to be checked carefully regarding their usage phase. They bind so much energy that an extended usage phase (as building) would be rather sensible.

Due to their dimension, the reused building elements are further discussed in the design phase.

§ 10.2.3.3 Construction for disassembly

The material mix and the level of connectivity influence the possible end of life scenario. If materials with different end of life scenarios are combined and strongly connected to each other, the resulting component will be incinerated, or even dumped in landfill, if it does not end op as hazardous waste (worst case scenario). Not just the burden by landfill is a problem. Additionally, the potential to protect resources gets lost. Ideally, materials are either easily disassembled or materials are connected with the same end of life scenario.

The connectivity of building materials is a separate field of research. it is only possible to state excerpts here.

Typical types of connection from high level of connectivity to low are: staple by gravity or pinching (e.g. insulation between beams), velcro fastened (Frauenhofer is currently researching this), click-connection, screwing, gluing, welding. Generally it is true that the lower the level of connectivity, the better for the end of life scenario. But these are not the only parameters influencing deconnectivity. The effort in time and money to disassemble plays an important role as well.

Connection can be improved for the interior. Regular wet screed can be replaced by dry screed. This creates slightly lower efficiency for a floor heating system, but the amount of building rubble can be reduced and easier demolished.

Gypsum board needs to be sorted separately at the end of life as it seals landfills and disturbs the building rubble treatment. Due to its positive contribution to fire safety it can hardly be replaced by wooden products like OSB. Here is a gap to fill, either by product improvement or with a development for the ecological treatment of gypsum.

As described earlier, the lamination of insulation, fabric and plaster within an EIFS is so strong that at the end of life this qualifies as hazardous waste. Techniques are being developed but a real breakthrough has not yet been accomplished. As long as this gap exists, the reared façade offers an alternative. This type of construction enables the disassembly of materials very easily.

The mullion and transom façade is mostly screwed, only the synthetic parts are pressed in the profiles and gaps. Unlike the EIFS, each connection is quite easy to separate. Minjung Kim states in her Master thesis that the scaffolding is the financial obstacle to efficiently disassemble façades. This problem can be approached from a construction perspective (maybe a façade that is demountable from the inside or demounts itself due to different level tension) or with external machinery which is quicker and less expensive than manual scaffolding.

In order to prepare for disassembly, a modular grid helps the process. Prefabricated concrete is most likely more clearly organised. In situ concrete that is organised according to the form work which does not necessarily follow a grid. This lowers the reuse ratio.

§ 10.2.3.4 Construction with renewable materials

Renewable materials perform best in all assessments. The solid wood construction with wood fibre insulation, a wooden substructure, wood cladding and wooden window frames will show negative figures for EE and GWP. Beyond the very well known timber construction, bio-plastics are also considered renewable material. This material has had difficulties with temperature but a recent project (2013) by ITKE and Tecnaro demonstrates the potential and future façade panel application.

§ 10.2.4 Materialisation

In the context of materialisation, the desired function is similar to the question that can be answered with a particular material. The requirements contain various aspects which the materials relate to differently. The designer organises the requirements by hierarchy and chooses the most suitable material. By highlighting ecological issues, the priorities are extended by another criterion. For example, a product does not only have to have a high-quality surface and fulfil humidity resistance requirements but also has to meet sustainability requirements.

The findings from the material chapter are the basis for materialisation strategies. The findings are:

- EE increases with the rising percentage of steel reinforcement.
- With cement sinter the EE increases. Blast furnace slag and aggregates cement help to decrease EE.
- EE correlates to weight. Lightweight material embodies low amounts of EE.
- For a concrete construction, recycled content offers a potential depending on the location of the site, treatment plants and the gravel pit.
- EE rises with treatment. Solid wood products bind the least, laminated products a little more, and wood fibre products the highest amount of EE
- Finer wood fibre boards require more EE than rougher.

- The longer wood is part of a building, the longer it keeps the carbon from being released.
- At the end of life of a wood product energy can be harvested which has a positive impact on its EE.
- The long duration of metals allows for several usage cycles.
- The purity of variety influences the end of life scenario.
- Secondary material can have the same physical capabilities with only a fraction of the EE for the product from primary resources.
- The production chain from raw material to the end product consists of many steps which lead to rather high EE values.
- Thermoplastics can be recycled more easily than duroplastics.
- Material mix corrupts recyclability.
- Mineral wool will most likely end as landfill.
- Insulation material in ventilated façades has a higher potential for recycling than in EIFS
- Glass wool embodies slightly more EE than rock wool.
- Wood profiles embody the lowest amount of EE, followed by PVC profiles. Aluminium profiles bind the highest amount of EE.
- Anodised or powder coated aluminium profiles can be processed and used for secondary aluminium.
- Glass can be recycled if separated correctly and it can become part of a new flat glass cycle.

§ 10.2.4.1 Embodied energy and emissions in material

Looking at a material's life cycle phases, the production phase embodies the highest amount of energy and emissions. Chapter 5 explained the hierarchy of materials without a functional context. These two components, ecological impact and function, are connected in this abstract.

A Insulation

Wood fibre insulation shows a valuable potential to decrease EE and GWP. This is only possible with an extension in wall thickness. While synthetic based insulation shows better thermal barrier capacities and can therefore be used in smaller thicknesses, the wood fibre insulation board uses more material to perform equally well but still has the lower ecological impact. Wood fibre insulation shows the lowest ecological impact.

B Windows

Today the (western EU) standard for windows is triple pane glass in order to provide the passive performance of the façade. From an embodied energy perspective it is not sensible to optimise this part of the window since it delivers a necessary function to keep the operational energy at a minimum. Additionally, for some countries this standard is required by law. The frame material on the other hand shows potential. The functionality during the first years is the same. Depending on the orientation, after 3-10 years, a timber window frame has to be painted. This effort is not part of the LCA but it is a functional disadvantage that promotes the low maintenance PVC and aluminium window frames. A timber core with aluminium shell would be an ideal solution for more than temporary usage phases. (LCA results are currently not available for this product.) Recycling works very well for both, PVC and aluminium window frames. This is not yet reflected in the LCA; and estimations have to be made. A rough assumption shows that timber frames bear the lowest amount of energy and even lower GWP results. Aluminium and PVC windows embody similar amounts of EE and GWP.

C Load-bearing

Timber constructions show the best solution for a load-bearing structure. For temporary usage periods, modular systems make sense. This is also true for modular metal structures. Depending on the need for adaptation, timber systems offer an advantage due to the low effort in processing. With big spans metal constructions can fasten the construction process.

For vertical loads, brick embodies the highest amount of EE, followed by limestone and concrete.

D Cladding

Ceramic cladding and natural stone are very heavy materials and require a massive substructure. This substructure is typically made of metal and is therefore responsible for large contribution of EE and GWP.

For natural stone, the transportation effort needs to be considered. This material does not need much maintenance and is therefore very advantageous for a long usage phase. Ceramic cladding also requires high effort for production, which shows a weak EE performance. Aluminium and fibre cement boards result in medium values. Timber claddings perform best. Maintenance needs to be considered as well. These façades change in their outward appearance or need to be treated. The use of low treated timber is especially useful for short usage scenarios.

§ 10.2.4.2 Local materials

The use of local materials helps to reduce the transportation energy and emissions and can thereby contribute to less production energy. The ideal scenario is to use waste products from a different product chain for the design. Considering the life cycle of the building, waste can be accounted for with no or very small amounts of EE and GWP, in other words with no ecological baggage.

If a site is close to a concrete recycling plant it might be sensible to substitute aggregates with recyclate.

§ 10.2.4.3 Reuse and recycling capacities

Reuse is more relevant for the construction phase. The reuse capacity depends; it is not limited to a certain material type. It depends on the conditions a material is exposed to. For example, with favourable conditions timber beams can last for more than 1,000 years (for example, constantly under water such as in Venice) or only 20 years when positioned in unfavourable circumstances. A product can be reused even after a long usage life span if the construction context supports this. Generally, it can be stated that a broad range in usage life span is true for all material groups.

On the material level recycling bears more potential. For mineral, synthetic and metal materials, the purity of variety is the decisive parameter. Additionally, information on synthetics and metals has to be easily accessible.

Recycling (outside the factory gate) for the same function is rather an exception than current practise. Theoretically it offers high potential for metals and synthetics. The lack of information is a problem, especially for metals and results in fractions with lower quality. Aluminium has an extremely high recycling potential as the energy intensive process is not necessary for secondary material. Material purity is extremely important within the materialisation process for all kinds of metals and synthetics.

Figure 214
Aluminium scrap

A Recycled synthetics

For synthetic materials, products from recycling should be considered. Products made entirely of recycled materials are available, for example for boards. For small amounts, only black or coincidental colour sheets are available. Larger amounts of sheets can be coloured with a dark colour.

B Fibre reinforcement

In order to prepare concrete for recycling, conventional steel reinforcement should be preferred over fibre reinforcement. The steel reinforcement can be separated mechanically, which is not possible for carbon or glass fibres. At least this is true as long as no efficient procedure has been developed.

Fibre reinforced plastics (FRP) waste occurs in great quantities from wind turbine wings. The industry claims to have found a recycling procedure in order to prevent them from ending as landfill (Fibreline Composites, 2010). It involves a small detonation and crushing of the material. It then becomes part of the cement production where it is burned and its energy is used to substitute primary resources. A recycling scenario on the same level is not yet developed. Due to their high structural performance, FRP can replace other products with less material (by weight or volume). This can offer an ecological advantage. But FRP and other components should only be installed if a satisfactory end of life scenario is possible.

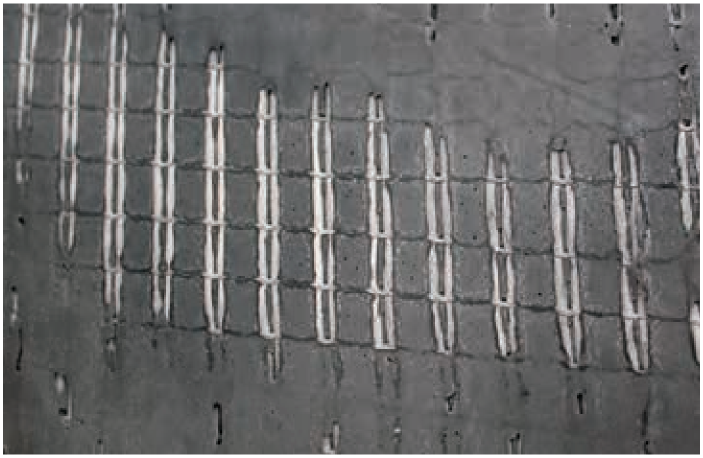


Figure 215
Concrete with fibre reinforcement. Reinforcement is visible due to a lack of coverage.

§ 10.2.4.4 Renewable material

It is wise to keep the effort spent from resource to product as little as possible; hence, if at all possible, low treated timber products should be preferred over highly engineered ones. Following this logic, rough fibre boards perform better than fine ones.

It is true for all renewable products, that they should be included in the building as long as possible unless they loose their function in order to postpone the point of GWP release.

The option of using bio-plastics should be weighed for all materials. When considering this, the effort for production needs to be taken into account as well. It is technically possible to replace the insulating bars within a transom and mullion construction. The effort for small amounts is rather high, hence very expensive. The decision which material is the best should be based on the façade area and the possible efficiency in this process.

More material mass is required for a vapour barrier or retarder. The exchange from fossil to renewable foils might be less complicated, and can be considered a potential to increase the amount of renewable material in the building. Institutes such as 3N in Werlte, Germany are currently developing applications for the building industry. Observing the bio-plastics in everyday products, a bio-plastic vapour retarder / barrier does seem within reach in the near future.

11 Conclusion and perspective

What perspective for applying the strategies can be drawn?

A design component not required qua function is questioned within the sustainability debate. This is especially true for buildings due to their size compared to products. Two angles will now sketched out as well as my position to them as I consider their relevance in the design phase.

§ 11.1 Sufficiency and effectivness

In 2011, the teachers of the class Sustainable Construction at the Detmolder Schule handed out the Lixcel tool to the students earlier than in the years before (for organizational reasons). Although we recommended using the tool after finishing the design phase, the students ambitiously applied it directly. Aiming at the lowest ecological impact, rigid and strict forms were developed by a majority, creating very compact buildings with an efficient layout and only the minimum of necessary window area. The A/V ratio was optimized and all advice carefully incorporated.

The outcome was frustrating however; The buildings were unattractive and could have been taken out of a developer's product catalogue or worse. Small windows, small hallways and no architectural identity. In sum, they offered very poor aesthetic or atmospheric quality.

The students proudly showed the ecological results, emphasizing that the task was to develop an ecologically friendly building. The question, whether they would like work in the building or even spend money on it and become the owner, helped. Most of them answered with no.

In 2009, Gerkan and Marg developed an after-use-scenario for the Tegel Airport in Berlin, Gerkan's first project, and invited a group of Chinese and German students for a workshop. They proposed to convert the runway and the terminal building into a sustainable city, a showcase for state-of-the-art technology. During the process one of the ideas was to remove the runways, to excavate soil below and create a reverse of the existing. Sealed area should become an underground level and on the non-sealed part buildings can be erected. All should be made from concrete. Prof. Marg supported this proposal and argued that this architecture relates to ideas by Le Corbusier. Due to the beauty of that concept it could be regarded as a sustainable solution. He argued that beauty is one of the most essential criteria of sustainable architecture. If people accept and love their built environment they will use it for a long time and make use of its full potential.

The debate is whether quality (or beauty) immediately means the out-of-limit use of resources and when it is allowed to use more than the minimum. One group agrees with the conclusion that sustainable architecture needs reduction and lower standards to solve the problem (sufficiency). The opposing camp states it is the way of using resources that is crucial and that defines value (C2C, effectiveness).

The approach to reduce the demand immediately solves parts of the problem and it creates awareness that might lead to avoid unnecessary steps. It supports a strong decision about what is essential and what loses its relevance with time. When it serves the quality I agree with the approach of sufficiency. Working with what already exists is similar to climate design's approach to integrate existing potential in the planning process, which creates an identification with the location and offers efficient use of resources.

This one idea for the Tegel Sustainable City included an unbalanced relation of ecological impairment and the generated quality. The huge material amounts would be directly visible, communicating the wrong message. One of the goals was to keep the airport's character, so especially the runways should remain recognizable. This could even better be experienced by leaving at least a part of them visible and use other parts to erect buildings on.

The idea developed in that direction; in the final design the buildings were placed between the two runways and themselves were used for recreation and transport. (The new schedule for closing Tegel as airport is 2015-2018, depending on the BER Airport. Currently the municipality is willing to support a technology park "Urban Tech Republic" similar to gmp's vision. (Fahrun, 2013))

The cradle to cradle approach by Braungart and McDonough claims the superfluous use of what is good in the sense that it can endlessly perform the same function. Maybe Braungart would have supported the new underground level with the use of a biodegradable material or a concrete product that changes its consistency multiple times so it could be used over and over again.

Closed loop construction means the preference of reused building elements over material recycling and primary resources. Only few materials work within a closed loop. Aluminium is a material with a high recycling potential which already works in a loop in the sense that it is reused and recycled but not within one continent. The loops the material in cycling in are too big. It is a task for the industry to reduce this loop at least to a European, better to a national radius. The closed loop construction principle is relevant when planning a new construction. The use of reused building elements can be a central motive and become part of the building's identity. Even if this is not the case, reused building elements support resource protection and can be considered as a replacement for construction elements from primary material.

The advantage of reducing a demand is its prompt effect. It shortens a complex process by not looking for a solution but instead questioning the problem and restraining its scope. The architect needs to strategically decide whether a measurement over the minimum is worth it and invest the amount of energy he thinks is suitable considering its performance. This can mean the dispensation of an extension. It would also follow the advice Matthias Michel gave during a student consultation in Detmold: if you can take something off, the design is not done yet. But reducing the demand only works for a limited perspective as the situation will reappear and a permanent solution is required.

Designing a building with materials in closed loops is the ideal scenario but today we lack construction methods which support the level of connectivity according to the exchange cycles and products which fulfil contemporary functional requirements while additionally offering adequate after- use scenarios. Some products already exist and their variety needs to be broader in order to match the design and functional desires.

The situation today was aptly expressed by K. Zahn: "The earth is a system that is energy-open but self-contained in its resources." The impact on nature by the built environment can be promptly addressed by the resources cycles. It addresses the problem of landfills and reduces the consumption of primary resource. Additionally, a building can be operated without non-renewable energy, which shifts the focus for architects on the building substance. Resource efficiency can be understood as follow-up to energy efficiency.

§ 11.2 The role of LCA

LCA is a valid tool to trace the ecological impact of planning decisions. It monitors the impact of each life cycle phase and by that indicates optimization potential. It thereby contributes essentially to the awareness of the last phase of a product, element or building. Integrating the end of life into the planning process is a necessary step and should be mandatory for new constructions.

Some green building certificates include LCA data and support sensibility for this topic. Right now the complexity of LCA inhibits its application as design instrument. LCA needs preselecting and within this selection the one with the least impact can be identified. This choice needs to be made carefully by a planner. A link to a parametric design tool could solve this limitation by the connection of planning decisions to a database. The parametric tool could identify the most suitable product while the planner would have to define its functional requirements. Maybe new technologies could also be used to link the intended life span to the ideal level of connectivity.

With LCA, the amount of resources can be indicated. Re- and further used products show better performances than primary ones and, by that, indicate resource efficiency of a building. This stimulates the careful or strategical distribution of embodied energy over the life cycle phases of a building.

§ 11.3 Implementation

LCA can show the impact of a planning decision but is not (yet) an integrated planning parameter. The planning process needs to address resource efficiency or a design in closed loops.

How can that be implemented and what is different to current practise?

The building substance needs to be recognized as valuable basis, as storage for materials that are part of a cycle which needs to be carefully installed and maintained in order to preserve its reliable performance.

Cities store raw materials and increasingly be perceived as these. Existing buildings show potential although buildings in the past have not been designed to be used further or to be disassembled. The awareness of this type of resource might support contextual design. Typical building materials might be used further and give a reason for keeping a traditional type of construction or the use of local material.

In order to use existing building material and elements research on cities' materials are necessary. Potentially usable materials need to be documented with construction and the potential point of becoming unnecessary for their original function. Formats for that need to be found where the building owner is willing to share knowledge as he receives monetary appreciation for his building substance.

The usage life span is an important factor which needs to be specified within the design phase. It effects the construction of structure, facades and the interior and their materialisation. The main tendencies are either a long usage span which includes a robust functional qualities with high flexibility or a shorter usage span with easily demountable connections. Research needs to be done on suitable formats. Maybe a document that is similar to the energy pass could fulfil this function.

Within this city data the quality of the building base elements should also be gathered. When the first usage period ends and building parts are disassembled, the functional capabilities of these needs to be assessed. For some building elements a declaration might be sufficient. The majority of building elements will not have that available and need to be tested. Testing methods need to be cost efficient so that a secondary resource including testing and transport is cheaper than a primary one.

The information on existing building substance needs to be easily accessible for architects for them to integrate it in the process, which might impact the form-finding process, adapt the grid or the material concept. Very little of these platforms already exist. On a small scale, local classified ads like those on Ebay are the best ways to access information on reused elements. The Dutch studio Superuse installed on only for building elements supporting the idea of the city as resource depot. A building element or material platform would need to include specific information on the dimension or potentially necessary treatments.

Unlike the existent substance, new construction can prepare for the time span after the first usage cycle. To do so, general experience show large sized elements should be preferred over small ones. Large elements have potentially less connecting area and their assembly tends to include less steps. For example, brick is very labour- intensive to disassemble and re-assemble again. Prefabricated concrete on the other hand can be deconstructed more efficiently.

Connection made to be force fitting and detachable are already existing. They are common practise for production halls or trade fairs stands. They need to be evaluated and transferred to other building element connections. Again, computer- aided manufacturing offers potential for machine-made connections.

The building structure is subject to less exchange cycles compared to the building envelope or the building interior. Current demolition practise interior walls are rarely further used or reused. For plasterboard wall, the metal profiles are extracted for the scrap money but the main materials end as waste. From a resource-efficient perspective the interior wall offers potential for modular systems that are either so adaptable that they serve for a very long time or only parts of the building element are exchanged while the major part retains its function. An approach to reduce the waste volume could be to have a mono material that serves all functions a layered one offers. Mono materials combine multi- functional performance with high recycling opportunities. For example, a wall from aerated concrete is able to bear loads, to insulate and to accumulate heat to a certain extent. Due to the material purity (with the exception of plaster and glue) the potential of recycling is very high. Furthermore, mono materials wall products can have cavities that are able to contain pipes. This optimizes the installation time on the construction side, as no slitting and stemming is necessary and could offer a resource-efficient approach.

The interior is exchanged more quickly than the building envelope but the amount of materials related to this most likely is higher for the latter. As described earlier, facades offer a high variety in functionality, construction type or material.

A closed material cycle for facade offers a great contribution to a buildings resource efficiency. Non load-bearing facades will be replaced during the buildings usage span. Especially interesting is the recycling ability of post-and-beam construction. Very few materials within this system are connected by glue. Most of them are screwed or clamped. Yet, very few system are reused or even recycled. The reasons for this need to be evaluated. One approach includes the high labour cost and the necessity for scaffolding. This is also true for the production halls which already are reassembled. This needs to be transferred to facades as well.

The use of lightweight construction could be categorized as a sufficiency approach as it offers a reduction of environmental impact compared to conventional construction methods. Beyond the calculated results this is one of the rare situations where the observer can recognise the low amount of material and a construction's good ecological performance. A good example are the second skins from foils. They show sufficient function while needing less substructure and surface material.

Additional lightweight construction can be changed easily and adapt to different conditions. It can be used for temporary construction or as climate skin in winter. Using products from renewable materials improves the performance even more.

The use of renewable materials has increased within the last decade. Timber constructions have become more popular due to the development of prefabricated high performance construction. This leads to application in buildings with more the than three storeys. Breakthroughs are the Forte Tower in Melbourne, the highest timber building, or the seven storey residential building e3 with hybrid concrete timber construction in Berlin.

Bio plastic offer a very attractive alternative to synthetics from fossil resources. Currently bio plastic cannot compete with regular synthetics but an improved performance can be expected.

Using products from timber and bio-plastic addresses global warming and the related consequences by capturing carbon. The use of non-renewable resources is avoided by the application of these kind of products. Furthermore, renewable products have a very positive end of life scenario and will not contribute to landfill. When the material cannot be given a function, energy is harvested, which again protects resources.

Beyond plants, sun, wind and geo-power are categorized as renewable. Fossil fuels are still the most common source. An approach to improve the performance of material could be the optimisation of the production process. In Island all electricity is generated from renewable resources so the metal industry produces significantly less emissions. The advantage of renewable energy is also relevant for companies in Western Europe. Some aluminium industries considered moving close to energy generating plants in order to save costs and improve the energy performance (reorganisation of industry locations). Values can be reduced significantly if the majority of companies with energy intensive products would do so.

Using renewable materials still means harvesting primary resources. If secondary raw material are available and the same amount of energy is necessary for the production from resource to product the impact on nature is lower compared to harvesting primary renewable materials. If secondary resources are not available, renewable material offer increasingly more potential especially in the non-traditional parts like bio-fibres or bio-composites.

The initial change is the perception of the building material's value. Building material needs to be carefully installed and maintained, too. It needs to be either modular or easy to recycle for short usage periods, or of long lasting functionality for permanent use. Old bricks are one example of the value that lies in beauty; while 100 year old bricks with patina are valuable enough for people to invest the time to disassemble them from old sites and substantial amounts of money (up to 3€/piece), 30 year old bricks are of no interest. We need to understand what makes a material beautiful and valuable in order to exploit these factors and thereby increase the potential of the building substance.

§ 11.4 Outlook

The city is a depot for resources and we (it involves a variety of professions) need to learn how to organize it. Architects will use already existing built substance for new construction and develop them so they fulfil current functions and are detachable in addition to it. Disassembly of building elements needs to be improved and constructions are required to be prepared for the phase after the first usage cycle. Information management is necessary on a city scale and for each building element in order to decrease the radius of materials. Using secondary material bears potential for all building elements, which offers a broad field of future research. (Potential of different materials installed in buildings/ detachable construction details of different building envelope types, floor types or interior walls.)

Modularity, light construction, the use of renewable materials and mono materials are also interesting fields which are looked at from a different point of view. They are relevant for all building elements. Although they are not initially invented to reduce the ecological impact of the built environment, they show potential to do so.

The facade is the essential parameter for the resource-efficiency of a building as it is exchanged and binds relevant amounts of material. Impact can be made within this element due to its high variation in construction and materialization

The material cycles need to become smaller and the gaps – landfill or downcycling-need to be closed. The use of resources will increasingly develop impact on architecture and by that resource efficiency is a successor of energy efficiency.

Supplemental graphs and tables

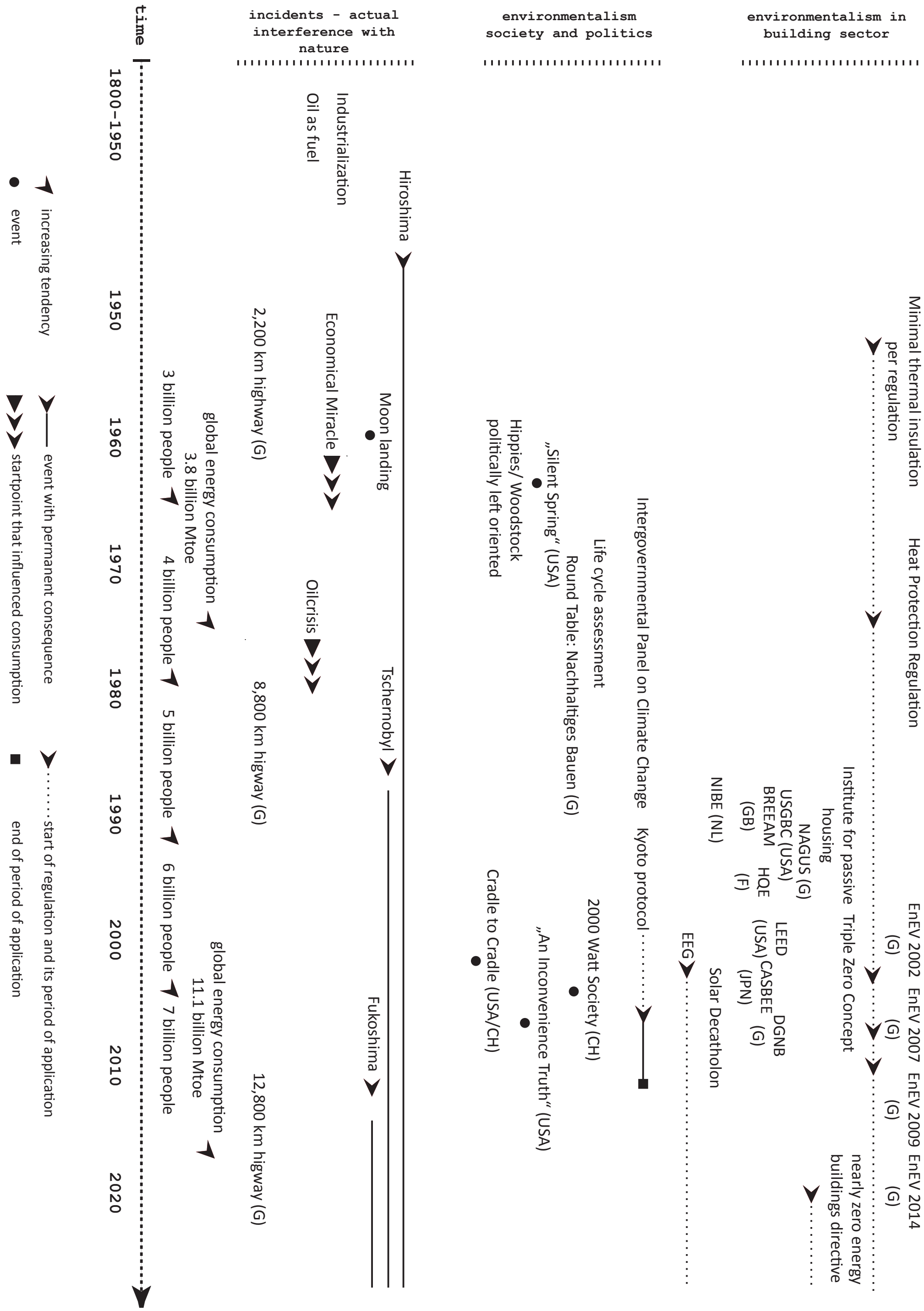


Figure 216

Impact on nature, political/social awareness and the building sector

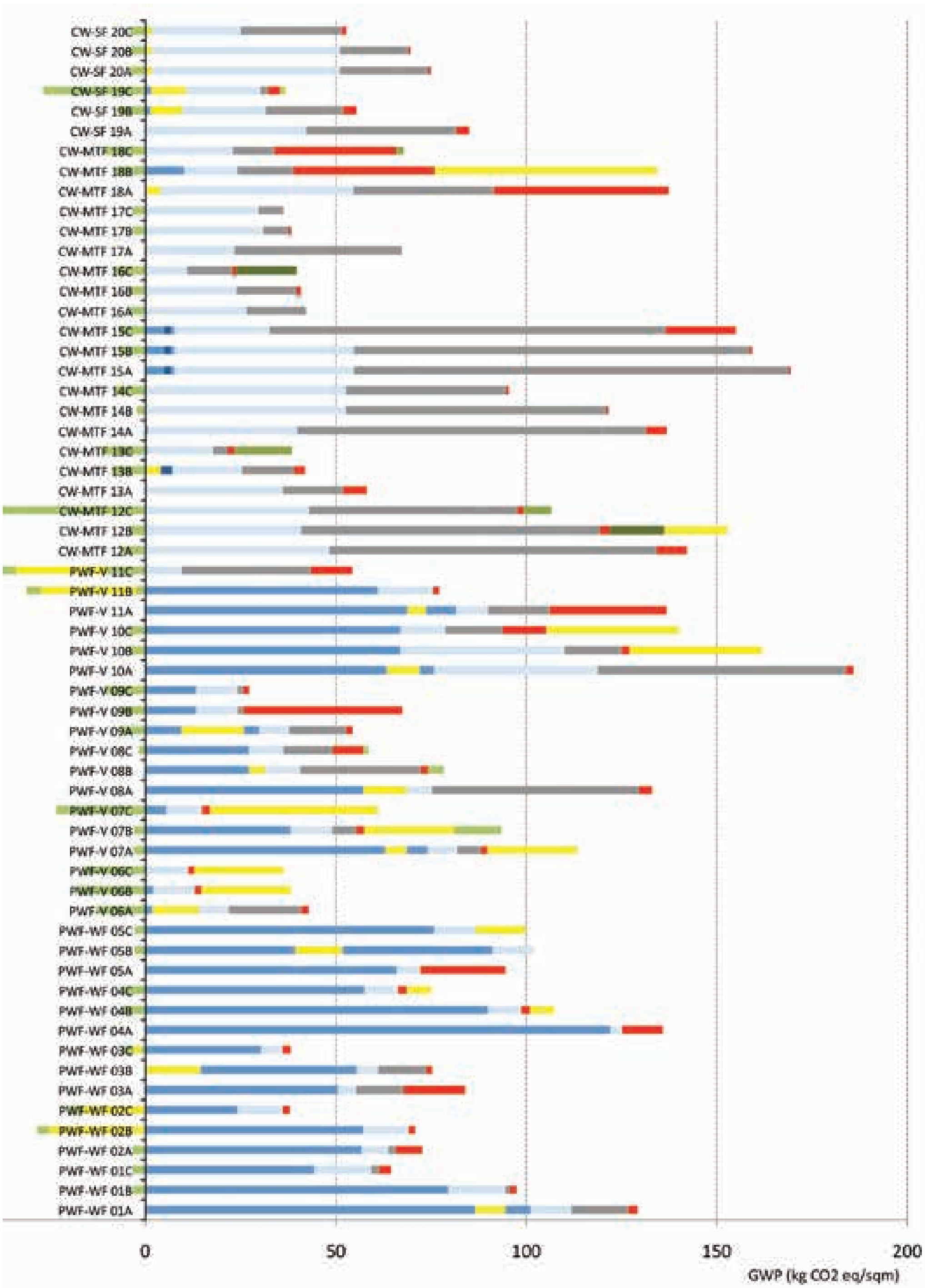


Figure 217

Addition to Figure 198, GWP material distribution.

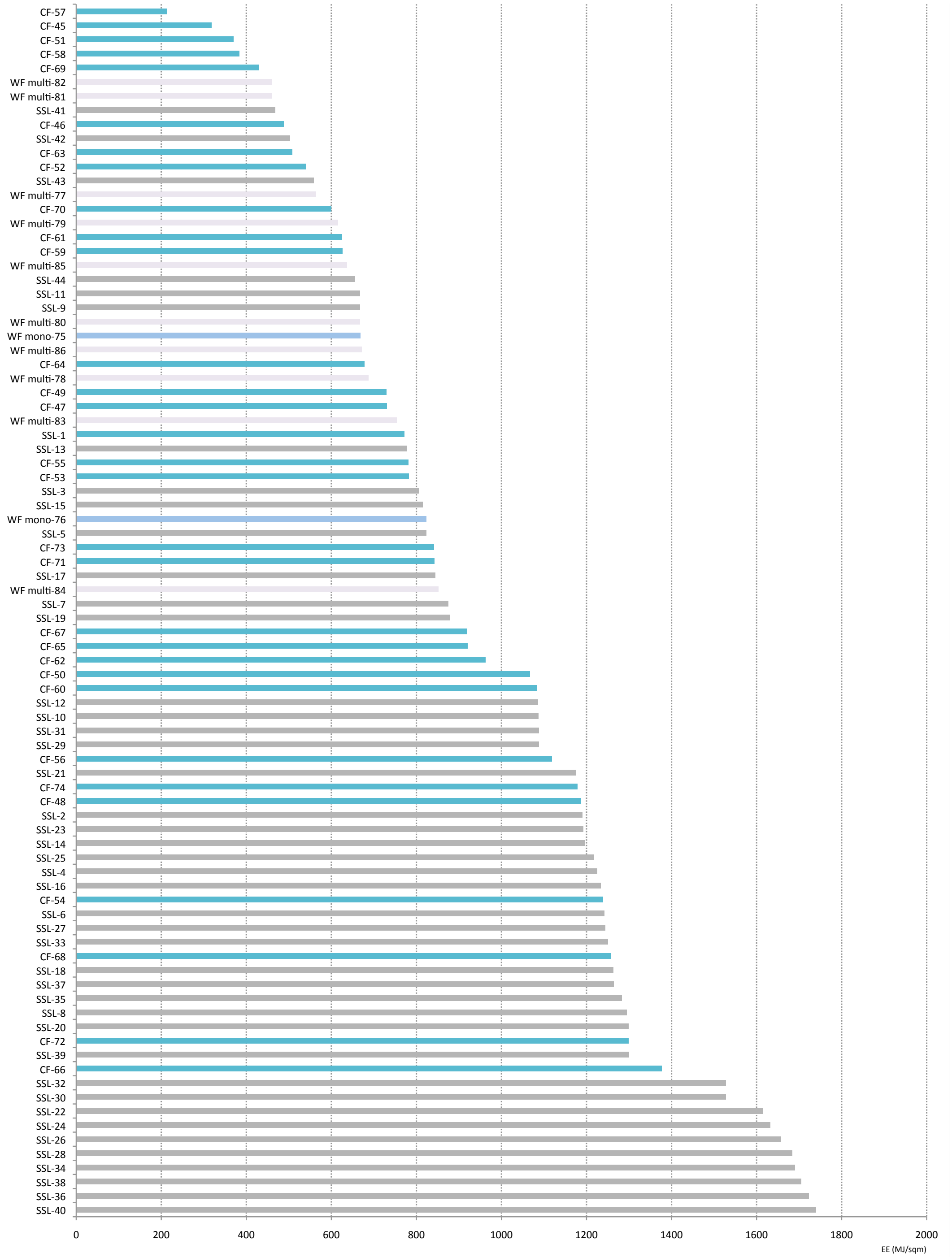


Figure 218

Addition to Figure 194, EE for opaque parts of solid façades,
Solid second layer -grey, Cold façade - petrol , Warm facade, mono-blue, Warm facade multi- light pink

Short name	Construction	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./sqm)
SSL-1	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm glasswool WLG 032, 115 mm limestone (1800 kg/m3)	771	108
SSL-2	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm glasswool WLG 032, 115 mm brick (1600 kg/m3)	1191	121
SSL-3	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm glasswool WLG 032, 115 mm limestone (1800 kg/m3)	806	110
SSL-4	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm glasswool WLG 032, 115 mm brick (1600 kg/m3)	1225	123
SSL-5	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm rockwool WLG 035, 115 mm limestone (1800 kg/m3)	823	115
SSL-6	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm rockwool WLG 035, 115 mm brick (1600 kg/m3)	1242	128
SSL-7	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm rockwool WLG 035, 115 mm limestone (1800 kg/m3)	875	120
SSL-8	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm rockwool WLG 035, 115 mm brick (1600 kg/m3)	1294	133
SSL-9	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 140 mm wood fibre insulation 040, 115 mm limestone (1800 kg/m3)	667	101
SSL-10	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 140 mm wood fibre insulation 040, 115 mm brick (1600 kg/m3)	1086	114
SSL-11	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 180 mm wood fibre insulation 040, 115 mm limestone (1800 kg/m3)	667	101
SSL-12	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 180 mm wood fibre insulation 040, 115 mm brick (1600 kg/m3)	1086	114
SSL-13	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm eps WLG 032, 115 mm limestone (1800 kg/m3)	778	108
SSL-14	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm eps WLG 032, 115 mm brick (1600 kg/m3)	1197	121
SSL-15	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm eps WLG 032, 115 mm limestone (1800 kg/m3)	814	111
SSL-16	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 160 mm eps WLG 032, 115 mm brick (1600 kg/m3)	1234	124
SSL-17	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 100 mm poly urethan 024, 115 mm limestone (1800 kg/m3)	927	114
SSL-18	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 100 mm poly urethan 024, 115 mm brick (1600 kg/m3)	1346	127
SSL-19	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm poly urethan 024, 115 mm limestone (1800 kg/m3)	979	116
SSL-20	15 mm lime cement render, 175 mm limestone (1800 kg/m3), 120 mm poly urethan 024, 115 mm brick (1600 kg/m3)	1398	129
SSL-21	15 mm lime cement render, 175 mm brick, 100 mm glasswool WLG 032, 115 mm limestone	1175	111
SSL-22	15 mm lime cement render, 175 mm brick, 100 mm glasswool WLG 032, 115 mm brick	1615	125

Short name	Construction	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./ sqm)
SSL-23	15 mm lime cement render, 175 mm brick, 120 mm glasswool WLG 032, 115 mm limestone	1192	112
SSL-24	15 mm lime cement render, 175 mm brick, 120 mm glasswool WLG 032, 115 mm brick	1632	126
SSL-25	15 mm lime cement render, 175 mm brick, 100 mm rockwool WLG 035, 115 mm limestone	1218	117
SSL-26	15 mm lime cement render, 175 mm brick, 100 mm rockwool WLG 035, 115 mm brick	1658	132
SSL-27	15 mm lime cement render, 175 mm brick, 120 mm rockwool WLG 035, 115 mm limestone	1243	120
SSL-28	15 mm lime cement render, 175 mm brick, 120 mm rockwool WLG 035, 115 mm brick	1684	134
SSL-29	15 mm lime cement render, 175 mm brick, 140 mm wood fibre insulation 040, 115 mm limestone	1087	105
SSL-30	15 mm lime cement render, 175 mm brick, 140 mm wood fibre insulation 040, 115 mm brick	1528	120
SSL-31	15 mm lime cement render, 175 mm brick, 180 mm wood fibre insulation 040, 115 mm limestone	1087	105
SSL-32	15 mm lime cement render, 175 mm brick, 180 mm wood fibre insulation 040, 115 mm brick	1527	120
SSL-33	15 mm lime cement render, 175 mm brick, 100 mm eps WLG 032, 115 mm limestone	1250	116
SSL-34	15 mm lime cement render, 175 mm brick, 100 mm eps WLG 032, 115 mm brick	1690	130
SSL-35	15 mm lime cement render, 175 mm brick, 120 mm eps WLG 032, 115 mm limestone	1282	118
SSL-36	15 mm lime cement render, 175 mm brick, 120 mm eps WLG 032, 115 mm brick	1722	132
SSL-37	15 mm lime cement render, 175 mm brick, 100 mm poly urethan 024, 115 mm limestone	1347	118
SSL-38	15 mm lime cement render, 175 mm brick, 100 mm poly urethan 024, 115 mm brick	1787	132
SSL-39	15 mm lime cement render, 175 mm brick, 120 mm poly urethan 024, 115 mm limestone	1399	120
SSL-40	15 mm lime cement render, 175 mm brick, 120 mm poly urethan 024, 115 mm brick	1839	135
SSL-41	180 mm concrete, 120 mm glass wool WLG 032, 100 mm concrete	556	99
SSL-42	180 mm concrete, 160 mm glass wool WLG 032, 100 mm concrete	591	101
SSL-43	180 mm concrete, 120 mm eps WLG 032, 100 mm concrete	647	105
SSL-44	180 mm concrete, 160 mm eps WLG 032, 100 mm concrete	744	111
CF-45	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 1.2 kg Substructure wood , 30 mm Wood	318	58
CF-46	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 1.2 kg Substructure wood , 25 mm HPL	488	84

Short name	Construction	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./ sqm)
CF-47	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 2 kg Substructure Aluminium, 2 mm Aluminium	730	94
CF-48	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 2 kg Substructure Aluminium , 30 mm Ceramik cladding	1187	121
CF-49	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 2 kg Substructure Aluminium , 20 mm Fiber cement boards	729	99
CF-50	15 mm lime cement render 180 mm reinforced concrete, 120 mm glasswool WLG 032, 3 kg Substructure Aluminium , 30 mm Natural stone	1066	121
CF-51	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 1.2 kg Substructure wood , 30 mm Wood	369	65
CF-52	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 1.2 kg Substructure wood , 25 mm HPL	539	92
CF-53	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 2 kg Substructure Aluminium, 2 mm Aluminium	782	102
CF-54	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 2 kg Substructure Aluminium , 30 mm Ceramik cladding	1238	129
CF-55	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 2 kg Substructure Aluminium , 20 mm Fiber cement boards	781	107
CF-56	15 mm lime cement render 180 mm reinforced concrete, 120 mm rockwool WLG 032, 3 kg Substructure Aluminium , 30 mm Natural stone	1118	129
CF-57	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 1.2 kg Substructure wood , 30 mm Wood	213	51
CF-58	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 1.2 kg Substructure wood , 25 mm HPL	383	78
CF-59	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 2 kg Substructure Aluminium , 2 mm Aluminium	626	87
CF-60	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 2 kg Substructure Aluminium , 30 mm Ceramik cladding	1082	115
CF-61	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 2 kg Substructure Aluminium , 20 mm Fiber cement boards	625	93
CF-62	15 mm lime cement render 180 mm reinforced concrete, 140 mm wood fibre insulation 040, 3 kg Substructure Aluminium , 30 mm Natural stone	962	115
CF-63	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 1.2 kg Substructure wood , 30 mm Wood	408	64
CF-64	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 1.2 kg Substructure wood , 25 mm HPL	578	90
CF-65	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 2 kg Substructure Aluminium , 2 mm Aluminium	821	100
CF-66	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 2 kg Substructure Aluminium , 30 mm Ceramik cladding	1277	127
CF-67	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 2 kg Substructure Aluminium , 20 mm Fiber cement boards	820	105
CF-68	15 mm lime cement render 180 mm reinforced concrete, 120 mm eps WLG 032, 3 kg Substructure Aluminium , 30 mm Natural stone	1157	127

Short name	Construction	Primary energy (MJ/sqm)	GWP (kg CO_2 eq./ sqm)
CF-69	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan, 1.2 kg Substructure wood , 30 mm Wood	430	68
CF-70	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan, 1.2 kg Substructure wood , 25 mm HPL	600	94
CF-71	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan, 2 kg Substructure Aluminium , 2 mm Aluminium	842	104
CF-72	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan, 2 kg Substructure Aluminium , 30 mm Ceramik cladding	1299	131
CF-73	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan, 2 kg Substructure Aluminium , 20 mm Fiber cement boards	841	109
CF-74	15 mm lime cement render 180 mm reinforced concrete, 100 mm poly urethan , 3 kg Substructure Aluminium , 30 mm Natural stone	1178	131
WF mo-no-75	15 mm lime cement render 360 mm aerted concrete, 30 mm render	668	90
WF mo-no-76	15 mm lime cement render 360 mm poroton, 30 mm render	823	114
WF mul-ti-77	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 120 mm glasswool WLG 032 , 30 mm render	564	79
WF mul-ti-78	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 160 mm glasswool WLG 032 , 30 mm render	687	87
WF mul-ti-79	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 120 mm rockwool WLG 035 , 30 mm render	615	87
WF mul-ti-80	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 160 mm rockwool WLG 035 , 30 mm render	667	91
WF mul-ti-81	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 140 mm wood fibre insulation 040 , 30 mm render	459	72
WF mul-ti-82	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 180 mm wood fibre insulation 040 , 30 mm render	459	72
WF mul-ti-83	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 120 mm eps WLG 032 , 30 mm render	754	82
WF mul-ti-84	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 160 mm eps WLG 032 , 30 mm render	852	85
WF mul-ti-85	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 100 mm poly urethan 024 , 30 mm render	719	85
WF mul-ti-86	15 mm lime cement render 175 mm limestone (1800 kg/m3) , 120 mm poly urethan 024 , 30 mm render	771	87

Table 44

Table for SSL.Supplement to Figure 194

List of Abbreviations

AP	Acidification Potential
ADP	Abiotic resource depletion potential
BIM	Building information modelling
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (engl.: German Ministry for traffic, construction and urban planning)
BREEAM	Building Research Establishment Environmental Assessment Method
cbm	Cubic meter
CED	Cumulative energy demand
CF	Cold façade
CW	Curtain wall
C2C	Cradle-to-Cradle
DGNB	Deutsche Gesellschaft Nachhaltiges Bauen (engl.: German Green Building Council)
EE	Embodied energy
EEP	Ecological Evaluation Profile
EIFS	Exterior insulation facade system
EPD	Environmental Product Declaration
EoL	End of Life
EP	Eutrophication Potential
FRP	Fibre reinforced plastic
FSC	Forest Stewardship Council
GWP	Global warming potential
HVAC	Heating ventilating air-conditioning
ICE	Inventory of carbon and energy
IPP	Integrated Product Policy
kg	Kilogram
LCA	Life cycle assessment
LCI	Life cycle inventory
LEED	Leadership in Energy and Environmental Design
MJ	Mega Joule
MRPI	Milieurelevante Productinformatie
ODP	Ozone Depletion Potential
OE	Operational energy
OSB	Oriented straw board
PAT	Performance Assessment Tool

POCP	Photochemical Ozone Creation Potential
PWF	Punctured wall façade
SIA	Schweizerischer Ingenieur- und Architektenverein (engl.: Swiss engineer and architects association)
SNARC	Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt SNARC (engl.: methodology for the evaluation of sustainability in architectural projects in an environmental context)
sqm	Square meter
SSL	Solid second layer
WF mono	Warm facade - mono layer
WF mulit	Warm facade - multi layer

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Imagery credits

I am especially greatful for the student's contribution. All images of the office buildings and the facades have been drawn by the students at the Detmolder Schule. Rebbecca Bach was kind enough to improve the drawing quality were needed.

All other images with no note given I provided my self, either illustrations or photographies.

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Summary per part

Part 1 – Background and motivation

Building industry impacts natural cycles and has potential for optimization. While impariment on nature reached a new dimension already some three centuries ago the building industry started to realize the dependency in the second half of the 20th century.

With LCA method all life cycle phases can be monitored and the environmental impact of each can be quantified.

The energy consuming and emission generating components in the building context can be distinguished in the groups transport, operation and material. An architect deals with the operational energy and the building substance. With nearly zero (not renewable) energy for operation an ecological building is defined by the building substance.

Part 2 – Evaluation of the building substance

While the building structure accounts for the highest share of embodied energy and GWP, the facade offers high potential for optimisation.

This potential is even higher when considering a long (50-100 years) usage life span; the buidling structure remains wihle the (non load-bearing) facade is object to exchange cycles.

Part 3 – Findings and their integration into the architectural planning process

The city is a depot for resources and we (it involves a variety of professions) need to learn how to organize it.

Modularity, light construction, the use of renewable materials and mono materials are also interesting fields which are looked at from a different point of view. They are relevant for all building elements. Although they are not initially invented to reduce the ecological impact of the built environment, they show potential to do so.

The facade is the essential parameter for the resource-efficiency of a building as it is exchanged and binds relevant amounts of material. Impact can be made within this element due to its high variation in construction and materialization

The material cycles need to become smaller and the gaps – landfill or downcycling- need to be closed. The use of resources will increasingly develop impact on architecture and by that resource efficiency is a successor of energy efficiency.

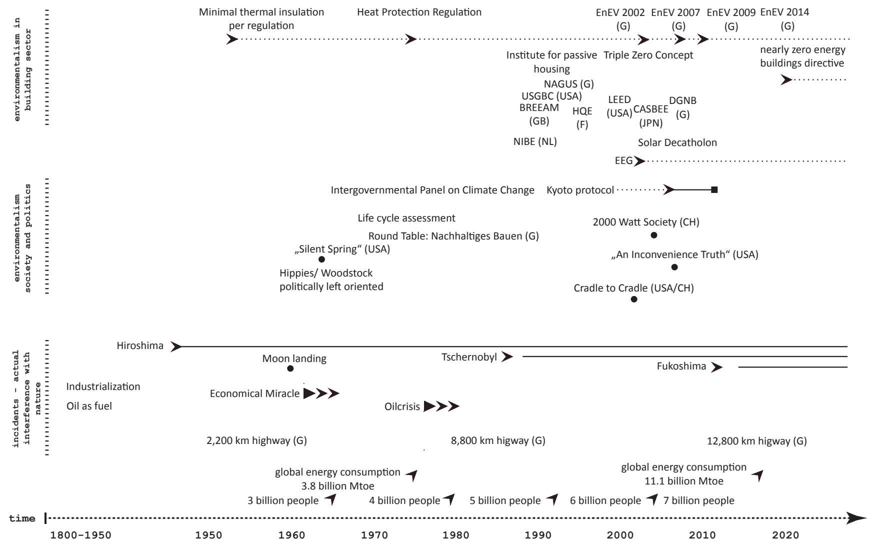
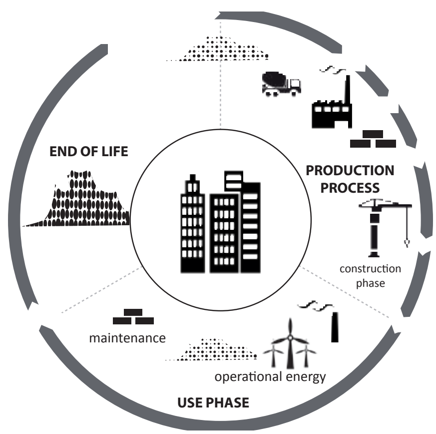


Figure 219



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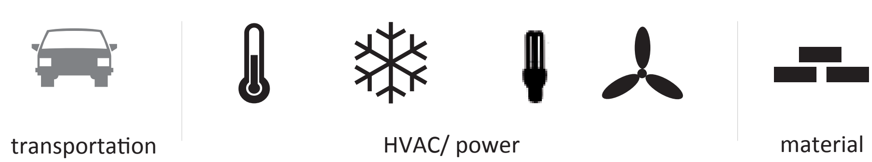

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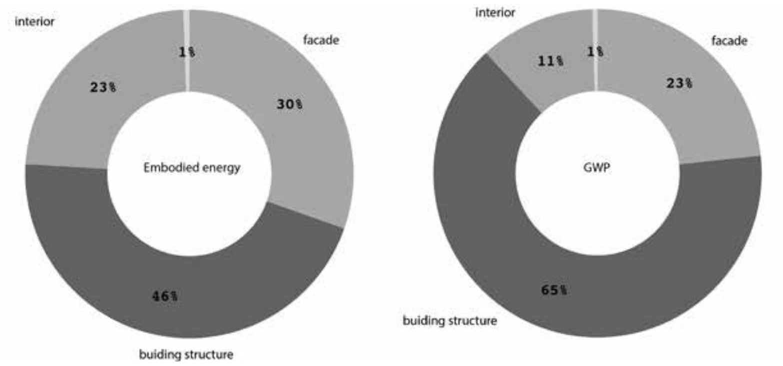

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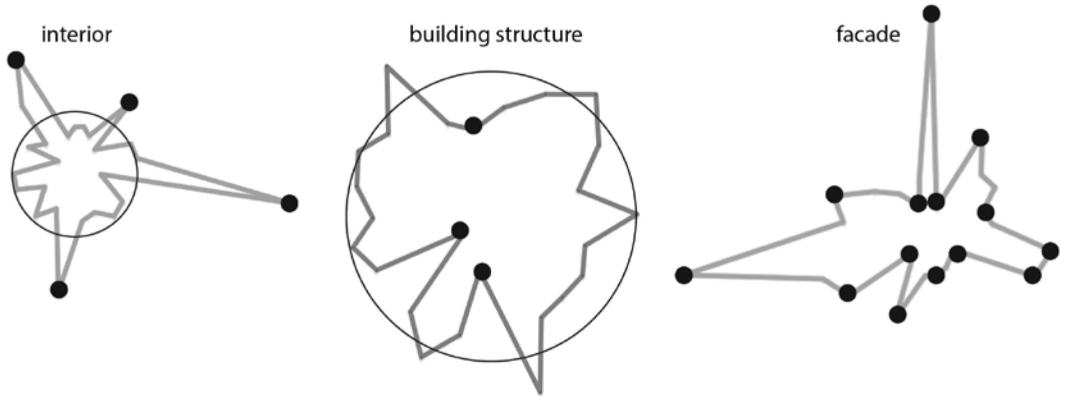

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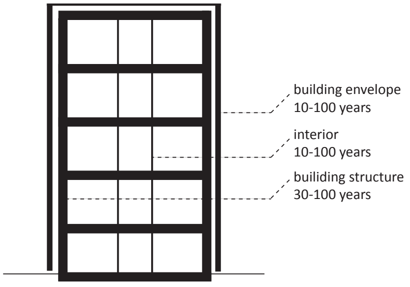

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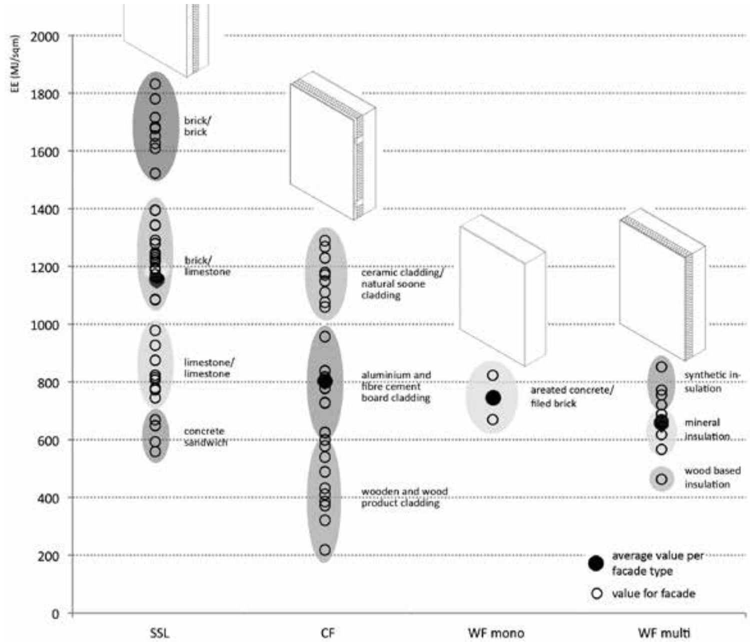

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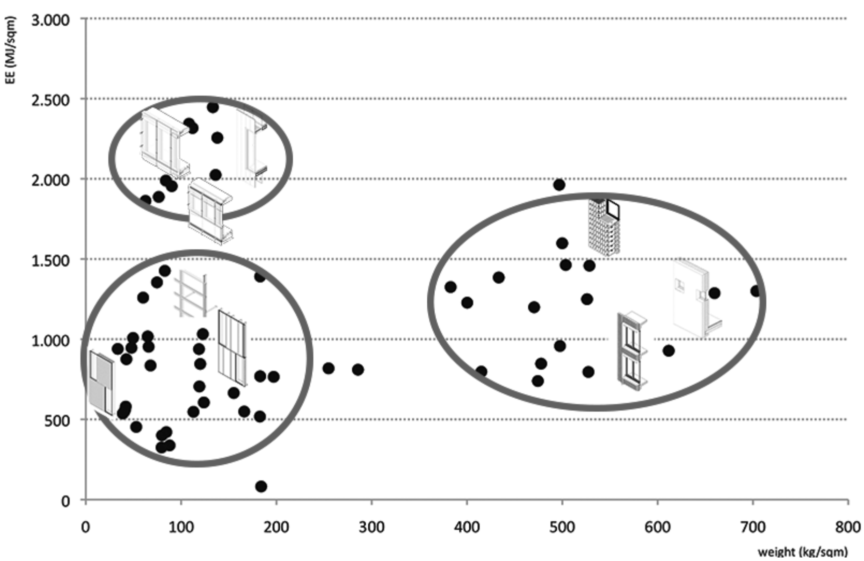

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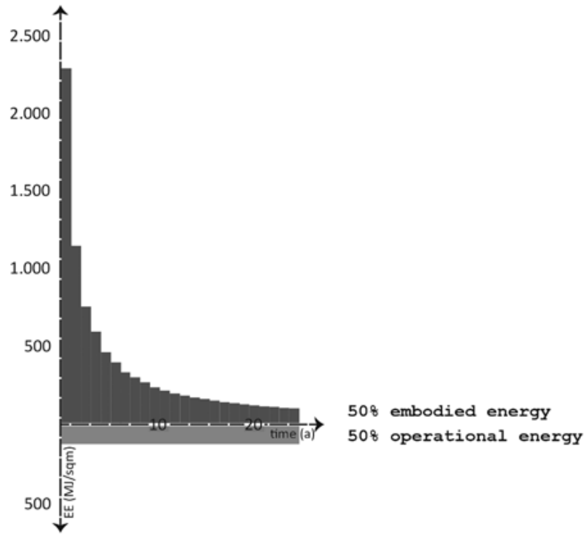

Figure 227

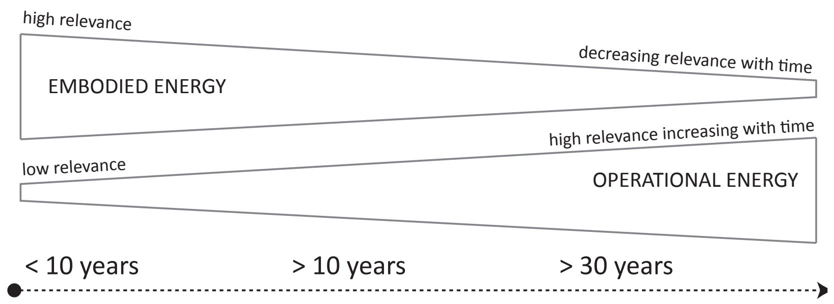

Figure 228

Summary of chapters

LCA is widely accepted as method to trace the ecological impact of services or product. It includes very detailed information about processes which leads to complex data management. (Millet, Bistagnino et. al., 2007) In the last 20 years a range of databases for building material became easily available and is now increasingly relevant in the architectural practice. Architects are more and more familiar with the concept of LCA and accept its significance but not able to include it the planning process. Educated planners can use databases and LCA software to assess the impact of different scenarios by an ecological comparison. This requires specification and offers a niche for new specialists. Like a climate engineer or an acoustic professional the LCA expert can guide architects and planners through the decision making process. LCA is new profession that the architect does not necessarily have to be capable off but he needs to understands basic concept and apply them in different stages.

Chapter 2 – What is the motivation to reduce the ecological impact caused by building construction?

Mankind interferes with nature and changes its constitution. Both natural cycles and mankind's contribution affects the global condition on different levels. Over the last three hundred years the impairment exceeded a dimension that a significant number of scientists constitute as potentially harmful for the human species. Non-renewable resources decrease and become more difficult to access.

Having a big part in this, it is the responsibility of the building sector to optimise its share of the environmental impact. Looking at the field of architecture, potential can be found in the optimisation of performance energy and the building substance.

The EPBD limits performance energy to a minimum; from 2021 onward only nearly zero energy buildings will be allowed. The building substance is already an important factor for the impairment of nature, and will develop an even higher relevance.
With this, the construction method and material choice defines the dimension of environmental impact. The consideration of ecologic parameters in the planning process contributes to conservative consumption of resources; it helps to reach political climate goals, and stimulates an efficient application aiming at the full exploitation of a material's potential.

Building certificates label the level of sustainability after planning decisions are made. They stimulate the sensitivity for sustainable buildings but do not directly affect the design process and thereby related impact. The essential stage concerning ecological impact is the architectural design phase. Here, the level of impairment can be controlled.

Knowledge is available but has not been integrated into the process decisive for the level of impact. The building products industry and research institutes prepared information that now has to find application in the architectural planning process. The complex matter of LCA for building materials has to remain valid and has to meet the requirements of the design process.

The motivation for this thesis can be summarised as follows:

- Mankind influences nature and influences climatic phenomena.
- Society is interested in environmentalism.
- The building sector has potential to reduce the impact mankind has on nature.
- The amount of resources used for the building substance could be optimised, and reduce the volume of global waste.
- Knowledge is available but is not linked to the decision making process.

Chapter 3 – What is an adequate methodology to rate ecological impact? Where In the building industry can the LCA methodology be applied?

The complex nature of ecological information has to be simplified in order to be integrated into the architectural planning process. In the building context, three levels can be distinguished; material, building element and building. The complexity increases with size of the investigated element. All three levels are important in order to gain a general understanding of the functionality, and furthermore to be able to identify the relevant parameters in the building context.

In order to understand the interdependencies between material and ecological impairment, the next step should be examining the smallest unit. Chapter 4 introduces the parameters of an ecological material evaluation in order to provide fundamental comprehension.

Chapter 4 – What is an adequate method to rate the ecological impact of the building material? What parameters are suitable for the ecological evaluation of the building substance? How can the parameters be communicated?

The ecological evaluation of building material can be done within a framework of eight parameters. These can be expressed by a table, as well as a descriptive part. The two different angles of this evaluation are assessing the information on material and on material group level.

On the material level, evaluation Goal, data source and system border are presented in both forms; table and description. The information is displayed in the EEP, while the background is explained in a descriptive part. The type of data, the reference unit, the life cycle phases, the duration and the indicator are expressed within the table. The relevant data, the calculation method and tool and the evaluation goal require more background information and are explained in a separate descriptive part.

Chapter 5 – How can the ecological impact of materials be categorised?

Mineral material embodies the least amount of EE per mass and volume. This is followed by the wood based products. For this second group, the GWP values exceed all other groups. Insulation material can be distinguished in mineral based material with lower values and synthetic material with 2-3 times higher values. These are similar to the range of synthetic material. Metals show the highest values for both EE and GWP:

Mineral material has a very long duration. However, recycling on the same quality level is rarely done. Most of the time, the mixed rubble is used for other purposes than mineral materials production. Wood based products have the least problematic End of life scenario. Though the reuse rate is relatively low (in comparison to metals, for example), the material or energetic recycling delivers relevant gains. Synthetic material can be burnt very efficiently when sorted according to type of plastic. Metals have the best reuse and recycling potential. They can be reused on a big scale, and re-melted and reintroduced to the production process. The insulation material behaves according to its material group. When synthetic insulation material can be separated without any permanent connection, the calorific value delivers a relevant energetic gain. Mineral insulation on the other hand can only be put in landfill. If it is installed without any permanent connection it has potential for material recycling.

Material mixture with a permanent connection decreases the recycling potential. EIFS is an example for that. No recycling method is yet found.

LCA works mass-based. The heavier the material, the more energy it will bind.

Material information management increases the potential for reuse and material recycling.

Function and considered time influence the evaluation and play a role in connection of LCA information and the architectural planning process.

Chapter 6 – What is an adequate method to rate the ecological impact of the building substance? What parameters are suitable for the ecological evaluation of the building substance? How can the parameters be communicated?

Ecological information on building substance level can be communicated by categories similar to the material evaluation. The information can be of a descriptive nature as well as being presented in a table. Characterising the case studies is equivalent to the description of the material group and its production process. Here, the building features need to be communicated in order to relate these to environmental impact.

Chapter 7 – What are the characteristics of embodied energy in the building substance? Which building elements have the highest potential to improve the environmental impact? How is embodied energy distributed over the building elements for office buildings?

This chapter discussed the characteristics of embodied energy in the buildings substance according to the following aspects:

- Value range and its causes
- Similarity to other studies
- Distribution of material groups
- Distribution of building elements

This was followed by the investigation regarding the optimisation potential of one building element by evaluating the value distribution regarding the level of heterogeneity.

The range of EE starts with 1,371 MJ/sqm to 4,029 MJ/sqm and GWP varies from 27 to 377 kg CO_2 eq./sqm. The average EE is 2,354 MJ/sqm and the average GWP 211 kg CO_2 kg eq. Values above the average result from a massive concrete building envelope or a high metal and glass share.

Similarities to other study can be found, and it has been stated that the values vary within a plausible range.

The building structure shows the highest percentage and relative homogeneous values. The interior walls are less relevant and show optimisation potential by the choice of construction. The façade shows both, significant percentages and optimisation potential. It can be deduced that the highest optimisation potential is offered by the façade. The interdependencies of façade types and their ecological dimension need to be further investigated. It needs to be specified how the characteristics, the material choice and the construction method affect the ecological dimension.

The general categories for façade investigation will be discussed in chapter 8, and chapter 9 will show an evaluation of 60 façades.

Chapter 8 – What is an adequate method to rate the ecological impact of the façades? What parameters are suitable for the ecological evaluation of façades? How can the parameters be communicated?

The environmental impact of façades can be assessed by LCA tools. Ecological information on façade level can be communicated by categories similar to the material and building evaluation. The information can have a descriptive nature or can be displayed in a table. This is equivalent to the description within the material group and its production process. In the façade evaluation the construction and material need to be communicated in order to relate these to the extent of the total environmental impact.

Chapter 9 – What are the characteristics of embodied energy in façades? Does the type of façade define the environmental impact? How can embodied energy in façades be optimised?

Throughout the last sub-chapter, the relevance of different façade design aspects has been outlined.

It has been stated that the following parameters affect the ecological extent:

- Façade construction
- Façade deconstruction
- Opaque and transparent area
- Materialisation

Especially the second layer, transparent or solid, has a potential to improve the ecological performance as it adds a substantial amount of EE and GWP. Mono-layered façades show advantages compared to multi-layered façades.

The complex nature of façades is defined by their functional requirements. For an ecological evaluation both parts have to be considered. One façade solution cannot be judged over the other. Only similar façade variants can be discussed when one aspect is isolated. Like a high financial investment, EE can be perceived as a currency that expresses the value of a construction. For example, the high EE in a masonry construction can be perceived as potential that supports a maximum usage phase by prolonging its function.

Chapter 10 – How can the information about the embodied energy in the building context affect the design process? How can knowledge about embodied energy be translated into strategies for the design process?

Embodied energy and operational energy vary in relevance according the usage scenario. With time the operational energy increases while operational energy decreases. For short usage time span the opposite is true.

The findings from the evaluation can be integrated into the architectural planning process by strategies. These can be subdivided by planning stage (design phase, construction phase and materialization) and the usage time span. According to usage time span, the relevance of one strategy in- or decreases.

The nature of strategies is abstract and they need to be specified for each individual situation.

Chapter 11 – What perspective for applying the strategies can be drawn?

The city is a depot for resources and we (it involves a variety of professions) need to learn how to organize it. Architects will use already existing built substance for new construction and develop them so they fulfil current functions and are detachable in addition to it. Disassembly of building elements needs to be improved and constructions are required to be prepared for the phase after the first usage cycle. Information management is necessary on a city scale and for each building element in order to decrease the radius of materials. Using secondary material bears potential for all building elements, which offers a broad field of future research. (Potential of different materials installed in buildings/ detachable construction details of different building envelope types, floor types or interior walls.)

Modularity, light construction, the use of renewable materials and mono materials are also interesting fields which are looked at from a different point of view. They are relevant for all building elements. Although they are not initially invented to reduce the ecological impact of the built environment, they show potential to do so.

The facade is the essential parameter for the resource-efficiency of a building as it is exchanged and binds relevant amounts of material. Impact can be made within this element due to its high variation in construction and materialization

The material cycles need to become smaller and the gaps – landfill or downcycling- need to be closed. The use of resources will increasingly develop impact on architecture and by that, resource efficiency is a successor of energy efficiency.

Zusammenfassung

Ökobilanzierung ist als Methode zur Ermittlung des ökologischen Einflusses von Dienstleistungen oder Produkten weitgehend anerkannt. Ökobilanzdaten beinhalten detaillierte Informationen über Prozesse, die komplexes Datenmanagement erfordern (Millet, Bistagnino et. al., 2007). In den letzten 20 Jahren wurden Datenbanken für Gebäudematerialien zugänglich gemacht, wodurch die Methode zunehmend Relevanz in der Architektur erfuhr. Architekten sind immer mehr mit dem Konzept Ökobilanz vertraut und akzeptieren ihre Bedeutung. Sie sind jedoch nicht in der Lage diese in den Planungsprozess zu integrieren.

Fachplaner können Datenbanken und Ökobilanz-Software benutzen, um den Einfluss unterschiedlicher Szenarien durch einen ökologischen Vergleich zu bewerten. Dies erfordert Spezifikationen und eröffnet eine Planungsnische. Ähnlich einem Klima-Ingenieur oder Akustiker kann ein Ökobilanz-Experte Architekten und Planer während des Entscheidungsprozesses beraten. Ökobilanzen eröffnen eine neue Profession, deren Fachkenntnisse ein Architekt nicht unbedingt beherrschen muss, aber ein Grundlagenwissen ist sinnvoll um diese in unterschiedlichen Planungsphasen anzuwenden.

Kapitel 2 – Was ist die Motivation den Einfluss des Gebäudesektors auf die Umwelt zu reduzieren?

Die Menschheit beeinflusst die Natur und verändert ihre Konstitution. Sowohl natürliche Kreisläufe, als auch der menschliche Beitrag beeinflussen den globalen Zustand. In den letzten dreihundert Jahren überschritt der menschliche Einfluss eine Dimension, die eine bedeutende Anzahl von Wissenschaftlern als potentielle Gefährdung für die Menschheit ansieht. Nicht erneuerbare Ressourcen verringern sich und werden immer schwerer zugänglich.

Da der Bausektor einen wesentlichen Anteil daran hat, trägt er eine hohe Verantwortung und hat gleichsam ein großes Potenzial zur Optimierung dessen. Betrachtet man das Feld der Architektur, liegen Potenziale in der Optimierung der Betriebsenergie und der Gebäudesubstanz.

Der EPBD begrenzt die Betriebsenergie auf ein Minimum; ab 2021 werden nur noch Gebäude zugelassen, die nahezu keine Energie verbrauchen. Die Gebäudesubstanz ist bereits ein bedeutender Faktor für den Einfluss auf die Natur und wird noch eine größere Rolle einnehmen. Damit definiert die Konstruktionsmethode und die Materialwahl das Ausmaß der Umweltbeeinflussung. Die Berücksichtigung ökologischer Parameter im Planungsprozess trägt zum zurückhaltenden Konsum von Ressourcen bei. Dies hilft politische Klimaziele zu erreichen und regt eine effiziente Anwendung an, mit dem Ziel das Potenzial von Materialien voll auszuschöpfen.

Gebäudezertifikate deklarieren den Grad an Nachhaltigkeit, nachdem die Planung bereits abgeschlossen wurden. Sie regen die Sensibilität für nachhaltige Gebäude an, haben aber keinen direkten Einfluss auf den Entwurfsprozess und den damit verbundenen Umwelteinfluss. Die wichtigste Phase, in der der ökologische Einfluss definiert wird, ist die architektonische Entwurfsphase. In dieser kann das Maß des Einflusses kontrolliert werden.

Das Wissen ist verfügbar, es findet jedoch keine Anwendung als wesentlicher Planungsparameter. Die Bauprodukte-Industrie und Forschungsinstitute stellen Informationen zur Verfügung, welche jetzt in den architektonischen Planungsprozess integriert werden müssen. Die komplexe Bedeutung der Ökobilanz für Gebäudematerialien muss den Anforderungen des Entwurfsprozesses angepasst werden.

Die Motivation dieser Arbeit kann wie folgt zusammengefasst werden:

Die Menschheit beeinflusst die Natur und klimatische Phänomene.
Die Gesellschaft ist an Umweltbewusstsein interessiert.
Der Bausektor hat Potenzial, den Einfluss der Menschheit auf die Natur zu reduzieren.
Die Menge an Ressourcen, die für die Gebäudesubstanz verwendet werden, kann optimiert werden und das Volumen des globalen Mülls reduzieren.
Wissen ist zugänglich, ist jedoch nicht mit dem Entscheidungsprozess verbunden.

Kapitel 3 – Was ist eine adäquate Methode, um ökologischen Einfluss zu bewerten? Wo findet Ökobilanzierung Anwendung in der Bau-Industrie?

Der komplexe Charakter der ökologischen Information muss vereinfacht werden, um in den architektonischen Planungsprozess integriert zu werden. Im Gebäudekontext können drei Ebenen unterschieden werden: Material, Gebäudeelement und Gebäude. Die Komplexität wächst mit der Größe der zu untersuchenden Elemente. Alle drei Ebenen sind wichtig, um ein generelles Verständnis der Wirkungsweise zu erlangen und um außerdem in der Lage zu sein, die relevanten Parameter im Gebäudekontext bestimmen zu können.

Um die Zusammenhänge zwischen Material und ökologischem Einfluss verstehen zu können, ist der nächste Schritt das Untersuchen der kleinsten Einheit, der Materialebene.

Kapitel 4 – Was ist eine adäquate Methode den ökologischen Einfluss von Gebäudematerialien zu bewerten? Welche Parameter sind zur ökologischen Auswertung der Gebäudesubstanz geeignet? Wie können diese Parameter vermittelt werden?

Die ökologische Auswertung von Gebäudematerialien kann mit acht Parametern beschrieben werden. Diese können durch eine Tabelle, sowie einen beschreibenden Teil dargestellt werden. Die beiden unterschiedlichen Perspektiven dieser Auswertung bewerten die Informationen zum einen bezogen auf das Material selbst, zum anderen in Materialgruppen.

Die Materialien werden anhand von Auswertungsziel, Datenquellen und Systemgrenzen sowohl als Tabelle, als auch durch eine Beschreibung dargestellt. Die Informationen werden in einem ökologischen Auswertungsprofil (engl.: Ecological Evaluation Profil, EEP) aufgeführt, während die Beschreibung den Hintergrund erklärt. Der Datentyp, die Referenzeinheit, die Lebenszyklusphasen, die Lebensdauer und der Indikator werden in der Tabelle aufgeführt. Die relevanten Daten, die Kalkulationsmethode, das Kalkulationswerkzeug und das Auswertungsziel benötigen mehr Hintergrundinformationen und werden in einem separaten beschreibenden Teil behandelt.

Kapitel 5 – Wie kann der ökologische Einfluss von Materialien kategorisiert werden?

Mineralische Materialien binden den geringsten Anteil von Graue Energie bezogen auf Masse und Volumen, gefolgt von Holzprodukten. Dämmstoffe können in mineralische Materialien mit geringeren Werten und synthetische mit zwei- bis dreimal so hohen Werten unterschieden werden. Letztere sind dann im Bereich der

Kunststoffe. Metalle haben die höchsten Werte in beiden Kategorien, Grauer Energie und Treibhauspotenzial.

Mineralische Materialien haben eine lange Lebensdauer, jedoch wird Recycling auf gleichem Qualitätslevel selten durchgeführt. In der Regel wird der vermischte Bauschutt zu anderen Zwecken als zur Produktion von mineralischem Material genutzt. Holzprodukte haben das unproblematischste ‚End of Life' Szenario. Obwohl die Wiedernutzungs-Rate relativ gering ist (z.B. im Vergleich zu Metallen), liefert das materielle oder energetische recyceln relevante Gewinne. Synthetische Materialien können sehr effizient verbrannt werden, wenn sie nach Plastiktyp sortiert wurden. Metalle zeigen das höchste Wiedernutzungs- und Recyclingpotenzial. Sie können in großem Umfang weiter und wiedergenutzt, eingeschmolzen und in den Produktionsprozess eingeführt werden. Wenn synthetisches Dämmmaterial ohne permanente Verbindung getrennt werden kann, bietet der Heizwert einen relevanten energetischen Gewinn. Mineralische Dämmung andererseits kann nur noch auf einer Deponie untergebracht werden. Wenn es ohne eine permanente Verbindung ausgeführt wurde, hat es das Potenzial zum materiellen Recycling.

Materialgemische mit permanenter Verbindung verringern das Recycling Potenzial. Ein Beispiel dafür sind Wärmedämmverbundsysteme. Eine überzeugende Recycling Methode ist noch zu entwickeln.

Ökobilanzen funktionieren massebasierend. Je schwerer das Material, desto mehr Energie bindet es.

Materialinformations-Management verbessert das Potenzial zur Wiedernutzung und zum Material-Recycling.

Funktion und voraussichtliche Dauer sind relevant für die Auswertung der Ökobilanzen. Diese Parameter spielen eine wichtige Rolle für den Planungsprozess.

Kapitel 6 – Was ist eine adäquate Methode, um den ökologischen Einfluss von Gebäudesubstanz zu bewerten? Welche Parameter sind zur ökologischen Auswertung der Gebäudesubstanz geeignet? Wie können diese Parameter vermittelt werden?

Ökologische Informationen zur Gebäudesubstanz können durch ähnliche Kategorien wie zur Materialauswertung charakterisiert werden. Die Informationen können beschreibend ausgeführt werden, genauso wie in einer Tabelle dargestellt werden.

Die Übersicht der Fallstudien ist äquivalent zur Materialgruppenbeschreibung. Für die Gebäudesubstanz müssen die Funktionen dargestellt werden, um diese mit dem ökologischen Einfluss in Beziehung zu bringen.

Kapitel 7 – Wie kann graue Energie innerhalb der Gebäudesubstanz charakterisiert werden? Welche Gebäudeelemente haben das größte Potenzial, um den ökologischen Einfluss zu verbessern? Wie ist der Energieinhalt über die Gebäudeelemente eines Bürogebäudes verteilt?

Graue Energie in der Gebäudesubtanz wurde in diesem Kapitel unter folgenden Aspekten diskutiert:

- Wertespektrum und seine Ursachen
- Ähnlichkeit zu anderen Studien
- Verteilung der Materialgruppen
- Verteilung der Gebäudeelemente
- Heterogenität der Indikatoren
- Optimierungspotenzial

Die wesentlichen Ergebnisse dessen:

Das Spektrum des Energieinhalts geht von 1,371 MJ/m² bis 4,029 MJ/m² und das Treibhauspotenzial variiert von 27 bis 377 kgCO2ä/m². Die durchschnittliche graue Energie beträgt 2,354 MJ/m² und das durchschnittliche Treibhauspotenzial liegt bei 211 kgCO2ä/m². Werte oberhalb des Durchschnitts resultieren aus einer massiven Gebäudehülle aus Beton oder hohen Metall und Glas Anteilen.

Das Tragwerk des Gebäudes weist die höchstens prozentualen Anteile auf und zeigt relativ homogene Werte. Die Innenwände sind weniger relevant und haben Potenzial durch die Wahl ihrer Konstruktion (Holzständerwerk, Metallrahmen, Glaswände mit Aluminiumprofilen zeigen die schlechtesten Werte). Die Fassade weist beides auf, einen signifikanten prozentualen Anteil und Potenzial zur Optimierung. Es lässt sich schlussfolgern, dass hier das größte Optimierungspotenzial liegt. Die Wechselwirkungen zwischen Fassadentypologien und deren ökologischen Dimension müssen weiter untersucht werden. Es muss bestimmt werden, wie die Beschaffenheit, die Materialwahl und die Konstruktionsmethode die ökologische Dimension beeinflussen.

Kapitel 8 – Was ist eine adäquate Methode, um den ökologischen Einfluss von Fassaden zu bewerten? Welche Parameter sind zur ökologischen Auswertung von Fassaden geeignet? Wie können diese Parameter vermittelt werden?

Der Umwelt Einfluss der Gebäudesubstanz von Fassaden kann mit Hilfe der Ökobilanzierung beurteilt werden. Ökologische Informationen zu Fassaden können mit Kategorien, ähnlich denen der zur Auswertung von Material und Gebäude genutzten Parameter, vermittelt werden (EEP). Diese Informationen können in Form von Beschreibung oder in einer Tabelle aufgeführt werden. Bei der Fassadenauswertung müssen Informationen über die Konstruktion und das Material mitgeliefert werden, um diese mit dem Umfang des gesamten Umwelteinflusses in Beziehung zu bringen.

Kapitel 9 – Wie kann graue Energie in der Gebäudesubstanz von Fassaden charakterisiert werden? Definiert der Fassadentyp den Umwelteinfluss? Wie kann der Energieinhalt in Fassaden optimiert werden?

In diesem Kapitel wurde festgestellt, dass die folgenden Parameter den ökologischen Einfluss prägen:

- Fassadenkonstruktion
- Fassaden Dekonstruktion
- Opake und transparente Anteile
- Materialität

Vor allem die zweite Schicht, transparent oder massiv, beinhaltet das Potenzial die ökologischen Leistungen zu verbessern, indem es eine erhebliche Menge an Energieinhalt und Treibhauspotenzial hinzufügt. Einschichtige Fassaden weisen Vorteile gegenüber mehrschichtigen Fassaden auf.

Die komplexe Natur der Fassaden wird durch ihre funktionalen Anforderungen definiert. Für eine ökologische Auswertung müssen beide, Funktionalität und ökologischer Einfluss, berücksichtigt werden. Nur funktional ähnliche Typen können verglichen werden. Genauso wie eine hohe finanzielle Investition kann der Energieinhalt als eine Währung gesehen werden, die den Wert einer Konstruktion ausdrückt. Zum Beispiel kann der hohe Energieinhalt in einer Mauerwerkskonstruktion als Potenzial, dass die maximale Nutzungsphase durch die Verlängerung seiner Funktion unterstützt, angesehen werden.

Kapitel 10 – Wie können die Erkenntnisse zur grauen Energie den Entwurfsprozess beeinflussen? Wie kann das Wissen über den Energieinhalt in Entwurfsstrategien umgesetzt werden?

Graue Energie und Betriebsenergie verteilen sich unterschiedlich abhängig vom Nutzungs-Szenario. Mit zunehmender Zeit steigt die Betriebsenergie, während die graue Energie sinkt. Für kurze Nutzungszeitspannen ist das Gegenteil der Fall.

Die Ergebnisse der Auswertung können durch Strategien in den architektonischen Planungsprozess integriert werden. Diese können in die verschiedenen Planungsphasen (Entwurf, Konstruktion und Materialisierung) und den Nutzungszeitsraum unterteilt werden. Im Bezug auf die Nutzungszeitspanne steigt oder sinkt die Relevanz einer Strategie. Der Charakter der Strategien ist abstrakt und muss für jede individuelle Situation spezifiziert werden.

Kapitel 11 – Welche Perspektiven ergeben sich aus der Anwendung der Strategien?

Die Stadt ist ein Rohstofflager und wir (zahlreiche Professionen sind angesprochen) müssen lernen dieses zu verwalten. Architekten werden sich stärker als vorher mit bestehender Gebäudesubstanz auseinandersetzen und prüfen, ob diese sich zur Verwendung von Bauteilen nutzen lassen. Dabei müssen diese den technischen Standard erfüllen und zusätzlich rückbaubar sein. Die Demontage von Bauteilen muss optimiert (effizienter und damit günstiger) werden und neue Bauteile müssen die Phase ihrer Nutzung mit vorbereiten.

Informationsmanagement ist auf städtischer Ebene, sowie bezogen auf ein Gebäude, notwendig mit dem Ziel den Materialradius zu verringern. Sekundäre Rohstoffe zu verwenden bietet Potenzial für alle Bauteile. Damit eröffnet sich ein breites Forschungsfeld (z.B. Potenzial eingebauter Materialien, zerstörungsfreier Rückbau im Detail bezogen auf Gebäudehülle, Fußbodenaufbauten oder Innenräume).

Modularität, Leichtbau, der Einsatz erneuerbarer Energien oder Monomaterialien sind bekannte Ansätze, erfahren aber aus ökologischer und auch nachhaltiger Perspektive eine neue Relevanz. Diese Ansätze können für alle Bauteile eine Anwendung finden. Der Fassade kommt eine besondere Bedeutung zu, da sie über eine lange Nutzungszeit ausgetauscht wird und vergleichsweise hohe Materialmengen bindet. Durch die unterschiedlichen Gestaltungsmöglichkeiten in Konstruktion und Materialität variiert die Umweltbeeinflussung stärker als in anderen Bereichen.

Der Materialkreislauf muss kleiner und die Lücken wie Deponien oder Downcycling müssen geschlossen werden. Rohstoffnutzung wird die Architektur als nächstes großes Thema beeinflussen und Rohstoffeffizienz entwickelt sich zum Nachfolger von Energieeffizienz.

Samenvatting

Life Cycle Assessment (LCA)wordt algemeen aanvaard als methode om de ecologische impact van diensten of producten vast te stellen. LCA-data bevatten zeer gedetailleerde informatie over de processen die ervoor zorgen dat een complex datamanagement is vereist (Millet, Bistagnino et. Al., 2007). In de laatste 20 jaar is er een scala aan databases voor bouwmaterialen eenvoudig toegankelijk gemaakt waardoor het nu steeds relevanter geworden is voor de architectuur. Architecten zijn meer en meer vertrouwd met het concept van LCA en erkennen het belang ervan,echter zijn ze niet in staat om deze te integreren in het planningsproces.

Opgeleide planners kunnen databases en LCA-software gebruiken om de impact van verschillende scenario's te evalueren door middel van een ecologische vergelijking. Dit vereist specificatie en biedt een niche voor nieuwe specialisten. Net als een klimaatingenieur of akoestisch professional kan een LCA deskundige architecten en planners adviseren tijdens het besluitvormingsproces . LCA's zijn een nieuw vakgebied die een architect zich niet per se volledig hoeft eigen te maken , maar hij moet de basis begrijpen om deze om te kunnen zetten in de verschillende stadia van de planning.

Hoofdstuk 2 – Wat is de motivatie om de door de bouwsector veroorzaakte ecologische impact te verminderen?

De mensheid heeft invloed op de natuur en verandert de grondbeginselen. Zowel natuurlijke cycli als ook de bijdrage van de mensheid beïnvloedt de wereldwijde staat op verschillende niveaus. In de afgelopen driehonderd jaar overschreed de menselijke impact een dimensie die een aanzienlijk aantal wetenschappers ziet als een potentiële bedreiging voor de mensheid. Niet-hernieuwbare grondstoffen worden alsmaar schaarser en worden steeds moeilijker te bereiken.

Aangezien de bouwsector hierin een grote rol heeft, is het de verantwoordelijkheid van de bouwsector om haar aandeel in de impact op het milieu te optimaliseren. Kijkend naar het vakgebied van de architectuur, ligt er potentie in de optimalisatie van de energieprestatie en de gebruikte bouwmaterialen.

De EPBD heeft het toegestane energieverbruik tot een minimum beperkt; vanaf 2021 zullen alleen bijna energieneutrale gebouwen worden toegestaan. De gebruikte bouwgrondstoffen is al een belangrijke factor in de impact op de natuur en gaat een steeds grotere rol spelen. De constructiemethode en de keuze voor het bouwmateriaal bepaalt de omvang van de impact op het milieu. Door rekening te houden met de ecologische parameters tijdens het planningsproces draagt dit bij aan spaarzaam verbruik van grondstoffen. Dit draagt bij aan het behalen van politieke klimaatdoelen en spoort aan tot het efficiënt toepassen en het volledig benutten van de gebruikte materialen.

Bouwcertificaten verklaren de mate van duurzaamheid nadat de planning reeds is afgerond. Ze stimuleren de bewustwording voor duurzame gebouwen, maar hebben geen directe invloed op het ontwerpproces en de bijbehorende invloed op het milieu. De belangrijkste fase waarin de impact op het milieu wordt gedefinieerd is de architectonische ontwerpfase. In deze fase kan de mate van invloed worden gecontroleerd.

De kennis is beschikbaar, maar is nog niet geïntegreerd in de processen die bepalend zijn voor de uiteindelijke mate van invloed. De bouwproducten industrie en onderzoeksinstituten geven informatie die nu in het architectonische planningsproces moet worden toegepast. De complexe materie van LCA met het oog op bouwmaterialen moet aansluiten bij de vereisten van het ontwerpproces.

De motivatie voor deze publicatie kan als volgt worden samengevat:

- De mensheid heeft invloed op de natuur en de klimatologische fenomenen.
- De samenleving is geïnteresseerd in bewust omgaan met het milieu.
- De bouwsector heeft het potentieel om de impact van de mens op de natuur te verminderen.
- De hoeveelheid middelen die worden gebruikt voor bouwmaterialen kunnen worden geoptimaliseerd en de grootte van de globale afval gereduceerd.
- Kennis is beschikbaar, maar wordt niet gekoppeld aan het besluitvormingsproces.

Hoofdstuk 3 – Wat is een geschikte methode om de milieueffecten te evalueren? Waar in de bouw kan de LCA-methodologie worden toegepast?

De complexiteit van de ecologische informatie moet worden vereenvoudigd om te worden geïntegreerd in het architectonische planningsproces. In de context van een gebouw kunnen drie niveaus worden onderscheiden; materiaal, bouwelementen en het gebouw. De complexiteit neemt toe met de grootte van het onderzochte element. Alle drie niveaus zijn belangrijk om een algemeen begrip van de werkingswijze te verkrijgen en om daarnaast de relevante parameters in de context van het gebouw te identificeren.

Om de relatie tussen materialen en milieueffecten te begrijpen, is de volgende stap het onderzoeken van de kleinste eenheid, op niveau van het materiaal.

Hoofdstuk 4 – Wat is een adequate methode om de ecologische impact van het bouwmateriaal te evalueren? Welke parameters zijn geschikt voor de ecologische evaluatie van de substantie van het gebouw? Hoe kunnen deze parameters worden gecommuniceerd?

De ecologische evaluatie van bouwmaterialen kan worden beschreven door acht parameters. Deze kunnen worden weergegeven door een tabel en een beschrijvend gedeelte. De twee verschillende perspectieven van deze evaluatie geven de gegevens enerzijds op basis van het materiaal zelf en daarnaast op basis van de materiaalgroepen.

De materialen worden middels een tabel op basis van evaluatiedoel, gegevensbronnen en systeemgrenzen weergegeven als ook door een begeleidende beschrijving.
De informatie wordt getoond in een Ecological Evaluation Profil (EEP), terwijl de achterliggende informatie wordt uitgelegd in een beschrijvend gedeelte. De soort gegevens, de referentie-eenheid, de fasen van de levenscyclus, de levensduur en de indicatoren worden weergegeven in de tabel.

De relevante gegevens, de berekeningsmethode en de manier van berekening en het specifieke doel ter evaluatie vereisen meer achtergrondinformatie en worden toegelicht in een apart beschrijvend deel.

Hoofdstuk 5 – Hoe kan de ecologische impact van materialen worden gecategoriseerd?

Minerale stoffen hebben het laagste aandeel qua benodigde productie-energie, gerelateerd aan massa en volume, gevolgd door houtproducten. Dit laatstgenoemde product overtreft daarnaast scores qua broeikaseffect ten opzichte van alle andere groepen. Isolatiemateriaal kan worden onderscheiden in mineraal materiaal met lagere waarden en synthetisch materiaal met twee tot drie keer hogere waarden. Laatst genoemde zijn vergelijkbaar met de reeks kunststof. Metalen geven de hoogste waarden voor zowel benodigde productie-energie als ook qua broeikaseffect.

Mineraal materiaal heeft een zeer lange duur. Echter, recycling op hetzelfde kwaliteitsniveau wordt maar zelden gedaan. In het algemeen zal het gemengde bouwafval worden gebruikt voor andere doeleinden dan de productie van mineraal materiaal. Houten producten hebben het minst problematische scenario aan het einde van de levensduur. Hoewel hergebruik relatief laag scoort (in vergelijking met metalen, bijvoorbeeld), levert hergebruik of energetisch recycling van het materiaal relevante winsten op. Synthetische materialen kunnen zeer efficiënt worden verbrand als ze zijn gesorteerd op soort kunststof. Metalen hebben het beste potentieel qua hergebruik. Ze kunnen namelijk op grote schaal worden hergebruikt, opnieuw gesmolten worden en zo opnieuw aan het productieproces worden toegevoegd. Als kunststof isolatiemateriaal kan worden gescheiden zonder permanente verbindingen levert de verwarmingswaarde een relevante energetische winst. Minerale isolatie daarentegen kan alleen naar een stortplaats worden gebracht. Als deze is echter zijn verbouwd zonder permanente verbinding heeft het wel potentieel voor recycling.

Materiaal mengsel met een vaste verbinding verlaagt het recycling potentieel. EIFS is hier een voorbeeld van. Een recycling methode is hiervoor nog niet ontwikkeld.

LCA werkt op basis van massa. Hoe zwaarder het materiaal, hoe meer energie het zal binden.

Materiaal- informatie management verbetert de mogelijkheden voor hergebruik en recycling van materiaal.

Zowel de functie als de verwachte levensduur zijn van invloed op de evaluatie en spelen een rol in het kader van LCA informatie en de architectonische planning.

Hoofdstuk 6 – Wat is een geschikte methode om de ecologische impact van de gebouwsubstantie te waarderen? Welke parameters zijn geschikt om de ecologische impact te evalueren? Hoe kunnen deze parameters worden gecommuniceerd?

Ecologische informatie over de gebouwsubstantie kan worden gecategoriseerd op een zelfde manier als die gebruikt wordt ter evaluatie van het materiaal. De informatie kan worden toegelicht en beschreven of in een tabel worden opgevoerd. Het overzicht van de case studies is hier gelijk aan de beschrijving van de materiaalgroepen. Met betrekking tot gebouwsubstantie moeten de eigenschappen van het gebouw worden weergegeven om te relateren aan de belasting op het milieu.

Hoofdstuk 7 – Hoe kan de 'embedded energy' van een gebouw worden gecategoriseerd? Welke bouwelementen hebben het hoogste potentieel om de invloed op het milieu te verbeteren? Hoe wordt 'embedded energy' verdeeld over de bouwelementen van kantoorgebouwen?

'Embedded energy' in de gebouwsubstantie werd besproken in dit hoofdstuk onder de volgende aspecten:

In dit hoofdstuk worden de kenmerken besproken van de 'embedded energy' in de gebouwsubstantie volgens de volgende aspecten:

- Waardebereik en de oorzaken
- Overeenkomsten met andere studies
- Verdeling van de materiaal groepen
- Verdeling van de bouwelementen
- Heterogeniteit indicatoren
- Optimalisatiepotentieel

Dit werd gevolgd door het onderzoek met betrekking tot de optimalisatie mogelijkheden van een bouwelement door het evalueren van de waarde distributie met betrekking tot heterogeniteit.

De belangrijkste resultaten hiervan zijn:

Het bereik van de EE begint met 1,371 MJ / m² tot 4.029 MJ / m² en GWP varieert tussen 27-377 kg CO 2 eq. / M². De gemiddelde EE is 2354 MJ / m² en de gemiddelde GWP 211 kg CO 2 kg eq. Waarden boven het gemiddelde zijn het resultaat van een massieve betonnen bouwschil of een hoog metaal- en glas aandeel.

Overeenkomsten met andere studies kan worden gevonden en er werd vastgesteld dat de waarden variëren binnen een plausibele range.

De structuur van het gebouw heeft de hoogste percentages en toont relatief homogene waarden. De binnenmuren zijn minder relevant en hebben potentieel door de keuze van hun constructie (houten constructie, metalen frame en glazen wanden met aluminium profielen tonen de slechtste waarden). De gevel heeft zowel een aanzienlijk percentage en het meeste optimalisatiepotentieel. Geconcludeerd kan worden dat het grootste potentieel voor optimalisatie daarom hier ligt. De interacties tussen de gevel typologieën en hun ecologische dimensie moeten verder worden onderzocht. Onderzocht moet worden hoe de eigenschappen, de materiaalkeuze en bouwmethode de ecologische dimensie beïnvloeden .

De algemene categorieën voor gevel onderzoek zal in hoofdstuk 8 worden besproken, en hoofdstuk 9 zal een evaluatie van 60 gevels weergeven.

Hoofdstuk 8 – Wat is een adequate methode om de invloed op het milieu van gevels te evalueren? Welke parameters zijn geschikt voor de ecologische evaluatie van gevels? Hoe kunnen deze parameters worden gecommuniceerd?

De invloed van gevels op het milieu kan worden beoordeeld middels LCA. Ecologische informatie op gevelniveau kan worden gecommuniceerd per categorie op gelijke wijze zoals ook gebruikt wordt ter evaluatie van materiaal en gebouwen (EEP). De informatie kan een beschrijvend karakter hebben of kunnen worden weergegeven in een tabel. Dit komt overeen met de beschrijving in de materiaalgroep en het productieproces. In de evaluatie van de gevelconstructie moet informatie over materiaal en constructie opgevoerd worden om het verband te kunnen leggen met de omvang van de totale milieubelasting.

Hoofdstuk 9 – Hoe kan de opgeslagen energie in de gevels van gebouwen worden gecategoriseerd? Definieert het type van de gevel de milieueffecten? Hoe kan de opgeslagen energie van gevels worden geoptimaliseerd?

In dit hoofdstuk werd vastgesteld dat de volgende parameters de invloed op het milieu beïnvloeden:

- Gevelconstructie
- Gevels deconstructie
- Ondoorzichtige en transparante onderdelen
- Materialiteit

Vooral de tweede laag, transparant of ondoorzichtig heeft het potentieel om de milieuprestaties aanzienlijk te verbeteren qua hoeveelheid energie-inhoud en broeikaseffect. Gevels van een enkele laag hebben voordelen ten opzichte van gevels met meerdere lagen.

De complexiteit van de gevels wordt bepaald door de functionele eisen. Voor een ecologische evaluatie moeten beide, functionaliteit en milieu-invloed, worden beschouwd. Enkel functioneel gelijkwaardige varianten kunnen worden vergeleken. Net als een bij grote financiële investering kan EE worden gezien als een valuta die de waarde van een constructie uitdrukt. Bijvoorbeeld kan de hoge EE van een metselwerk worden beschouwd als een potentieel dat de maximale gebruiksfase ondersteund door de uitbreiding van zijn functie.

Hoofdstuk 10 – Hoe kan de informatie over de opgeslagen energie van het gebouw van invloed zijn op het ontwerpproces? Hoe kan kennis over ‘embedded energy’ worden vertaald in strategieën voor het ontwerpproces?

Productie-energie en operationele energie variëren afhankelijk van het gebruiksscenario. Met toenemende tijd loopt de operationele energie toe, terwijl de opgeslagen energie afneemt. Voor kortstondig gebruik is het tegenovergestelde het geval.

De resultaten van de evaluatie kan in het architectonische planningsproces worden geïntegreerd middels strategieën. Deze kunnen worden onderverdeeld in de verschillende planning fasen (ontwerp, bouw en materialiteit) en de periode van gebruik. In termen van beoogde gebruiksperiode verhoogt of verlaagt de relevantie van een strategie. Het karakter van de strategieën is abstract en moet worden opgegeven voor elke individuele situatie.

Hoofdstuk 11 – Welke perspectieven vloeien voort uit de toepassing van de strategieën?

De stad is een bewaarplaats voor de middelen en wij (het gaat om een verscheidenheid van beroepen) moeten leren hoe we deze beheren. Architecten zullen in toenemende mate naar de bestaande bouw kijken om te beoordelen of hieruit nieuwe bouwonderdelen te verkrijgen zijn. De componenten moeten voldoen aan de technische standaard en bovendien ook weer afbreekbaar zijn. Demontage van componenten van gebouwen moet worden verbeterd (efficiënter en dus goedkoper) en constructies moeten worden voorbereid voor de fase na de eerste gebruikscyclus. Information Management is noodzakelijk op stadsniveau en voor elk bouwelement om de materiaalradius te verminderen. Het gebruik van secundaire materialen heeft potentieel voor alle bouwelementen, die hierdoor een breed gebied (potentieel van verschillende materialen in gebouwen, niet-destructieve demontage in detail gebaseerd op de bouwschil, vloerconstructies en interieur inrichting) voor toekomstig onderzoek biedt.

Modulariteit, lichtgewicht constructie, het gebruik van hernieuwbare energiebronnen en mono- materialen zijn bekende benaderingen die bezien vanuit een ecologisch gezichtspunt nieuwe relevantie krijgen. Deze benadering kan voor alle genoemde bouwaspecten worden toegepast. Hoewel ze in eerste instantie niet zijn uitgevonden om de ecologische impact van de gebouwde omgeving te reduceren tonen ze wel potentieel om dat te doen.

De gevel is van bijzonder belang qua resource-efficientie van een gebouw omdat zij voor een lange gebruiksperiode wordt vastgesteld en relatief veel verschillende materialen bindt. Door de uiteenlopende ontwerpmogelijkheden in constructie en materiaal varieert de invloed op het milieu op dit gebied sterker dan op andere gebieden.

De materiaalcyclus moeten kleiner worden en de verspilling, zoals bij een stortplaats of downcycling, moeten worden beperkt. Het gebruik van grondstoffen zal in toenemende mate het onderwerp worden binnen de architectuur en grondstof-efficiëntie ontwikkeld zich tot de opvolger van energie-efficiëntie.

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