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MASTER THESIS:

Life cycle assessment of sustainable residential building concepts

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Statutory declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material, which has been quoted either literally or by content from the used sources.

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Abstract

Buildings are one of the longest lasting objects in our society. Whilst they represent a shelter and a place for everyday living, they also have, during the different life phases, a significant impact on the environment. The thesis objective is the evaluation and comparison of different sustainable building concepts, such as the Passive House Standard, the Sun House concept and the Low-tech Building concept, embedded within the analysis of their Life Cycle performance.

The Life Cycle Assessment is based on EN 15978, DGNB-certification by ÖGNI in Austria and the database 'ÖKOBAUDAT'. The analysis was performed for the Viennese housing complex 'young corner' in Passive House Standard with about 8,500 m² gross floor area. The 10-floor-building was planned by 'Treberspurg & Partner Architekten' and completed in 2011. Based on this residential building, a scenario according to the Sun House concept and a further scenario according to the Low-tech Building concept were assessed. Furthermore, former building evaluations and Life Cycle Analyses from Koch (2007), König (2009), Ritter (2014) and Treberspurg (1999) were used as complementary sources for a holistic contemplation.

A central outcome of the conducted analysis was that all concepts range on a similar level for an aggregated interpretation of seven evaluated environmental impact indicators. Nevertheless, in a contrasting manner the concepts vary significantly, up to 33 % for individual environmental indicators and 38 % for particular life cycle phases.

In order to get a reference to conventional new buildings, a scenario representing the minimal requirements of the Austrian OIB directive 6 (2011) was investigated. On the other hand, referring towards a best case option, a scenario representing the combination of Passive House Standard and Sun House concept was analyzed. As the results show, both options represent the extremes. Whereas the optimized scenario 'Passive Sun House' gets an overall virtue of 14 %, the scenario OIB house performs 18 % worse compared to the major concepts. Summarizing it can be said, that this thesis points out differences but also strengths and weaknesses of five building concepts and relates them in a holistic manner.

Acknowledgement

Firstly, I would like to express my sincere appreciation to my first advisor Prof. Martin Treberspurg for giving me the opportunity of writing this thesis on his division and for the constructive cooperation during the last semester. Furthermore, I want to express my gratitude to DI Roman Smutny for the continuous support of my study and related research, for his patience, motivation and immense knowledge. Their guidance helped me through the research and writing of this thesis. I could not have imagined having better advisors and mentors for my Master study.

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1 Preliminaries

1.1 Personal motivation

Realizations of great developments were always, as the history demonstrates with democracy, gender equalization and abolition of apartheid, strongly influenced by people's acceptance. As long as people did not approve an idea, former profiteers kept on the common and known principles which brought them comfort in various conceivable ways. However, from the origin of an idea, until a level of broad consensus even decades can pass by. A telling example for this assertion is the progress of the "chimney sweep's apprentices":

During the 18th and 19th century in Britain it was very common to force young boys between the age of five and ten, and sometimes even girls, to sweep chimneys in areas where neither a sweep master nor a tool could be used. Many of them suffered from ailments like twisted spines and kneecaps, eye inflammations or respiratory illnesses. Furthermore, there are recorded instances where these children suffocated to death from inhaling the chimney dust or were killed from falling. Unfortunately, it took almost one century (1788 to 1875) from the first legal action to a rigorous abatement of such practices. Even the progress of turning out a general consensus in society took at least as long as the legal progress, without raised voices by the people we probably would still use children for this dangerous work (Price, 2013).

However, back to my addressed aspect from the beginning; acceptance is the crucial factor for great developments in a democratic society. This also counts for the imminent energy transition. Due to catastrophes like various oil spills (e.g. Gulf of Mexico in 2010) or nuclear accidents (e.g. Chernobyl in 1986 and Fukushima 2011) people became more aware of the impending danger of such technologies. In relation to this, during the last 20 years people and governments put as much effort into the sector of renewable energy as never before. These and similar aspects motivated me to go to university and learn more about sustainability and possible ways how such an energy transition can be implemented. At university and during different internships with an energy supplier and an energy consultation company I realized that this challenge cannot be solved by only considering the supplying side. Even enough photovoltaic-, wind-, biomass- and waterpower units would be installed to cope with the daily short time gap between energy supply and actual consumption respectively its fluctuations the problem of the long term gap between seasons will remain unsolved until affordable and reliable storage capacity is implemented. In contrast to the aspect of energy supply, I realized that especially energy efficiency actions provide an important contribution to the idea of the energy transition. As a consequence of the fact that the building sector respectively the act of conditioning them is consuming about 50 % of the total primary energy, it became obvious that this could be an interesting field for further investigation. My motivation was further pushed when I came in contact with a building structure analysis of the "Allgäu" (the most southern region in Germany) during my second internship. The result was that the average building standard has a heating demand of 170 kWh/(m^2.a). This is more than ten times of the upper limit of a 'Passive House'. In consequence, this means the energy demand for heating could be reduced by a factor of ten.

Nevertheless, another and maybe even more important factor than the efficiency potential comes with circumstance of acceptance respectively the people's willingness to realize a transition from conventional to a renewable energy based economy. For the undoubting fact, that the upcoming energy transition will decentralize the energy sector and force a bottom up movement, it also will require the people's eager involvement. Even this stadium of eager involvement has been sharpened by the above mentioned accidents; it has not reached the required level from my point of view. For further improvements the field of buildings can be a crucial element by increasing people's awareness. A good example for this was the development of photovoltaic installations during the last years in Germany. Even though it was highly subsidized by the government respectively by the taxpayers, the expansion of this technology conveyed to the people that the energy transition has already started and they are a part of it. For the fact that people are spending around 90 % of their lifetime in buildings, it can be said that buildings are the center of everybody's life. Hence, for me the following question arose: What would be easier to increase people's awareness and acceptance regarding to an energy transition instead of their houses? My assumption: Probably nothing!

From this account I want to contribute this thesis for a better understanding in life cycle process of buildings. Due to the interdisciplinary approach of my degree it seems perfect for me to push myself forward in a direction of getting a better idea about the holistic view in the aspects of energy and buildings. For this reason, an increase of resource awareness and sensitive utilization is my integrated objective with this work.

1.2 Central objectives and research question

Deriving from the integrated objective and in the context of an environmental Life Cycle Assessment (LCA), the central goal of this master thesis is defined as an ecological life cycle assessment of three different sustainable residential building concepts. The different multi-storey building concepts are characterized by the following features (detailed information about the research subjects are given in chapter 5):

- Version 1 (= actual building) – 'young corner' (Leystraße 157-159, 1020 Vienna):
  'Passive House' - massive construction with reinforced concrete and brick-aerated concrete masonry as well as semi-centralized ventilation system
- Version 2 (= scenario building) – based on 'Sonnenhaus Freistadt' (Zemannstraße/ Lasbergerstraße, 4240 Freistadt):
  'Sunhouse' – massive construction with reinforced concrete and brick-aerated concrete masonry as well as solar thermal energy utilization
- Version 3 (= scenario building) – based on '2226' (Millennium Park 20, 6890 Lustenau):
  'Low-tech house' – brick massive construction with simplified building services

Based on the functional unit of one m^2 gross floor area, the optimized life cycle evaluation is implemented for each building concept. The 'Passive House' concept represents the basis model. Deriving from Version 1, the two other concepts are modeled and assessed with their own particular attributes. Instead of analyzing every detail of the buildings, the focus is more on an exact depiction of the particular variations. The gained calculations and evaluations are prepared in a way that the results can be utilized for later implemented sustainable certifications like the ÖGNI ('Österreichischen Gesellschaft für Nachhaltige Immobilienwirtschaft' means in Engl. Austrian Sustainable Building Council) or the DGNB ('Deutschen Gesellschaft für Nachhaltiges Bauen' means in Engl. German Sustainable Building Council).

With help of LCA methodology the following research questions will be answered:

- Which building concept has the lowest environmental impact?
- What are the most relevant components and which effect do they have on a particular concept?

In addition to the research questions a further statement of the results regarding their contextual classification shall clarify unattended aspects of the integrated view. The primarily addressed interest groups of this thesis are planners, LCA-analysts, politicians but also students with interest relating to this topic.

1.3 Thesis structure

The thesis follows the standardized scientific structure. The introduction (chapter 2) is dealing with the concept of sustainability from different perspectives and from an historic point of view. This includes a general, a building based, a life cycle orientated and finally a legal related view. The content of Section 3 is an overview of different sustainable building concepts from the past and the present. This includes basic information about the historic 'Sonnenhaus' (Engl. Sun House), 'Passivhaus' (Engl. Passive House), Low-tech house and is completed by a current inventory of the Austrian building sector and its relevance towards energy consumption. Moreover, chapter 4 is completed by a specification of instruments respectively methods. This is further complemented by sections of results: Chapter 5 contains a description of the examined building concepts which were already mentioned in a general matter. It further contains aspects like the particular building structure, construction method, concepts of the building services as well as utilization details of the basic model. Section 6 deals with the LCA results (material balance, impact balance, economic analysis, sensitivity analysis). Chapter 7 is a discussion of the assessed results and contextualizes those with regards to a holistic matter. Finally, the thesis closes with a classic conclusion which summarizes the most important aspects of this evaluation.

2 The concept of sustainable building

2.1 Origins and development of the sustainability concept

Sustain implements to last over time. As a result, sustainability is the ability of something to last. This perspective was first officially introduced with the concept of 'Sylvicultura oeconomica' from 'Hans Carl von Carlowitz' in the 18th century (von Carlowitz, 1713). In his publication he stressed the importance of a constant, high and prime quality utilization of wood (König et al., 2009). Which implies in other words, the logged wood must not exceed the growth rate and involves therefore an irreplaceable natural capital. In 1798 the first material based growth limitation was conceptualized by Robert Malthus (Malthus, 1905). He made the discrepancy between a rapid population growth and limited resources as well as food supply as a subject of discussion and declared an unavoidable population catastrophe. His critics took the point of a continuing improving productivity of inserted resources. Until today Malthus critics were right. Instead of an overall resource scarcity, the productivity increased and new resources were found and finally have been utilized. From that point, the concept of sustainability vanished until mid of the 20th century (Dorsch et al., 2012). Beside the arousing book 'Silent Spring', which was dealing with the consequences of herbicides and pesticides in the environment, scientists like Dennis Meadows (1972) tied their publication "Limits to Growth" to Malthus theory. They modeled several scenarios according to resource consumption, pollution and population growth. The result was many scenarios of total collapses (similar to Malthus theory) and a few sustainable opportunities which did not end in devastation. Whereas the second approach did not find a lot of interest, the first approach in contrast resulted in hot discussions about collapse scenarios. Hence also this report was considered as a prophecy of apocalypse. In general it can be said, that Meadows study underwent the same criticism as the theory from Malthus: no consideration of technological development as well as a holistic view of the earth without including local respectively regional disparities (Turner, 2008). Even this study was besieged with criticism, the central message remained and was verified serval times. One was the study 'Global 2000': This project was launched by the US-President Jimmy Carter in the 1980s. Also this study proclaimed the risk of high population growth, climate change and growing environmental issues (Dorsch et al., 2012).

In relation to the growing concerns from scientists but also from society, the United Nations founded the independent expert council WCED (World Commission on Environment and Development) in 1983 (Dorsch et al., 2012). Under the leadership of Gro Harlem Brundtland, the commission set up probably most familiar definition of the term sustainability (WCED, 1987, s.p.):

> 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

The two major aspects of this definition are the inter generation perspective as well as the focus on humankind. The strong anthropocentric view represents the center of the definition and the originally stressed out preservation of the natural capital is not revived anymore. Nevertheless, a further important step in the context of sustainability was set by the World Summit in Rio in 1992. Its enacted declarations are still a major concern of current global environmental policies. As a supplement to the World Summit the three-pillar-concept of sustainable development was born in the EU. Thus it can be said, a development is sustainable as long as economical, ecological as well as social aspects were constantly perpetuated (Dorsch et al., 2012). In a following agreement, the members of the EU passed the '2020 Climate and Energy Package' (2008). The central objective was to cope with the defined declarations of the World Summit and pushing further the ecological development standards by reducing the CO_2 emissions by 20 % compared to the level from 1990, increasing each the renewable energies and energy efficiency by 20 % until 2020 (BMLFUW 2012).

2.2 Sustainability in the building sector

> 'Sustainable buildings are built, utilized and finally dismantled at the end of their life time under the highest consideration of ecological guardrails. As a consequence of their longevity and their adapting potential towards changed ecological, economical as well as social circumstances they are characterized by an intrinsic value' (translated into English by Armin Holdschick: Dorsch et al., 2012, 14).

The intrinsic value, longevity as well as the holistic dimension from the production till the dismantling is pointing out the buildings required dimension of consideration. Thus, it is necessary to reflect the entire life cycle and its interdependencies with the environment. For bringing it into legislation, the 'Comité Européen de Normalisation' (CEN) published the standard CEN/TC 350 which is about sustainability of construction works. Based on this, several European laws were enacted. An overview of the sustainable building legislation is given in Figure 1:

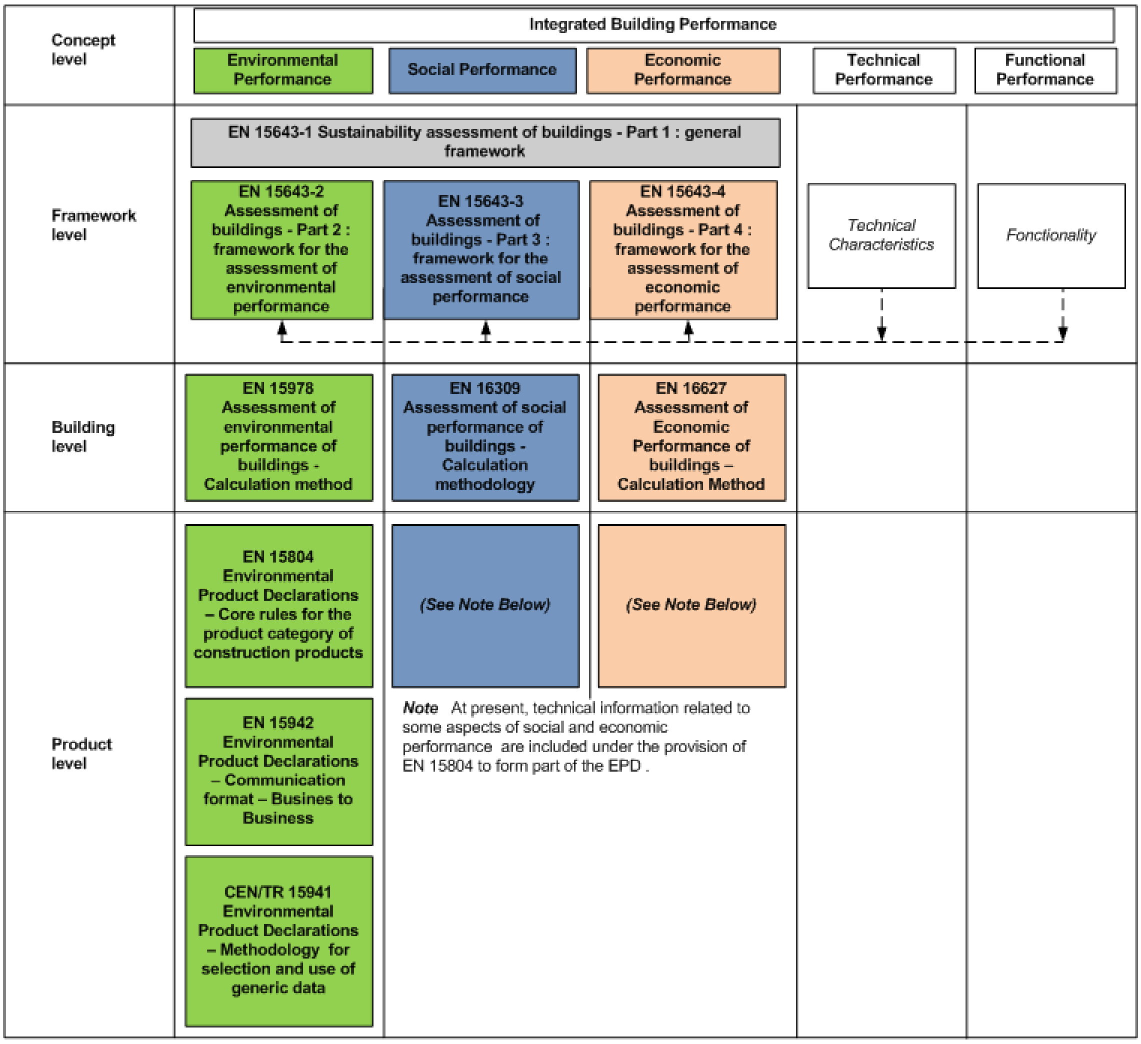

Figure 1: Published standards from CEN/TEC 350
(Source: URL 1)

In the context of this topic the federal ministry for environment, conservation, construction and reactor safety of Germany (bmub = Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit) published in its guideline 'Nachhaltiges Bauen' (Engl.: sustainable construction) six dimensions respectively qualities (see Figure 2) which are subsequently further considered (2014):

I. The Ecological Quality addresses its objective towards a conservation of the natural environment. An optimized selection of building components as well as sources of energy should help to minimize the utilization of energy and other resources. This includes:

- minimal land usage
- life extension
- reducing transportation processes
- application of reusable building components
- minimizing energy consumption during utilization
- application of renewable energy sources
- reducing fresh water consumption
- riskless substance repatriation into the natural substance flow

II. The Economic Quality is reflected by

- optimized life cycle costs,
- increased resource productivity according to the principles of economics and
- capital- as well as value preservation

III. The aspect of Social Quality is defined by the people's needs and includes factors like integration, participation, education, health and many more. Based on this it seems necessary to perpetuate at least the following protection objectives:

- guarantee of the building functionality
- securing the quality of creation
- securing of health, comfort, user satisfaction and safety

IV. The Technical Quality is focusing the technical performances and functions of a building. Thus the following aspects should be included:

- structural integrity and resistance towards environmental influences
- fire protection
- sound insulation
- heat- and moisture protection
- dismantling capability

V. In the context of the Procedural Quality the subsequent aspects have to be considered:

- quality of the planning process
- quality of the building construction
- quality of the operational management preparation

VI. Location Profile can be seen as a meta-dimension. They are surrounding and therefore influencing all other qualities and their constellation is an essential factor for the entire consideration.

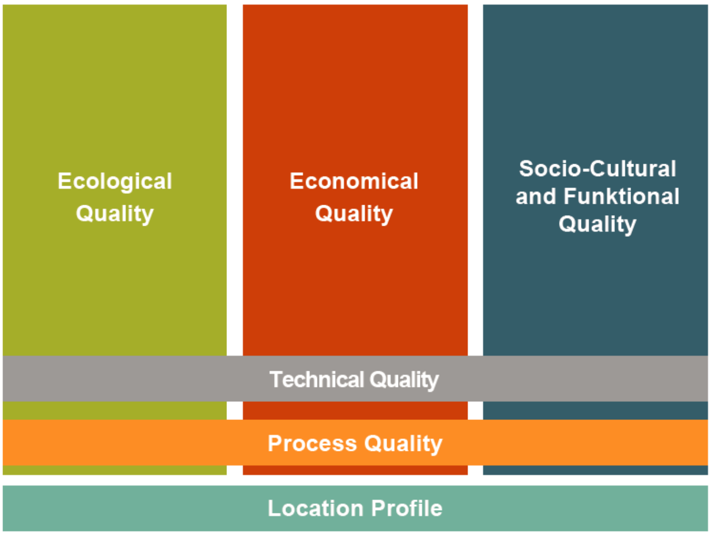

Figure 2: Qualities of Sustainability – Main Criteria Groups
(Source: BBSR, 2011)

Consequently, sustainable planning, building, using and operating can be characterized by an integrated consideration of the above mentioned dimensions. Thus, the central objective of the sustainable building concept can be seen as achieving a longevity and high building standard including a maximum of occupational quality by optimized costs but also by minimizing any negative external effects on the environment simultaneously (bmub, 2014).

Nevertheless, the process of building construction remains as a manifold field where various tasks and interests are brought together. This leads to a complex construction of activities and therefore in serial planning often in an incomplete flow of information. The consequence is mostly a discontinuity of the building process. However, the utilization and dismantling process also can be highly affected by these problems during the construction phase. Especially sustainable buildings are sensitive towards such developments. In these circumstances, a proper planning is inevitable. This means, leaving the concept of stand-alone solutions and forcing integrated and iterative planning and operating processes instead (König, 2009). Furthermore, sustainable building cannot be conducted by an inflexible pattern. On the contrary single projects have to be designed with individual approaches and arrangements (bmub, 2014).

By pursuing the strategy of sustainable building, an effective resource management is inevitable. On the one hand, this can be achieved by prolongation of the building components and on the other hand, by implementation of a closed-loop economy, which is inspired by the natural circular flow (Dahlhaus et al., 2009). Anyway, the most important factor of a sustainable building concept is an integrated and moreover holistic point of view. Only the combination of all spheres can lead to a high quality result. As an example, the application of wall insulation will be considered: Wall insulation for reducing the operational energy consumption has become a routine practice for new and retrofitted buildings but the environmental effect can vary significantly. This is caused by the different materials which underlay different manufacturing processes and disposal opportunities. Synthetic insulation products are often price efficient, but their environmental 'backpack' has generally a low performance. This originates from long manufacture process chains and energy intensive production processes. Nevertheless, even near-natural insulation components have a higher environmental perfermance and they are not always as harmless as they seem. Those materials have to cope with aspects like added boron salt as a method for reducing flammability, monocultivation (e.g. hemp and flax) or substantial energy expensenses for transportation of sheep wool from New Zealand or cork from Protugal (Königstein, 2011).

2.3 Instruments and methods for sustainable building programs

As mentioned above, the planning process is a crucial part of the entire object's life cycle. This attains further significance in the context of longevity. In current analyses residential buildings are assessed with a life span of 50 to 100 years. Therefore, buildings do not only have to fit in the present but also in the future with changed conditions of local and global factors: fossil fuels are running out, climate change is increasing the temperature by 2-6°C and weather extremes occurring more regularly (Dorsch et al., 2012). In expectancy of those developments any construction which is not built in the state of the art will turn out as an unsustainable and cost-intensive object. In regard to this the demand of suitable instruments, methods and data for proper planning is high. The subsequent figure (Figure 3) gives an overview of popular auxiliaries in the field of buildings.

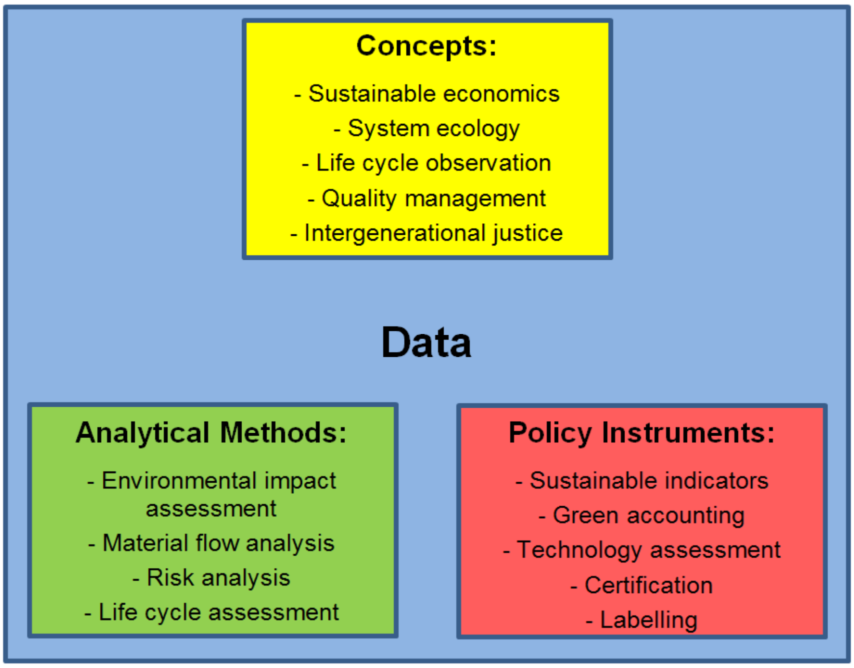

Figure 3: Sustainable progress in the context of data relevant methodology (Source: König et al., 2009 adapted by Armin Holdschick)

The limited available space as well as the paper's context, only the life cycle assessment respectively the life cycle cost accounting will be further scrutinized in the following subchapters.

2.3.1 Environmental Life Cycle Assessment (LCA)

The International Reference Life Cycle Data System (ILCD) defines the term LCA as follows (2010, iV):

> 'Life Cycle Assessment is a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services ('products')'.

With the standardization by ISO, LCA can be seen as a widely accepted tool which helps to quant- and objectify environmental issues and assists decision makers during the complex planning process (Kümmel, 2000; Sorensen, 2011). The origin of this technique comes from the demand of internalizing externalities as well as gaining more information about environmental effects of certain products. The entire development was long-lasting and influenced by the environmental movement which started with Carsons book 'Silent Spring' in the early 1960s. As a consequence of heated discussions about negative external effects, scientist established the first rational approach by assessing externalities with a cost-benefit analysis. During the 1970s further investigation was conducted with indirect economics and with the increasing importance of environmental issues in the 1980s and 1990s the first LCA about packing materials was published by the Swiss Federal ‘Office of Environmental Protection’ (Bundesamt für Umweltschutz) in 1984 (Sorensen, 2011; Kaimer et al., 1994). Nevertheless, LCA is not only an instrument for assessing environmental aspects it also considers economic and social factors (Kümmel, 2000). Thus all factors of the conventional 3-pillar concept of sustainable development are integrated. Generally, the evaluation is following by a dual scheme, which includes quantitative and qualitative elements (Treberspurg, 2006). The remaining technical- and procedural aspects of the ‘sustainable construction’ concept however cannot be assessed in the context of LCA. Anyway, with the detailed data from the LCA an excellent basis for further investigation is provided. The methodological basis is given by the ISO standard ‘Environmental management - Life cycle assessment - Principles and framework’ (EN ISO 14040, 2006) and Environmental management - Life cycle assessment - Requirements and guidelines (EN ISO 14044, 2006).

The concept of LCA is based on the incorporation of all impacts during the entire life span or in other words from ‘cradle to grave’ (see Figure 4). This implies all direct and indirect impacts derived from materials or facilities to manufacture, tools and equipment for the process under study, all operational impacts during utilization as well as the entire effects from the final disposal respective dismantling process, whether involving reuse, recycling or waste disposal (Sorensen, 2011). This prevents from a limited view which only includes the process of manufacturing moreover from the shifting of problems (König, 2009).

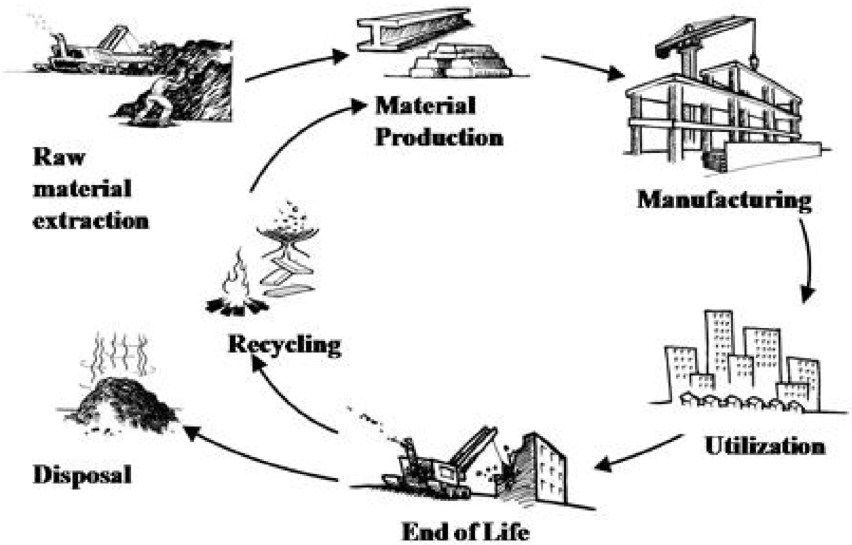

Figure 4: Idealized material flow in the context of LCA
(Source: Frauenhofer Institut, s.a.)

The LCA conduction follows a four step scheme (see Figure 5). The first step specifies the goals and framework of the study which includes definitions of the research objective, system boundaries, functional unit and target audience. The second step is the Life Cycle Inventory (LCI) and includes data collection for all required input/output materials as well as energy flows. The third part is a Life Cycle Impact Assessment. This phase is based on the results from the LCI and refers to the calculation of potential environmental impacts, effects on resource availability including human health impacts. The last step is the interpretation of the calculated results from phase two and three regarding to the defined goals from step one (Frauenhofer Institut, s.a.; Treberspurg, 2006).

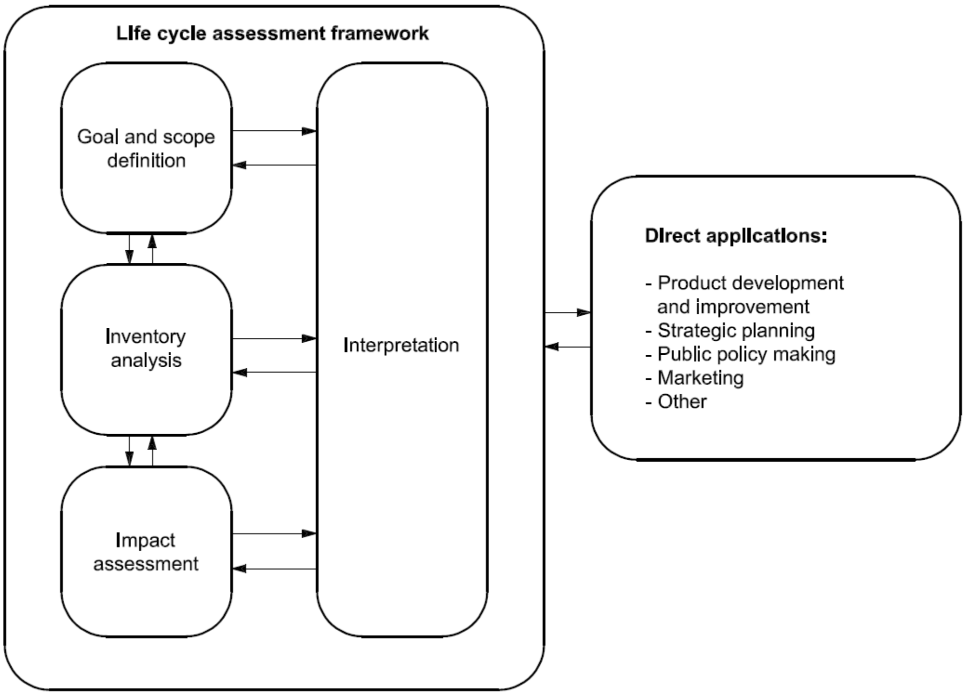

Figure 5: Phases of an LCA process
(Source: EN ISO 14040, 2006)

Finally it can be said, LCA has the objective of an integrated accounting and represents a connection of traditional engineering as well as economic methods for an evaluation of building components and systems in reference to an environmental point of view (Kümmel, 2000). The most relevant standard relating to this issue is DIN EN 15978. It entails an assessment of environmental performance of buildings and represents the basis for a LCA.

2.3.2 Life cycle cost accounting (LCC)

In addition to material and energy flows the LCA is also considering cash flows which are implemented in the LCC. By means of the LCC, entire buildings but also single building components can be evaluated and optimized by their cost. Central elements are the investment and operational costs. However, caused by the long life span of buildings the evaluation of operation costs is confronted with uncertainties and its adequacy is therefore controversially discussed when it comes to the budget plan preparation. Especially the choice of discounting rate is a crucial and highly influencing factor for the economic calculation. The LCC is mainly applied for prearrangements of investment decisions, determination and verifying of trade-offs, benchmarking and provides supplementary information for building components as well as building services (König, 2009). The LCC is based on the ISO standard 'Buildings and constructed assets - Service life planning: Part 5, Life-cycle costing' (ISO 15686-5: 2008). The standard contains term definitions plus methods for the implementation.

2.4 Legal foundations for sustainable building in Austria

In the context of LCA and sustainable building processes, only a few directly related legal regulations exist. The focus thereby lies on energy efficiency guidelines. The most representative example is the 'Energy Performance of Buildings Directive', which was recasted by the EU in 2010 (2010/31/EU). This policy was firstly developed in the context of the '2020 Climate and Energy Package' (as mentioned in chapter 2.1) and launched in the policy 2002/91/EG in 2002. The central objective is to increase the overall energy efficiency performance of buildings which includes:

- thermal characteristics of a building (thermal capacity, insulation, etc.),
- heating insulation and hot water supply,
- the air-conditioning installation,
- the built-in lighting installation
- indoor climatic conditions

Furthermore, the policy is prescribing realization of energy certificates, calculation methods as well as regular inspections of boilers, ventilation and air conditioning technologies (VAT). By 31st December 2020 all newly constructed buildings shall achieve a ‘nearly zero-energy’ standard (2010/31/EU). The international policy was finally implemented by the Austrian legislation with the following important documents (Bergauer-Culver, 2014; Energieagentur Steiermark, 2012; energiebewusst, e.a.):

- OIB guideline 6 (2015) - Energy saving and thermal protection: Is including all construction related aspects of the ‘Energy Performance of Buildings Directive’.
- Energy certificate law (EAVG 2012): Is dealing with all aspects relating to the energy certificate implementation.
- Heating system law (Art. 15a B-VG): Is dealing with aspects like system introduction and controlling of heating systems.

Another aspect besides energy relates to building products. In this case, the regulation No 305/2011 (EU) is laying down harmonized conditions for the marketing of construction products. The ‘Construction Product Regulation’ is therefore providing the necessary transparency and establishes ‚a clear system of allocation of the responsibilities between its actors’ (European Commission, 2014, s.p.). Beside, repealing the ‘Council Directive 89/106/EEC’, the new directive affiliates some recommendation from the ‘European Network of the Heads of Environment Protection Agencies’ (EPA) like novels relating to hygiene, health and environmental protection as well as sustainable utilization of natural resources (Umweltbundesamt, 2015). The regulation is directly incepted in all nations of the EU and therefore does not need any legal implementation into the national legislation.

As mentioned at the beginning of this chapter, sustainable development with buildings does not really have specific legal regulations. Instead of this many certifications have been established over the last 20 years. The most important and for Austria the most relevant certification systems are ‘BREEAM’, ‘LEED’ and ‘DGNB’ and ‘ÖGNI’. Those systems are based on different approaches which make a direct comparison impossible and as a consequence raise the desire for unification. Nevertheless, all systems aspire for visualizing transparency of quality, raising awareness of sustainability and benchmarking of different constructions. Further information can be gained by detailed publications of certification system like ‘Zertifizierungssysteme von Gebäuden’ from Ebert et al. (2010).

3 Sustainable building concepts

In context of sustainability a resource orientated approach is indispensable. Therefore, the goal should be an efficient usage or consumption of resources without shedding quality towards comfort and functionality. On the contrary, living quality should be raised to a higher standard (Treberspurg, 1999). Energy, ground, water and raw materials are the most important resources in the building sector. Whereas resources like ground and raw materials are mainly influenced by the building process, energy and water consumption is highly affected during the time of utilization. Thus, in the concept of sustainable building, it is important to follow a holistic approach by reducing all negative effects already from the beginning.

One of the first building concepts which followed this premises was the ‘Socrates House’ which was built on the concept of sun tempered architecture. The outstanding characteristics of this building concept (see Figure 6) are the south orientated alignment (1) and zone structured room division (2). Moreover, it also considers the aspect of thermal mass. With the jutting canopy (3) the house receives radiation from the low standing sun during the winter, which heats up the implemented thermal mass in walls and floors (4) and blocks the same during the hot weather period. In addition to that, the house includes also a grounded consideration of cross ventilation (5) which allows the transportation of hot air from the house to the surrounding during the night.

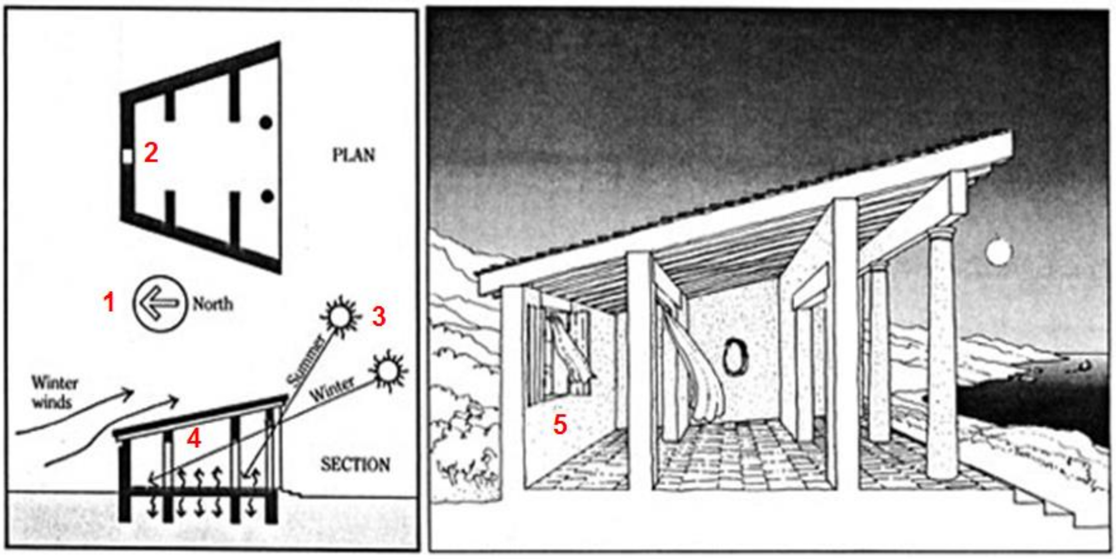

Figure 6: Graphical depiction of the ancient ‘Socrates House’
(Source: URL 2)

Even though this concept was developed almost 2500 years ago, all five principals have not lost any glimpse of importance towards new sustainable building concepts. In point of fact, by applying these principals with the technological progress in aspects of construction material and building services the construction of energy and resource efficient houses becomes possible also in northern longitudes of the globe.

This approach not only addresses environmental aspects it largely entails quantitative and qualitative advantages for the occupants respectively proprietors. Due to a tight and well insulated construction almost no heat gets lost. Consequently, the cheapest heat is that, which has not to be produced and finally not paid. According to the type and standard of the building energy savings of up to a factor of 10 can be reached. This implies a tenfold reduction in energy bills. Even though a well-planned and high quality constructed building results in higher capital costs, with a large decrease in annual energy expenditures, these costs can be paid back within 5 to 20 years. Compared with a building’s life span of 50 to 100 years, this creates a great benefit and a high sale value can be guaranteed in the future. Furthermore, people who live in buildings with a low energy demand are less vulnerable to price fluctuations in the energy market. Nevertheless, a consideration of insulation, correct alignment and zone structure implies a more comfortable indoor atmosphere and full floor utilization. The higher the thermal resistance of exterior constructions the less uncomfortable radiance will be emitted. The temperature of the wall conforms more to the interior conditions and reduces towards the relative humidity on the construction surface and lessens the risk of mold. However, the aspect radiance is not only obtained in cold weather periods, but also heat from outside can cause uncomfortable conditions in the building. As long as effective shading, proper insulation and thermal mass are provided, no further cooling systems should be needed to create a comfortable indoor climate. Additionally to these major factors a well-conceived ventilation concept balances the living quality in the building. It guarantees a continuously available fresh-air, a steady and comfortable temperature and minimizes the heat loss due to aeration.

With respect to these factors several building concepts arose during the last 25 years. Three currently popular of them (Passive house, Sun house, Low-tech house) will be further examined and evaluated in this thesis. The next three sections discuss the basic principles and show representatives of these chosen approaches.

3.1 Passive House (PH)

3.1.1 Basic principles of the Passive House

Derived from the 'Socrates House', the Passive House (PH) was established by the Passivhaus-Institut (PHI) Darmstadt (Germany) respectively by Prof. Feist and Prof. Adamson in 1991. The PH represents a construction standard instead of a construction method (Treberspurg, 2006). This entails certain predefined criteria (Feist, 2001):

- Primary energy demand $_{\text{non-renewable}}$ ≤ 120 kWh/(m^2.a), for all energy uses (thereof maximal 55 kWh/(m^2.a) for electricity generation)
- Heating demand[1] ≤ 15 kWh/(m^2.a) (energy per floor area)
- Maximum heat load < 10 W/m^2 (energy per floor area)
- Heat transition coefficient for exterior walls, roofs and floor constructions < 0.15 (W/m^2.K) (target value 0.10 W/m^2.K)
- Heat transition coefficient for exterior windows and doors < 0.8 W/(m^2.K)
- Air tightness ≤ 0,6 h^{-1}
- Ventilation with heat recovery system (efficiency factor ≥ 0.75)

According to Passipedia, a PH can be further defined as a building '…in which thermal comfort (ISO 7730) can be provided solely by postheating or postcooling of the fresh air flow which is required for good indoor air quality (DIN 1946) - without using recirculated air in addition' (Feist, 2015).

[1] There are two established approaches for dertmining the heating value for PH in Austria. The first one relates to the mandatory standard of 15 kWh/m^{2}a (energy per floor area) which is set by the Passivhaus-Institut Darmstadt. This approach is decisive in the context of certification of a PH. The other approach relates to the Austrian Building Code of the Austrian Institute of Structural Engineering (OIB) and relevant standards of the Austrian Standards Institute. ÖN 8110-6 claims, that PH are within the efficiency class of A^{++} which is equivalent to a heating value < 10 kWh/m^{2}a (per conditioned gross floor area). Because of different calculation methods, system boundaries and level of detailed balances, the results of these two approaches cannot be compared directly. In general it can be assumed, a heating value of 15 kWh/m^2 and year, according to the PHI equates to 8 kWh/(m^2.a) of the OIB standard. In this thesis the first approach is therefore used in the context of describing PH standards in chapter 3 and 5. The second approach counts for all calculating activities (chapter 6 and 7).

Based on these factors the classic PH represents a building standard which does not need a conventional heating system for providing comfortable interior temperatures over the year (Treberspurg, 2006). For achieving this advanced status, special focus has to be laid on all exterior constructions. The building envelope must resemble a thermos flask, which keeps the heat inside the building during winter and the heat outside during the summer. With respect to the air tightness and the omitted heating system a ventilation system, with heat recovery is a crucial part of the building services. With considerations, more than 70 % can be saved compared to components of conventional buildings (windows 70 %; walls 90 %; VHR 90 %). Despite the high energy efficiency PH do not suffer from inflexibility of design possibilities. As PH are not linked to certain shapes or building materials they can be built in any architecture style (Sommer, 2008).

Yet, a typical PH is characterized by specific construction features (see Figure 7). A compact design is one of them, assuring a favorable relationship between a building's volume and its building shell area. The so called compactness or area-volume-ratio (A/V), overridingly determines the heating demand overridingly and the following rule applies: the smaller the value, the smaller the heating demand. Another important aspect is the orientation of the building. With the correct alignment of the building and a proper arrangement of the rooms according to their utilization, a building can gain a considerable amount of passive solar energy. Depending on the location on the planet, the building has to be aligned either to the South (northern hemisphere) or to the North (southern hemisphere) (Sommer, 2008). The rooms should be arranged according to their usage. Therefore actively used rooms (e.g. living room, kitchen and office) should be placed in that part of the building which is in sunshine during the day, whilst less used rooms (e.g. bed-, bath- or storeroom) are located in the shaded area (Urmee, 2014). In addition to the passive solar energy, it has to be considered, that direct sun ray access during the hot temperature period should be avoided. It can be chosen respectively combined between shading components on the building like canopies or blinds and shading features in the surroundings like leaf trees (Treberspurg, 2006). A highly insulated building surface is the third crucial factor of a well performing PH. As mentioned above, in order to keep the transmission heat loss as small as possible, the heat transition value (U-Value) of exterior walls and roofs must not exceed 0.15 $W/(m^2.K)$ and the U-Value of the windows and doors must be less than 0.8 $W/(m^2.K)$. Only a sophisticated insulation prevents the inside of the exterior components from a drop in temperature and furthermore from moisture based damages. However, the high level of insulation only works properly if thermal bridges and leakages of air tightness are eliminated (Sommer, 2008). For a granted air tightness in PH of less than 0.6 h^{-1} a 'Blower-Door-Test' has to be conducted (Treberspurg, 2006). Summarizing, the design of PH forces a minimization of heat loss until a level in which a considerable amount of heat can be gained from passive solar radiation and other energy emission sources within a building e.g. electrical appliance (light, stove, etc.) or the occupants itself.

In addition, to the'Classic Passive House' described above, there is also a call for a further integration of renewable energy. Thus during the 18th international Passive House conference in Aachen (2014), Feist proclaimed two other concepts:

- The first is '**Passive House Plus'**. This model follows the idea of a balanced energy supply. This means, the averaged supply from renewable energy facilities is, as high as the demand.
- The second approach is the '**Passiv House Premium'**. Its purpose is to produce more energy from renewable sources than energy needed. If the renewable energy source is not restricted to one technology (e.g. solar thermal), a surplus could be produced, which can be used in other facilities.

In this context, the term of 'house as a power plant', fulfills its intension. Furthermore, as far as such an approach is feasible and can be realized, buildings might turn from energy consumers to energy producers and hence could bring their contribution for a sustainable energy transition.

Nevertheless, it needs to be stressed that, a well performing 'Passive Houses' only work as long as the occupants correctly use it (Treberspurg, 2006). So the saying 'a Passive House needs Active Users' fits perfectly.

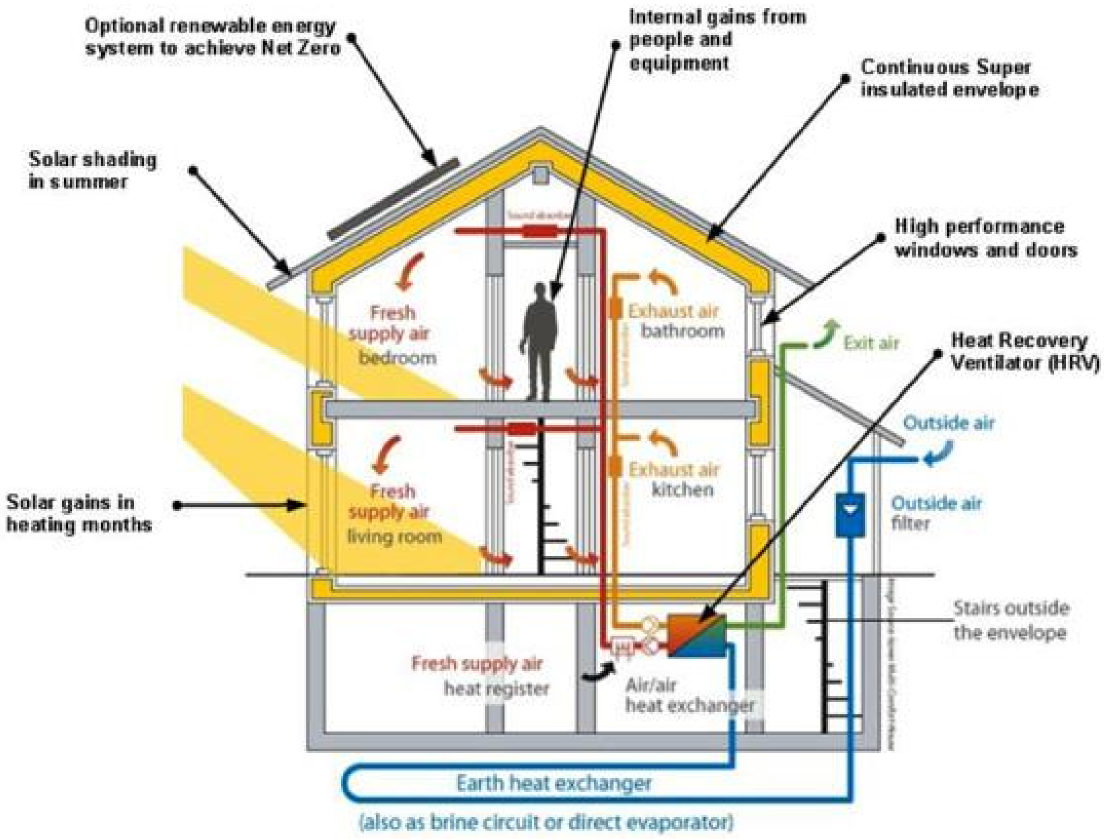

Figure 7: Configuration and functioning characteristics of a 'Passive House'
(Source: URL 3)

3.1.2 Housing complex 'young corner' as a representative of the Passive House concept

The examined housing complex 'young corner' (Figure 8) was designed by 'Treberspurg & Partner' and built by 'KALLCO'. Energy design and building physics were done by technical office of Wilhelm Hofbauer in cooperation with Schöberl & Pöll. The building is the world's largest construction with phenolic foam insulation and was finished in 2011.

With respect to a coherent structure regarding the modelling approach of the actual building and the additional created scenario buildings, further data of the PH can be found in chapter 5.1.

Figure 8 : South/west and south/east facade of the building ‘young corner’
(Source: Treberspurg & Partner Architekten (2011); Photographer: Treberspurg & Partner)

3.2 Sun House (SH)

3.2.1 Basic principles of the Sun House

Another but also officially defined concept is the ‘Sun House’ (SH). The SH was firstly defined in 2004 by the ‘Sonnenhaus-Institut’ in Straubing (Germany). Whereas, the PH concept is based on a very energy efficient building envelope and consequently a low heating demand value, the SH concept forces an increased utilization of solar energy which positively affects the primary energy demand with respect to fossil fuel based energy usage. According to the ‘Sonnenhaus-Institut’ (2014) following criteria are crucial factors:

- Primary energy demand according to EnEV[2] ≤ 15 kWh/(m^2.a) per net floor area (excluding household electricity) for a SH with renewable energy carriers
- Primary energy demand (EnEV) ≤ 30 kWh/(m^2.a)[3] per net floor area (excluding household electricity) for a SH with fossil energy carriers.
- Heating demand fall short of 15 % compared to a current EnEV reference building
- Specific transmission losses at least 15 % better than EnEV-reference building
- Solar coverage of heat demand ≥ 50 %

These fundamental factors are further complemented by Austrian regulations from ‘Initiative Sonnenhaus Österreich’ (2012):

- Primary energy demand ≤ 50 kWh/(m^2.a) (including household electricity)
- Heating demand ≤ 45 kWh/(m^2.a) (according to the ‘Low Energy House’ calculation for housing subsidy in upper Austria)
- Air tightness ≤ 1,5 h-1

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[2] Energie-Einspar-Verordnung (engl. energy saving regulation) in Germany

[3] Relating to the building’s supplemantary heating: a fossil fuel based heating allows a primary energy demand of 30 kWh/(m^2.a) but also has to be labled as ‘Sunhouse f’

As the figures demonstrate, the concept is highly based on the idea of a sun heated building (see Figure 9). Thus according to the original definition, at least 50 % of the required space heating and hot water services must be provided by the sun's energy. This can be achieved either by direct heating via thermal mass or indirectly via steeply arranged solar collectors (2) which either activate components used as surface memory heating systems (3) or heat up a buffer storage (4) (Initiative Sonnenhaus Österreich, s.a.). A volume of 150 to 200 liters per m² collector area is recommended. This buffer storage is an essential part of the concept, but its implementation follows diverse approaches. Some of them are long term storage which works over seasons. Others are designed for short period storage which contributes heat only for a few days (Ökotest, 2011). Depending on the type, the dimensions and costs can vary greatly. Nevertheless, the height-diameter-ratio should be within the range of 4:1 to 2:1 and the panels must not be affected by any shading of nearly located obstacles, such as trees and other buildings. Furthermore, the solar collectors should be mounted with a south facing (+/- 25°) direction and with an inclination of 40° to 70° (but also higher inclinations up to 90° are possible). Additionally, photovoltaic modules (6) can be installed to cover a part of the electricity demand which can be stored in lithium battery systems (7). Beside the self-supplied amount of energy, a SH has to possess a high insulation standard (1) and a regenerative resource based heating system like a pellet furnace (5). An installation of a ventilation system in the classic model is not envisaged. However from an air quality perspective, it can be seen as a beneficial fitting (Initiative Sonnenhaus Österreich, s.a.). The building's heat transition coefficients are not specified, but can be postulated to be within the following ranges for detached houses (Koch, 2008):

- Exterior walls 0.14 – 0.18 W/(m^2.K)
- Roofs 0.12 – 0.16 W/(m^2.K)
- Floor constructions 0.20 – 0.24 W/(m^2.K)
- Heat transition coefficient for windows and doors 0.8 – 1.0 W/(m^2.K)

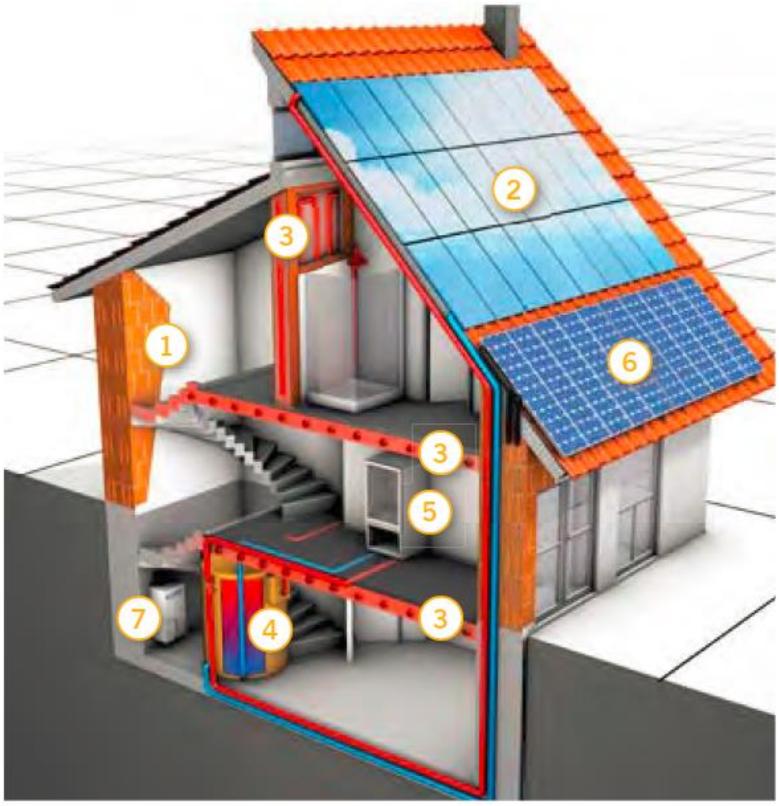

Figure 9: Characteristics of a Sun House
(Source: URL 4)

Beside advanced architecture, sophisticated insulation, building service installations or roof mounted solar panels, elementary features of the SH are also based on major characteristics from the antic archetype, the ‘Socrates House’. For the SH around 80 % of the final energy demand in the building sector is used for space heating and warm water supply, of which a large part could be provided by solar energy. For achieving this aim, the SH can be configured in diverse manners. The most distinctive aspect relates to the storage strategy. Either solar tempered heat is gained during the heating period, which reduces the core heating period or the solar heat is gained during the hot weather season and the energy is stored in large seasonal storage facilities. Even if the first approach is the most common one, it is indispensable to install high-selective panels. Besides being cost efficient, they enable the system to reduce the storage size, which makes an installation and integration easier (Oliva, 2015). Another option is also given for the heating system. In the most cases, a floor heating system is the favored choice. Its low flow temperature (outgoing flow 40°C; incoming flow 30°C) helps the entire system to work efficiently. But also radiator based systems (outgoing flow 55°C; incoming flow 45°C) can achieve, especially in renovated objects, also reasonable results (ibidem). As a matter of fact, also the SH match up with further advantages. As for the PH, the SH has a much lower final and primary energy demand for heating than standard houses. Furthermore, with the installed renewable energy facilities SH have lower CO_2 emissions and therefore a smaller impact on the environment. However, this performance can only be perpetuated as long as the building or rather its solar panels are not affected from shading of any kind. Otherwise its functionality can be significantly reduced.

3.2.2 Housing complex ‘Sun House Freistadt’ as a representative of the Sun House concept

The representative building for the SH concept is situated in Freistadt and is with a constructed area of 309 m^2 (gross floor area$_{conditioned}$ = 1,028 m^2) the largest SH in Austria (see Figure 10). The dwelling was designed by ‘Planungsbüro Schaufler’ and built by ‘Singer Bau GmbH’. The final completion was in 2013 (Stockreiter, 2015).

Figure 10: South/west facade of the SH in Freistadt
(Source: Peter Stockreiter; Photographer: Peter Stockreiter)

Freistadt is a small town in Upper Austria with about 7.500 residents and located in a 37 km distance to the regional capital Linz. The building is southern of the town center. However, almost every point in the village can be reached in a 15 min walking distance. Even though Freistadt does not offer many infrastructural highlights, all ‘every-day-life’ facilities (e.g. shopping malls, banks, medical services, etc.) are available in town. Nevertheless, in relation to the occupational background, the majority of working people has to commute between Freistadt and the greater area of Linz. Due to a well-established public transport connection, commuters are not only restricted to travel by car, they also can revert to train or bus.

The basic concept of the building (which is already mentioned in the general description of SH) is to provide a comfortable accommodation with a low fossil fuel based energy consumption. The building itself is reasonable, adapted to the given site conditions, which are highly influenced by a prefixed cross road and the preference of a maximum sun gain and light for solar panels as well as apartment rooms. There are nine Apartments in three floors of the building. The complete building has 5 floors in total, whereas only three floors are completely conditioned. The basement floor is used for storage, placing building services (e.g. puffer tanks and pellet furnace) and a commercial space, which is situated in the North/East part of the building. The ground floor is only partly constructed (north/east part) and is also used for commercial purposes. The rest is used as a kind of carport for the vehicles. All three apartment floors are arranged in a similar manner (see Figure 11). This means that each floor has three apartments: one in the north and one in the south wing, simultaneously there is another one in the middle with an orientation westwards. Each apartment has a floor space between 55 m^2 and 87 m^2.

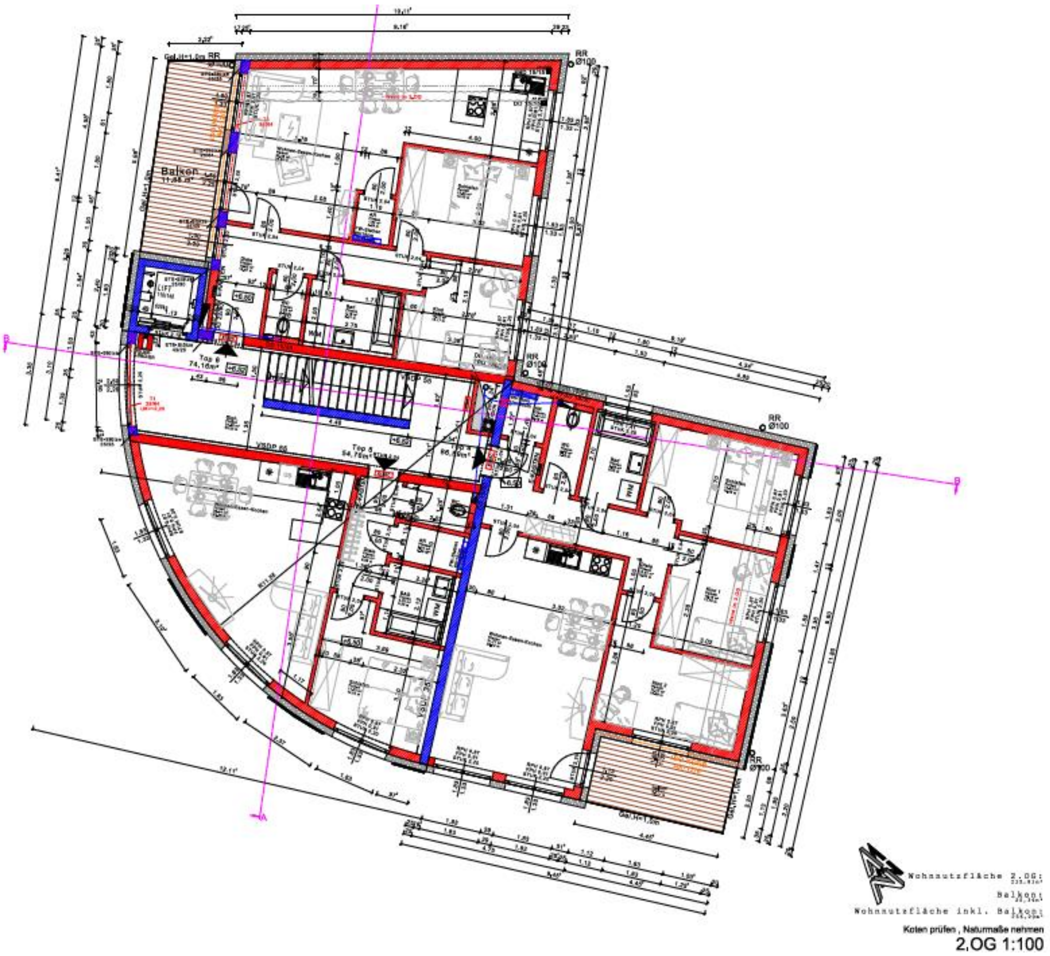

Figure 11: Standard floor plan of the SH in Freistadt
(Source: Planungsbüro Schaufler (2012))

The building construction is based on a massive structure. Concrete and brick-aerated concrete masonry are the elementary construction materials. The heated volume aggregates to 3,391 m^3. In addition to achieve a low energy standard conventional EPS insulation is installed in all exterior walls and the basement floor is insulated by BEPS and mineral wool. As a consequence to the solar optimzed building alingnment paired with its unconventional form, the building entails a A/V-ratio of 0.45 m^{-1}. This results, even with a solid average U-value of 25 W/(m^2.K), to an annual heating demand of 30.55 kWh/(m^2.a) according to the reference scenario (site scenario: 37.4 kWh/(m^2.a)). Signifying installed insulation concecpts and materials are:

- Exterior walls: 0.20 m thick EPS hard foam panels, U-value 0.16 W/(m^2.K)
- Flat roof: 0.30 m thick, U-value 0.12 W/(m^2.K)
- Floor ceiling: 0.20 m thick EPS hard foam panels + 0.12 m thick BEPS panels, U-value 0.12 W/(m^2.K)
- Exterior Windows: three paned thermal insulation glazing set in a wooden-aluminum frame, U-value 0.87 W/(m^2.K)

Maximum gain from solar radiation can be taken as the central principle in context to the implemented energy concept. The greatest part of the building is facing west and therefore receives a maximum of solar radiation and day light during the evening, whilst residents spend the most of their time at home. Except of the middle situated apartment, a functional room allocation is given. Living rooms are facing primarily west, whilst functional rooms and sleeping rooms are mostly facing north and east. Shading is only partly given by balconies and canopies on the east/west (and north/west) side of the building. All other windows are not equipped with any shading elements. In the context of room and water heating, 126 m^2 of high selective solar thermal panels[4] are situated on the buildings flat roof (see Figure 12). They are aligned directly to the south and their setting angle is 45°. This helps to avoid overheating during summer and increases the yield during winter. The gained heat is subsequently stored in four 10,000 liter puffer tanks (see Figure 12). They are situated in the basement floor. Consequently, the complete system has a calculated solar cover ratio of 51.8 % which means, that 51.8 % of the total energy (except of electricity) is covered by solar power. The rest is heated by a wood chip furnace (49 kW). Thus, this attains a reduction 5,000 liters of fuel oil and this again a save of 16,000 kg of CO_2 emissions per year (Forstenlechner, s.a.). The remaining and not covered energy for room and water heating is provided by a 40 kW pellet furnance. Its operation mode is modulating, and the feeding runs automatically via a screw conveyor. In a final step the rooms are conditioned by floor heating. The building is not equipped with a ventilation system and has in consequence calculated ventilation losses (via window) of about 290.86 W/K.

[4] According to the available energy certificate the building is equipped with 91 high-selective solar panels. By assuming each collector has an area of 2 m^2 it comes to a total area of 182 m^2. 56 m^2 are placed on the west facade, 30 m^2 on the south/east facade and 96 m^2 are mounted on the roof. However, facade collectors are not found in the pictures. Therefore a picture analysis was taken as the relevant source (63 panels * 2 m²/panel = 126 m²).

Figure 12: Solar thermal system of the SH in Freistadt
(Source: Peter Stockreiter (s.a.); Photographer: unknown)

3.3 Low-tech building (LTB)

3.3.1 Basic principles of the Low-tech building

The idea of ‘low-tech building’ (LTB) is not defined by a certain standard, as are the Passive House or the Sun House concepts. This makes an exact specification difficult to describe. According to one’s perspective and the set system boundaries, a huge variety of building standards, constructions and ways of living can influence their standpoint (Ritter, 2014). The concept is mainly based of the simplicity, functionality and robustness of a building which can be seen as a kind of countermovement to the continuous increasing level of technical services in buildings. On the one hand, automation of housing technology implies benefits of a better control as well as a less elaborated handling for the consumer. On the other hand, it also involves several disadvantages such as high initial and maintenance costs, difficult and time intensive adjustment as well as a life expectancy which is by far shorter than the life span of the building itself. However, the most problematic point goes back to the owner or user of a building. With increasing automation there is a decreasing understanding, which may outweighs the benefits from the outset (Streicher, 2014).

According to Streicher (2014, 9) a LTB can be defined as follows:

> ‘Low-tech buildings are buildings which achieve a high user comfort and an excellent energy performance by a minimum of technical installations. Natural physical effects, traditional knowledge, historic building techniques as well as local available resources and raw materials are the basis of a development and adaption of modern requirements’ (translated into English by Armin Holdschick).

Consequently, a LTB should assure a low heating demand and an optimum protection towards summer overheating. This can be achieved by high quality insulation and excellent window systems which have to reach the level of PH components. Moreover, an ideal alignment of the windows, summer shading as well as an utilizable thermal mass is necessary for a high comfort. For minimized building services, a multi functioning approach should be utilized. This implies that the installation itself can be used for several purposes e.g. ventilation for air transportation as well as heating (Streicher, 2014). Nevertheless, successful historic approaches should achieve a specific interest. They can help to answer questions like (Salzmann, 2010):

- How was it solved so far?
- What can we learn from the experience approved examples?

For instance, the ‘Bregenzerwälderhaus’ (see Figure 13) with its central heating system or several Arabic or Asian building concepts, like the Persian house (see Figure 14) with sun loggia and natural purge ventilation (wind tower), can be seen as such examples (Salzmann, 2010; Treberspurg, 2006). Amongst their advantage of simple and effective technologies those objects come with the benefit of perfectly adapted concepts to their specific local or regional conditions. Combining such historic approaches with new and sophisticated materials can create unconventional but simultaneously very effective concepts for the future (Salzmann, 2010).

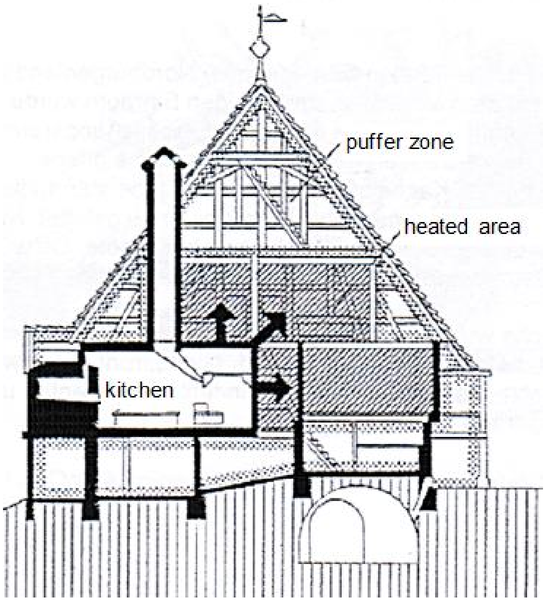

Figure 13: Bregenzerwälderhaus/south German farmer house with central heating
(Source: Hillmann, G., Nagel, J. and Schreck, H. (1987): Klimagerechte und energiesparende Architektur. C. F. Müller, Karlsruhe. Adapted by Armin Holdschick)

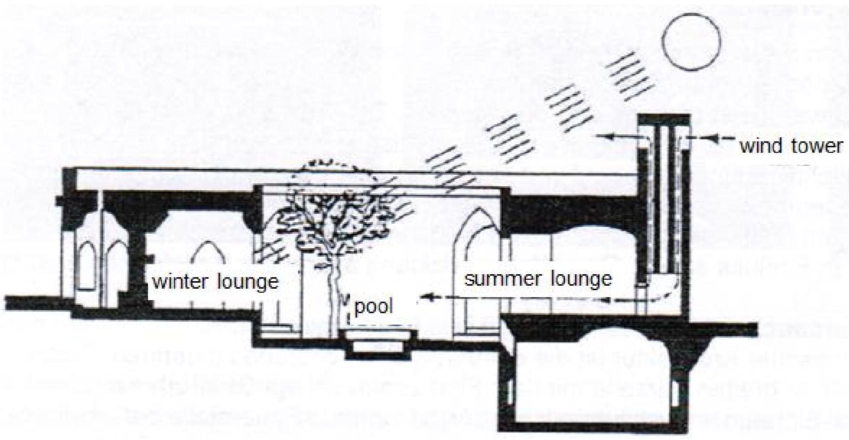

Figure 14: Persian building
(Source: Rezai - Hariri, M. (1980): Was du ererbt von deinen Vätern – Altpersische Bautradition als Muster einer energiebewussten Architektur. E-80 Fachzeitschrift der ÖNE/3. Adapted by Armin Holdschick)

As a generalized view, it can be said, that LTB often come with a greater labour input and therefore often with greater initial cost (Salzmann, 2010). However, in an integrated and not curtailed calculation consideration, LTB are in general very cost effective. The reasons lie, as already mentioned above, in lower maintanance, adjustment and replacement activities.

3.3.2 Office building ‘2226’ as a representative of the Low-tech building concept

In this thesis the office building ‘2226’ in Lustenau represents, in an adapted approach (see chapter 5.3), the concept of LTB (see Figure 15). Even a distinctive definition for LTB is difficult to give, ‘2226’ can be seen as the only multiple floor (> 3 floors) LTB in Austria. With its six floors and a cube shaped body (24x24x24 m) it has a heated volume of 13,824 m^3. The dwelling was designed by the architectural office ‘Baumschlager Ebele‘ and built by ‘AD Vermietung’. The final completion was in 2013.

Figure 15: Office building ‘2226’ in Lustenau
(Source: URL 9; Photographer: Baumschlager Eberle)

Approaching almost 22,000 residents, Lustenau is the most populous market community in Austria. It is located in a close proximity of 15 km to the regional capital of Vorarlberg, Bregenz. This circumstance offers not only a good infrastructure for all residents, due to the climatic influence of Lake of Constance, the building also benefits from a temperate climate especially during winter.

The fundamental idea of the building was to create a high performing and functioning object without being reliant on heating respectively cooling facilities. As a result ‘2226’ is not equipped with any heating, cooling or ventilation system. The required heat results from its occupants and existing facilities in the building such as computers, light bulbs, etc. Arising from that, the buildings temperature must kept in the range between 22°C and 26°C. Based on this concept the building got its name: 2226. In order to sustain comfortable room conditions, all windows are equipped with a motor based appliance, which opens and closes them relating to signals from CO_2 and temperature sensors.

The buildings gross floor area adds up to 3,456 m^2. Beside a gallery and a cafeteria in the ground floor, the other five floors provide space for offices. The principal floor arrangement is designed in an open manner, which is represented by the circumstance that neither doors nor drawn through walls are inside of the building (see Figure 16). Also remarkable room heights of 4.5 m in the ground, respectively 3.4 m in the upper floors reflect this concept. However, beside the design the great room heights were constructed to create a better atmosphere of natural light and a more effective air circulation. This effect is further contributed by the installation of room-height-windows. They enable an air transition over the complete room.

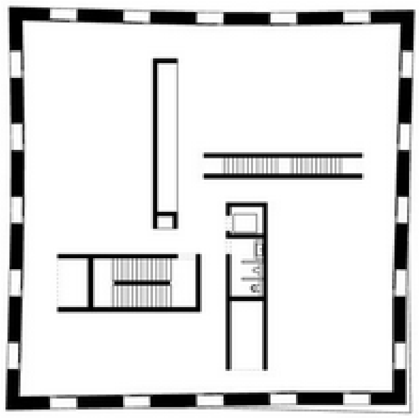

Figure 16: Standard floor plan of the building ‘2226’
(Source: URL 9)

The buildings massive construction is built in a specific way to loose only a minimum of heat through the wall. Furthermore, a maximum of energy shall be absorbed by the storage capacity of floors, ceilings and walls. In order to this aspiration, the building is equipped with a two-layer (76 cm) exterior wall, it is constructed with honey comb bricks (see Figure 17). Each layer has a thickness of 38 cm, whereas the inner layer has a statically supporting and the outer layer an insulating function. This is accomplished by different perforation ratios between the options: the inner brick has a smaller and the outer brick a greater ratio. Due to the low resulting U-value of 0.14 $W/(m^2.K)$, no further insulation material (e.g. mineral wool or polystyrene) was needed. Only the flat roof is conventionally equipped. This means, on a based concrete construction, additional layers of foil sealing, XPS tapered insulation and gravel contributes to a low U-Value. However, not only the thought trough constructions of the exterior layer help to achieve a low heating demand, also the cube based building shape and its optimized A/V-ratio of 0.25 m^{-1} are responsible. Additionally, three paned thermal insulated glazing sets in a wooden frame provide a good level of insulation of the transparent building constructions. Moreover, their deep position in the window soffit gurantees a natural shading especially during the summer. Otherwise, there are not any shading elements. Consequently, the solar radiation on east and west can contribute to an uncomfortable climate in the building. The window ratio of the whole building adds up to 24 %.

Figure 17: Wall construction with honeycomb bricks of the building ‘2226’
(Source: URL 10; Photographer: Baumschlager Eberle)

3.4 Building structure in Austria

During the last 40 years, Austrian power supply was facing an increasing demand of energy. Especially the transportation sector but also the industrial and household sectors induced significant expansions which lead to an almost doubling of the gross national energy consumption. According to the German Federal Ministry of Transport, Construction and Urban Development (2011), the rate for building conditioning amounts to 50 % of the total primary energy requirement. However, this does not include only the household sector. The service industry and the public sector are also influencing the heating demand. With the greatly increased heating demand and the possibility of an energy saving factor of 10, the huge potential becomes obvious. Even though the crucial technology has been available for more than 20 years, the progress is still in an infancy stage (Ruepp, 2012). According to the Federal Agency for Civic Education (bpb, 2013), 73.5 % of the energy in households is used for space heating and another 12 % for water heating. This concludes that less than 15 % are used for electricity. In 2012 this was around 4,100 kWh/a (Statistik Austria a, 2014). Nevertheless, in a holistic evaluation the consideration of daily energy consumption in buildings has to be extended by the aspect of grey energy. Grey energy denotes that energy which is required for manufacturing, delivery, construction, maintenance and finally disposal of building components. Consequently, designers and architects can influence a buildings energy performance not only by improving its building envelope to guarantee a low consumption in aspects of heating, they also can and should look for components with a low energy demand in construction, manufacturing and so forth (Salzmann, 2010).

A closer look to the building structure shows that almost 2.2 million buildings with 4.4 million dwellings exist in Austria. Nine out of ten buildings are used for residential purposes. Two thirds (1.44 million) of all buildings are single family houses and around 530,000 buildings having two or more dwellings (Statistik Austria b, 2014).

As Table 1 depicts, almost 50 % of the entire building inventory was built before 1970 and only 25 % in the last 20 years. This results in a relatively low overall energy efficiency standard. Even new buildings have to reach a heating value less than 54.4 kWh/(m².a), the average in Austria comes to 170 kWh/(m^2.a) (Austrian Energy Agency, s.a.; Proidl, 2009). Comparing the current average state with the possible potential, it becomes obvious that a significant amount of improvement is feasible. The ‘bpb’ (2013) estimates the reduction in the German heating energy demand of 40 % by 2030. However, this involves a modernization rate of 2 % each year.

Table 1: Buildings by type and year of construction in 2011
(Source: Statistik Austria (2014). Census 2011 Austria: Results of the Register-based Census)

Topics	Buildings	Of which			
		residential buildings	of which		other buildings[1]
			with one or two conventional dwellings	with three or more conventional dwellings	
Total	2 191 280	1 973 979	1 727 129	246 850	217 301
	Year of construction (in %)				
Before 1919	14.9	14.4	13.4	21.2	19.9
1919 to 1944	7.6	7.7	7.4	9.8	6.4
1945 to 1970	24.0	24.2	24.1	24.6	22.8
1971 to 1990	28.8	28.8	29.8	21.2	28.8
1991 or later	24.7	25.0	25.2	23.2	22.1

As exemplary country, Austria is, relating to ‘Passive Houses’, one of the most sophisticated nations in the world. Treberspurg (et al., 2009) has pointed this out by citing several examples: Thus Austria has the largest PH area per resident worldwide and Vienna has the greatest PH area of all towns on the globe. Furthermore, the largest (Eurogate) as well as highest PH (Raiffeisenhaus) are located in Austria’s capital city. Even exact numbers are not available, about 10,000 objects have been estimated (Lang, s.a.). Hence, ‘Passive Houses’ only amount up to 0.01 % of all Austrian dwellings. This figure illustrates the enormous potential for low-energy-buildings in Austria. Moreover, during the last ten years further building concepts (e.g. Plus energy buildings, Minergie) have emerged. These developments can bring further improvement to the building sector in the future.

4 Method and Material

Based on the demonstrated research question in 1.2, this chapter presents and explains all substantial process steps and applied methods in the context of a life cycle assessment of sustainable residential building concepts. In order to already listed and detailed information about the discussed building concepts, it might be helpful to read chapter 5, which discusses the building characterizations and adaptions, in advance or parallel.

4.1 Compilation of files and data

The compilation of literature, relating to the current state of research was primarily made by a bilingual (English and German) term quest via the search of the portal 'BOKU:LITsearch'. This platform shows results, which are available at the University of Natural Resources and Life Science (Vienna). This begins with university owned libraries and expands to a diverse selection of electric sources (e.g. e-books, journals and newspapers). My choice of buzz words was 'LCA building', 'eco balance building', 'cumulated energy demand' and 'life time expectancy building'. Complementary, I also consulted 'CatalogPlus', an online portal of the Technical University (Vienna) which was also used for the source search. In a second phase further literature was gathered via the pyramid scheme. From sources like König et al. (2009), Kümmel (2000) and Sorensen (2011) important sources are filtered and further examined. As an additional step towards the LCA of this paper, a guideline from 'ILCD' and relevant standards (e.g. EN ISO 14040/14044, ISO 15686-5, EN 15978, DIN 276) were gathered and studied.

The theoretical information was supplemented by documents and data of real building projects, which are used as a basis for the scientific approach of this paper. Data of the Passive House (PH) concept ('young corner') were provided by the architectural office 'Treberspurg & Partner', as well as the 'Institute of Structural Engineering' at the University of Natural Resources and Life Science. The relevant information about the Sun House (SH) concept, which is based on the Austrian largest SH at Freistadt; Mr. Stockreiter, who is the head of the Austrian Sun House Initiative, delivered important data. The building for the Low-tech (LTB) concept is represented by the already mentioned project '2226'. Access to essential data was very restricted. Unfortunately, neither the architectural office 'Baumschlager Eberle' nor the owner was willing to provide substantial information. Also a proclaimed book, which should be published in May 2015, is not yet available (status October 2015). Therefore only available articles and papers could be used as information sources.

4.2 Selection process of the papers representative buildings

With the aim of comparing building concepts for large volume residential buildings, the subsequent objects were chosen as representative buildings and for a deeper investigation. A detailed description can be found in chapters 5.1 (Passive House), 5.2 (Sun House) respectively 5.3 (Low-tech Building).

4.2.1 Passive House 'young corner' in Vienna

The housing estate 'young corner' (~7,000 m² useful floor area) is located in Vorgartenstraße/ Leystraße in the second district of Vienna and was chosen as the basic model in this study. The decision for choosing this particular object was influenced by several factors. A major aspect was the availability of relevant data. Due to the fact that the building was conceptualized and planned by the supervisor's (Univ. Prof. Arch. DI Dr. Martin Treberspurg) architectural office 'Treberspurg & Partner', an easy access was guaranteed. Moreover, the point of working with a building, which is also well known by the second supervisor (DI Roman Smutny) made it easier to clarify uncertainties and to adapt the building to the other two concepts.

4.2.2 Sun House in Freistadt

The selection of the SH in Freistadt resulted from an examination of all multiple dwellings in Germany, Switzerland and Austria, which are officially declared as SH. The process of survey was thereby based on the database of the German and Austrian Sun House Institute, respectively initiative. After the surveying process, it complemented the list with eight possible objects (see Table 2).

Table 2: Searching result of relevant Sun Houses in Germany, Switzerland and Austria (Source: URL 5)

Locality	Usable area	Residential units	Residents	Heating demand	Collector surface (in m2)	Storage volume (in l)	Solar cover ratio (in %)
Großostheim	1614	16	-	55	232,5	66900	65
Harrislee	1276	18	40	-	368	66000	75
Oberburg	1230	8	-	71	300	205000	100
Freistadt	1028	9	-	30	143	4x1000	52
Rodgau	579	4	-	43	102	23000	67
Grandl	549	3	-	36	62	14900	53
Regensburg	527	4	-	25	48	10400	75
Wottka	197	3	-	85	60	8720	56

As a result of this table, the dwelling in Freistadt turned out as the most suitable object. Relevant aspects for this decision were an appropriate and not over dimensioned solar cover ratio, the same utilization (dwelling house), comparable apartment sizes, the aspect of being Austria's largest sun house, which has a great geographic proximity to the base model of this thesis, as well as the access to essential data and documents. Moreover, with a heating demand of 30 kWh/(m^2.a), it exactly fulfills the minimum requirements related to the OIB-6 directive, for the given building structure of the base model.

4.2.3 Low-tech building in Lustenau

The office building ‘2226’ was chosen as the representative building for the concept LTB. The decision was made by consulting the participating experts during the final building workshop of the project ‘LOW TECH BUILDINGS = LOW COST BUILDINGS?’ in St. Pölten at April 9th, 2015. By analyzing 15 single houses, which were firstly declared as low-tech objects, the decision was made that ‘2226’ is Austria’s most appropriate multiple floor LTB. All 15 surveyed buildings (‘2226’ was not included) could not be seen as representatives of this concept. The main reasons were either an intricate system (e.g. concrete core activation, ground water heating pump or ventilation based heating systems) or the takeover of a poor working PH. Even, it can be controversially discussed, due to a missing specific concept and based on the lack of alternatives ‘2226’ became the first and only representative choice for this study. The reasons are an alternative double arrayed brick construction for exterior walls, low heating demand and relinquishment of a mechanical ventilation system. Nevertheless, as it can be seen in chapter 5.3 the conversion from an office to a residential building entails several adjustments compared to the principal concept.

4.3 Modelling process

Before the actually modeling process could be conducted, all essential details of the base model had been searched, investigated and finally reported. The intention of the research process aimed mainly to gain information from the energy certificate about building physics, which also include component assemblies and building services. The phase of investigation refers to working steps such as

- Scale measuring walls and floors:
  By means of the construction plans, which were available as pdf-files, all walls and floors were measured (see Appendix 1) with the 'Adobe Reader' measuring and finally compiled in an MS Excel file (see Appendix 2) to aggregate all surfaces of the entire building. On the basis of their different structures such as basement, ground floor, first floor, seventh floor and roof top were measured separately. From the second to the sixth floor, except of a very few variations, all are identical and therefore relating to the measurements of the second floor. A consideration of lintels and strip foundation was not conducted.

- Selection of the relevant building service components (see Appendix 3):
  According to the system boundary (outlined in chapter 4.5.2) not all building components where entered into the analysis. For eliminating negligible components, lists of all installed building technologies (electro technology, mechanical ventilation, process measuring and control technology) were screened and irrelevant data erased.

- Conformance of the component structure from the building physics and the available dataset of database 'ökobaudat' (which is further explained under chapter 4.5.1):
  Resulting from the fact that the databank has only a limited selection of evaluated and verified building components, it was necessary to match the real with the digital objects. This means to take material 'a' of manufacturer 'x' from the reality and exchange it with the material 'a' from manufacturer 'y' of the database, or taking material 'a' and replace it with an allied substance 'a*'. However, density or proportion of the particular material was unfailingly matched to the real conditions.

Originating from the PH and its findings, from the above mentioned process, the modeling procedure of the two bench marking concepts started. Preliminary with the idea of bringing up own created models the huge interrelated workload rejected this idea. Therefore, substantial influence came primarily from already existing objects, which were investigated in the already described process from chapter 4.2. This information was further supplemented by diverse literature sources such as Treberspurg (1999), Kaltschmitt et al. (2006) and Königstein (2011). After a phase of orientation and working through information, the consultation of the thesis supervisor (DI Roman Smutny) was the last step for approving the selected approaches. With the aligned ideas and arrangements for the SH and the LTB, the objects could be specified. The detailed adaptations are described in chapter 5.2 and 5.3 and complemented in the LCA.

After the definition of the particular changing components for the SH, it was necessary to calculate how far the solar thermal facilities of the original object in Freistadt could be adapted to the modeled house in Vienna. As a verifying instrument, the solar calculation software 'Polysun' was taken (more information in chapter 5.2.3). Moreover, for conducting a new LCA it was preliminary necessary to recalculate data of the energy certificate of the adapted building (more information in chapter 4.4). As a consequence of restricted access to detailed energy certification data, this task was taken by the thesis supervisor DI Roman Smutny. Finally, with the new data, the previous LCA (more information in chapter 4.5) was adapted with the changed constructions and building services. A similar procedure with different adaptions was also accomplished for the LTB.

4.4 Energy certificate

Energy certificates functioned amongst others (e.g. plans, component catalogues, etc.) as important sources for the whole LCA. Regarding to this, it was important to have certificates for all different objects. Unfortunately, it was not possible to get one for the LTB. However, with details about the buildings, which respond to the outer layer and a general absent of the mechanical ventilation system, it was also possible to use it as a modelling object, or rather to conduct all necessary calculations. In the process of modelling the SH, as well as the LTB, a further calculation map was compiled, which entails adjusted exterior walls with their changed structure, or at least different thicknesses, adapted building services and finally new U-values, as well as heating demand results for all three objects[5]. The underlain guideline for all calculations is the OIB 6 directive. This guideline contains relevant standardizations for energy savings and thermal insulating aspects. Being more specific, the underlain and actual validating formula for meeting requirements, regarding to the heating energy demand of new residential constructions (valid since 2011), is the ‘16s curve’, which composited as (OIB, 2015):

$$16 \times (1 + 3{,}0 / \ell_c)$$

The result, which underlies the compactness of a building, respectively its characteristic lenghts l_c (reciprocal value to the A/V-ratio). As long as the calculated value is below 54 kWh/(m².a) the building meets the requirements. Regarding to the topic of calculating energy certificates, another point has to be taken into consideration. As the building regulations determine (under 4.4 of OIB 6), constructions (related to its position) must not exceed a certain level of U-value (W/(m².K)). The levels are ranging between 0.2 and 2.5 W/(m².K), and the relevant categories and U-values for this study are:

Ceilings towards outdoor air	0.20 W/(m².K)
Walls towards outdoor air	0.35 W/(m².K)
Walls with contact to the ground	0.40 W/(m².K)

Based on the calculated and consequently increased heating demand of each modeled concept, an adaptation of the connected load for district heating should be considered in a practical perspective. However, in terms of a theoretical analysis and an absent influence on LCA results, this aspect was not further considered.

A compliance of the evaluated aspects is shaping the general conditions for adapting the variations to the given building in Vienna. At this point it has to be mentioned, that the solar system of the SH concept is not included in the calculations. The reason lies in the inappropriate reproduction, which is caused by the energy certificate calculation program, of large solar thermal systems. Only a pump is set into the program to represent the continuous energy demand for the water circulation process. Nevertheless, the solar contribution to the heating system is finally taken into consideration by including it in a LCA.

4.5 Implementation of the Life Cycle Assessment

The conducted LCA strives for an environmental analysis of three different building concepts on a quantitative basis. This entails a primarily focus on the climate relevant gas carbon dioxide which is highly related to the fossil based primary energy demand. According to this, the study assesses all major energy flows, from the process of manufacturing over utilization to disposal. The ‘EN 15978’ as well as ‘EN ISO 14040 and 14044’ represents the underlying standard. The methodology again, accords to the ÖGNI and DGNB.

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[5] The results are added in the Appendix 16

4.5.1 Database information

The main source for LCA relevant data was the Ökobau.dat (URL 8) which is based on the GABI data set – a well-known tool for LCA. The public accessible portal provides comprehensive data about products and materials with regard to their total life span (production – utilization – disposal) in which each phase is separately examined. With the consistent approach and free accessibility, the developers of the portal strive for a vast comparability of life cycle data. In about 950 records, different construction elements are described by their substantial characteristics (material, density, volume, etc.) as well as their energy intensity and consequential impact indicators (abiotic resource consumption, greenhouse-, acidification-, photochemical ozone creation-, eutrophication- and ozone depleting potential). For a better usability, the examined elements are split into nine different categories:

1. mineral materials
2. wooden materials
3. metals
4. coating and sealing
5. synthetic material
6. components of windows, doors and curtain walls
7. building technology
8. others

Some of the records have a generic basis, others are premised on investigations of enterprises or federations. However, due to the fact Ökobau.dat is based on German conditions, the energy-mix is not representing the Austrian energy production settings. With a great contribution of water power, Austria has a larger ratio of renewable energies in their production of electricity and therefore a lower greenhouse gas output than Germany (Obereder, 2013). For this reason, the 'Ökobau.dat' data set of electricity is replaced by figures from the ÖGNI (see Appendix 4).

Even the data set has been regularly updated (2011, 2013) and meets the standards of DIN EN 15804 since the last novation the results of this thesis are referring to the records from 2009. The reason lies primarily in the fact, that with the standardization the availability of records were reduced over the years. As an example, the section 'bricks' can be invoked: In 2009 the data set entails 1) facing bricks and 2) honeycomb bricks. But in the version of 2013, only the first option can be selected. This applies also for other materials and finally results in the fact that more than 25 % of the data set had been removed which made an examination in this case less feasible. One example of a record can be found in Appendix 5.

As a supplement for the requested aspect of lifespan evaluation for different materials and products in a LCA, two sources have been utilized. The first and major source is also included in the German Assessment System for Sustainable Building (bmub, 2015) and the guideline is called 'Nutzungsdauern von Bauteilen' (means in Engl. Service life of structural elements) and is partly examined in Appendix 6. The provided data relates mainly to construction related materials. The second source is from the VDI (Verein Deutscher Ingenieure means in Engl. Association of German Engineers). The relevant document for this is the directive VDI 2067 Blatt 1. This is the principal directive followed for building service related objects in terms of building facilities and their cost calculations.

4.5.2 System boundary

With the definition of the systems boundary, an adapted simplified calculation method is applied (see Figure 18). This omits the consideration of all outside facilities, transportation and construction processes, inspection and maintenance activities, as well as all compound materials. Moreover, a surcharge of 10 % is automatically calculated by applying the data set of Ökobau.dat. Outgoing from that, the assessment of the building includes the following components (ÖGNI, 2014):

1. exterior walls including windows and coating
2. roof and floor ceilings including floor structure and - surfaces
3. base plate including floor structure and – surfaces
4. foundations
5. interior walls including pillars, coating, windows and doors
6. mechanical ventilation facilities (including air duct)
7. other building related facilities (e.g. solar panels)
8. user equipment with relevant energy consumption during the utilization phase
9. aquiferous facilities
10. cable for electric installations

For the reason that the examined building concepts show remarkable differences relating to air and water ducts, as well as to cable and electric devices, point 9 and 10 are also considered in this thesis, even though they are not a part of the classically simplified calculation approach. All components are listed with their entire layer structure and connected with their total applied area. For all floor related components the gross floor area is used as the decisive dimension. For the specific goal of finding the concept with the lowest environmental impact, a major focus lies on building services. This entails a consideration of all technical facilities, as well as their corresponding supply system (e.g. pipelines and shafts). The assessment is set within a time frame of 50 years. Even many components exceed this limit, the factor remains as common observation period in practice because it makes bench marking more feasible. Moreover, in the end of life perspective all utilized components are considered and classified by their potential of recycling, reusing and recovery. Relating to the utilization phase, consumption of electricity and heat are considered by their pre-assumed and not real figures.

The attached Figure 18 gives a lucid outline of the considered (white) and excluded (blue) fields of the thesis' LCA.

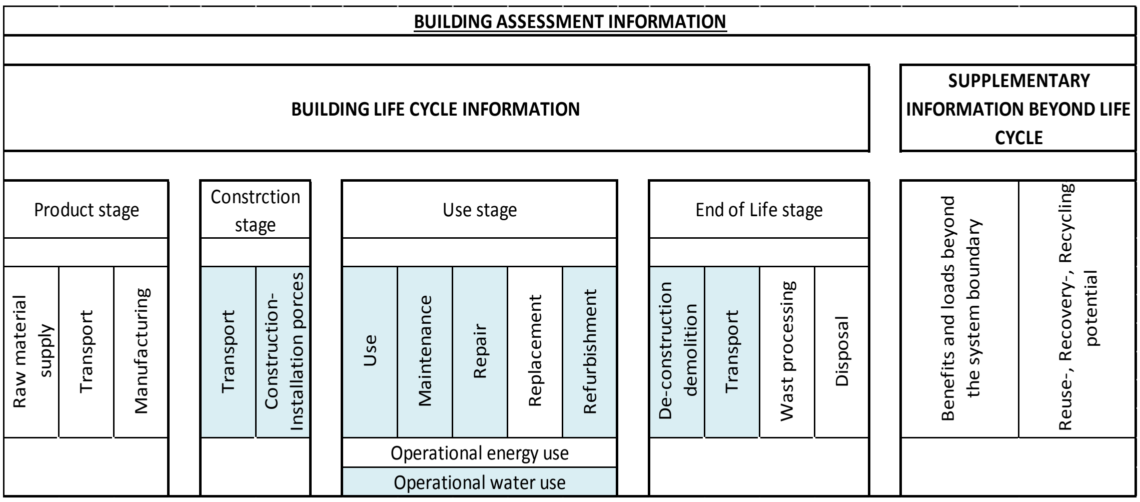


Figure 18: Considered and non-considered (blue shaded) fields of LCA
(Source: Own illustration in accordance to ÖNORM EN 15978)

4.5.3 Data compilation

The applied tool for the LCA calculation (LCA-tool) is based on Microsoft Excel and was designed by the staff members of the scientific work group 'Ressourcenorientiertes Bauen' (Engl. Division of Sustainable Construction) at the University of Natural Resources and Life Science, Vienna. The implemented tool is drafted in the German language. Its input is based on data from Ökobau.dat (2009). For not available materials, so called Environmental Product Declarations (EPD) were applied, respectively inserted in the tool. One specific example for this is given by the phenolic foam insulation (see Appendix 7).

As a small image, Figure 19 shows the principle design of the tools input area:

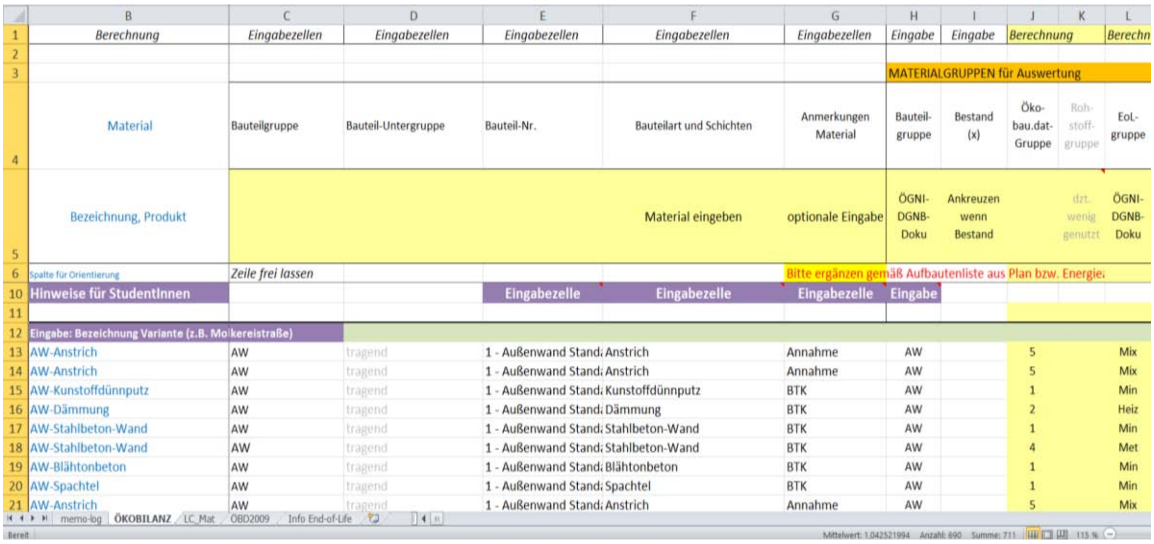


Figure 19: Input area design of the LCA-tool

The process of editing follows a continuing procedure for each material of every component which consists in turn of further sub-components:

1. Entering the components indication by specifying its application, title, layer structure, material and source.
2. Referring to its component assembly (regarding Ökobau.dat structure) the particular records are taken and pasted from a XML-file of the Ökobau.dat database into the Excel tool, which in turn is the basis for the result calculation.
3. The significant differences from the implemented to the calculated elements must be mentioned in a separate cell because of the limited availability of materials.
4. According to the determined unit (kg, m^2, m^3), the particular material characteristic from the Ökobau.dat record has to be inserted (this is an additional step to point 2 because the unit cannot be automatically inserted from the XML-file). If the theoretical value differs from the real value (building physic catalogue), the adaption is supplemented in step 8.
5. The components 'End of Life' determination is the next step. With information about potential recycling possibilities, every element is matched with a certain disposal method.
6. The components life span, according to the already mentioned source from 'nachhaltigesbauen.de', has to be inserted. As an additional task, it has to be screened that lifespan of outer-layers are not affected by shorter lifespans of internally located materials. Otherwise the longer lifespan has to be reduced and replaced (in reality) when the lifespan exceeds[6]. A further column displays the number of replacements within the evaluated timeframe of 50 years.
7. Entering the net-area of the particular component.
8. Entering the quantity of the particular (sub-) components can be done by three different approaches: I) sizing by the layer structure; II) sizing per area; III) sizing in total. Generally the first approach is the most common, but coating (II) and windows/doors (III) are sized by the alternative approaches.

[6] This approach represents the standardized method. However, parts with two massive constructions and an internally located insulation layer (e.g. EPS) or a ceiling which would require a complete demolition, a deviation from the provided approach is realized. This means, shorter lifespans of internally located layers are ignored and therefore adapted to the longer life span.

These eight steps had to be replicated for each component and subcomponent of the building. At the end of each element, the tool calculates its particular impact indicator. A small image of the tools output area is given in Figure 20. The green marked fields demonstrate a low level of CO_2-Emissions, yellow a medium, orange a high and red a very high level.

	B	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI
1	Berechnung								50		Bilanzrahmen:		50	Jahre
2		Rohdaten Ökobaudat - Herstellung							Rohdaten Ökobaudat - Herstellung		Ökobilanz Herstellung pro Jahr und pro m² NGFa			
3											kg	kg	kg	kg
4	Material	GWP 100	ODP	POCP	AP	EP	PE nr	PE r	PE s		GWP 100	ODP	POCP	AP
5	Bezeichnung, Produkt	kg CO2-Äqv./EH	kg/EH	kg/EH	kg/EH	kg/EH	MJ/EH	MJ/EH	MJ/EH		kg CO2-Äqv./m^2_{NGF}	kg /m^2_{NGF}	kg /m^2_{NGF}	kg /m^2_{NGF}
6	Spalte für Orientierung										Faktor 1,1 für vereinfachtes Verfahren ist in unten stehenden Werten be			
10	Hinweise für StudentInnen													
11														
12	Eingabe: Bezeichnung Variante (z.B. Mo													
13	AW-Anstrich	2	1,47E-07	0,006	0,041	0,001	48	1	0	5	15,272	9,77E-07	0,036700	0,26896
14	AW-Anstrich	1	6,93E-08	0,003	0,012	0,000	24	0	0	5	7,401	4,60E-07	0,020236	0,08171
15	AW-Kunstoffdünnputz	1	4,93E-08	0,003	0,007	0,000	19	0	0	1	282,479	1,61E-05	0,859409	2,38249
16	AW-Dämmung	87	2,61E-06	0,031	0,189	0,020	2 663	12	0	2	629,212	1,89E-05	0,223136	1,36645
17	AW-Stahlbeton-Wand	238	6,30E-06	0,043	0,416	0,059	1 201	22	432	1	866,123	2,29E-05	0,155552	1,51499
18	AW-Stahlbeton-Wand	1	7,85E-08	0,000	0,002	0,000	12	1	0	4	4 318,503	3,88E-04	1,353308	8,11166
19	AW-Blähtonbeton	338	7,95E-06	0,124	2,294	0,119	2 349	71	154	1	572,599	1,35E-05	0,209706	3,89114
20	AW-Spachtel	0	3,84E-09	0,000	0,000	0,000	2	0	0	1	23,086	7,52E-07	0,002743	0,02802
21	AW-Anstrich	3	1,85E-07	0,008	0,042	0,001	62	1	0	5	12,594	8,36E-07	0,033936	0,18909

memo-log ÖKOBILANZ LC_Mat ÖBD2009 Info End-of-Life

Bereit

Figure 20: Output area design of the LCA-tool

Following the above described process, steps 1), 2), 3), 4), 7) and 8) are relating to a components production phase. The underlying data comes from the energy certificate, component catalogues and building plans. However, in addition to the given data from the building physics component catalog coating/painting is a further material, which is considered for several in- and outdoor walls. Moreover the evaluation of windows and reinforced concrete requires several assumptions. Inasmuch as the energy certificate does not differentiate between frame and glass of a window, it is necessary to set a fixed frame-glass-ratio. As the experience shows, a 30:70 ratio seems practical. Another window relating aspect in this thesis goes back to the utilization of triple-glazing-windows inside the building. Because the data set of Ökobau.dat has not listed any triple-glazed-window systems, the double-glazing as well as the linked frame are multiplied by factor 1.5. Also the constructions with reinforced concrete are estimated in a similar way as the windows before. With the underlying information of the ÖGNI (2015) model component catalog (see Appendix 8) the ratio of steel is depending on the particular application. Thus, it can range between 1.02 V% for normal walls to 2.04 V% for ground touching baseplates. The process of measuring is not conducted in the claim of total accuracy. Instead, it shall represent a kind of rough evaluation of the buildings structure. In relation to this fact built parts above/below doors and windows are not considered. But also details (see Figure 21) are neglected, or rather spaciously measured in context to the dominating component construction in the particular area. Nevertheless, the neglected parts do not exceed the mandatory proportion of 10% (ÖGNI, s.a.).

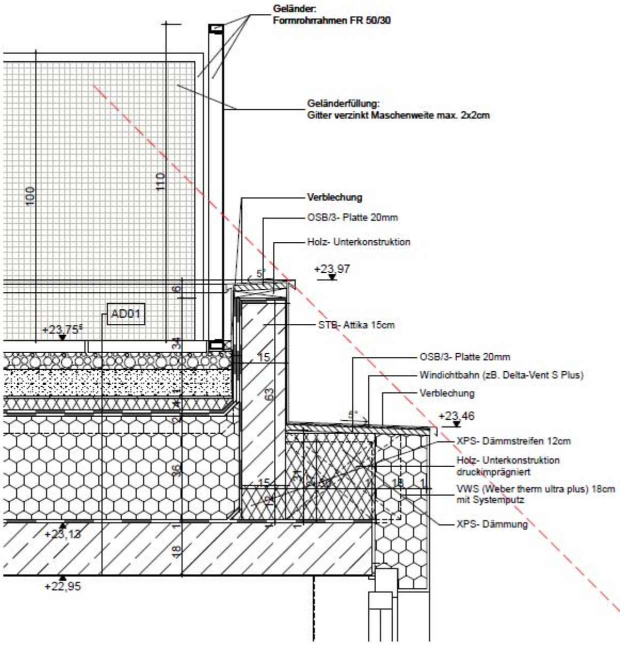


Figure 21: Detailed section of a component on the buildings roof
(Source: TREBERSPURG & PARTNER ARCHITEKTEN ZT GES.M.B.H., Projekt Nummer 2007-12, Detailplan VGS A)

Relating to maintenance, step 6) already describes the fundamental approach. Complementary in context with the entire utilization phase the final energy demand is also considered in the analysis. However, it has to be mentioned that the final energy demand relates to calculated results and not to real measured consumption figures. From the final energy demand a factor, related to the energy mix, converts it into the primary energy demand which allows analyzing different environmental impacts. Proportions of common eco-electricity dispositions and efficiency factors of heat generation facilities (e.g. district heating) are already considered in the calculation (ÖGNI, 2014).

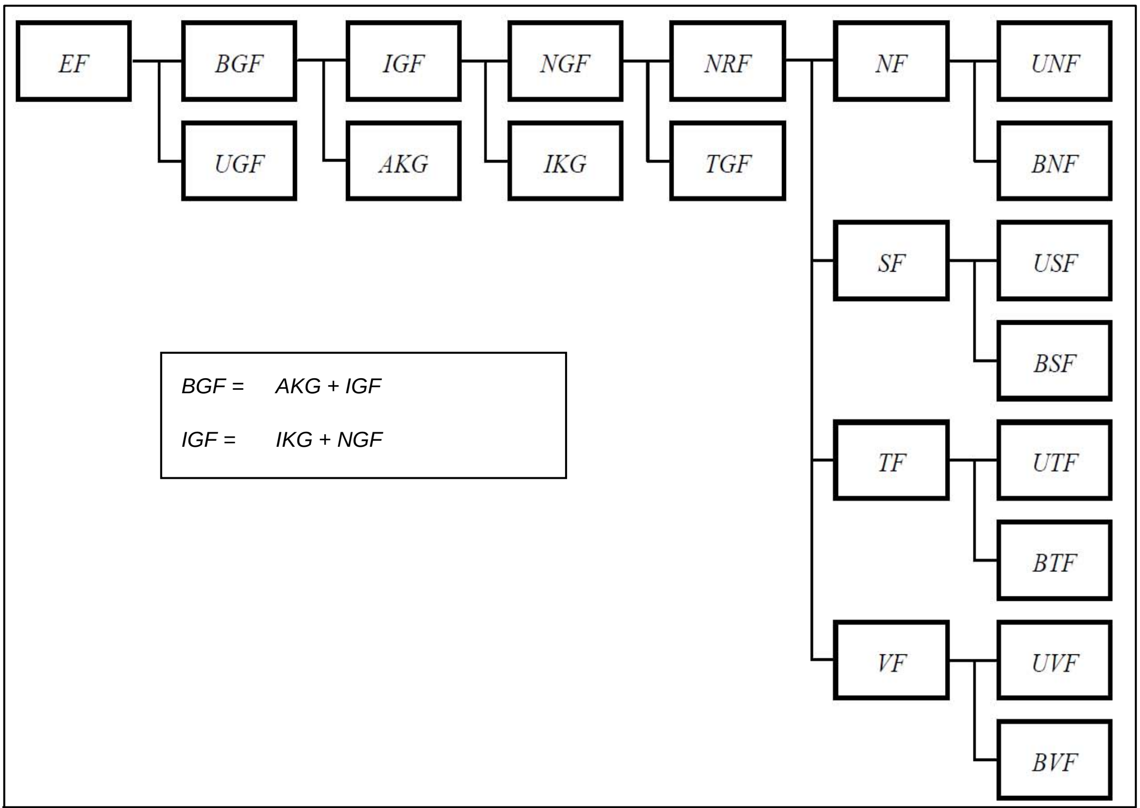
For an integrated LCA the so called End of Life (EoL) scenarios must not be missing. This means that all building materials have to undergo a specification relating to its disposal utilization. As a simplification, this specification also can be allocated to groups of materials with a similar EoL scenario. Following material groups can be differentiated (DGNB, s.a.):

1. Metals for recovery: Metal recovery applies in particular for metals from a primary production. All others, already recycled metals, do not feature any recovery potential.
2. Mineral materials for recovery: Mineral materials with potential for recovery are common components like concrete which can be used as a stowing for street- and landfill constructions.
3. Materials for thermal utilization: For a thermal utilization different materials like wood or plastic can be taken and the thermal gain (heating value) will be credited.
4. Materials for dumping: As far as materials cannot be used as sedimentary depositions they belong to the category of dumping materials. This is particularly the case with glass, mineral wool, bituminous sheeting, plasterboards, etc.
5. Mechanical ventilation systems: This category is not further considered in this thesis. All for mechanical ventilation relevant components are directly allocated to one of the four first mentioned groups.

The correct category has to be chosen for each material. With another XML-file all relevant information is transferred into the Excel calculation tool.

The subsequent evaluation is made on the gross floor area which does not represent the DGNB-method. Anyway, the approach of taking the fixed gross floor area allows to point out interrelations for different wall thicknesses without affecting the entire LCA by changing floor sizes. Furthermore, the gross floor area includes also all traffic-, technical and sanitary areas with all their built constructions. The process of gaining the gross floor area is based on summarizing the net floor area of each room, which is given by the building plans. Additionally, the summarized figure is multiplied by a factor of 1.1. This practical factor contains, added to the 'living area', all constructions of in- and outdoor walls and reflects approximately the factual scale. For a better understanding of the difference between gross- and net floor space

Figure 22 depicts the fundamental texture of different floor dimensioning approaches according to ÖNORM B 1800 (2003).



EF =	*level surface*	*IGF =*	*indoor floor area*	***BGF*** *=*	*gross floor area*
AKG =	*exterior wall constr. area*	***NGF*** *=*	*net floor area*	*NRF =*	*net room floor*
IKG =	*interiorly wall constr. area*	*TGF =*	*partition wall constr. area*	***NF*** *=*	*usable area*
SF =	*sanitary area*	*TF =*	*technical area*	*VF =*	*traffic area*

Figure 22: Floor related areas
(Source: ÖNORM B 1800 (2013) adapted by Armin Holdschick)

4.5.4 Data evaluation

Outgoing from the functional unit (gross floor area) all inserted elements in the inventory analysis and linked results (see Appendix 14) get examined by several approaches. The first hierarchy of comparison is based on:

- Representing the final results over all applied environmental impact factors
- Comparing Global Warming Potential and Primary Energy (non-renewable) demand on a material based approach
- Comparing Global Warming Potential and Primary Energy (non-renewable) demand on a component based approach

However, the focus lies on the two last mentioned approaches. Thus, the primary indicators are kg/(m^2.a) for Global Warming Potential and kWh/(m^2.a) for Primary Energy (non-renewable). In a second hierarchy, the elements get further evaluated either by

- comparing the concepts to the different life cycle phases or the
- comparison of the concepts to any possible approach of the already mentioned methods (e.g. component based assessment with their related material utilization).

These approaches are applied in subsequent Excel spreadsheet and consequently representing the impact balance of ecological impacts. The interpretation is explained in chapter 6 and 7. In accordance to the operational energy, a further sheet was prepared and linked to the main inventory balance. However, additional to this, a fourth building concept is also considered. Specifically, it represents a standard building after legislation requirements and furthermore serves as an example for the sophisticated standard of the examined sustainable buildings. It also flows into the above mentioned comparing categories.

5 Examined building concepts

In this section of the thesis, the actual building “young corner” and scenarios for this housing complex are described in detail regarding to their life cycle inventory.

- Version 1 - actual building: Housing complex “young corner” in Passive House Standard (PH)
- Version 2: Scenario Sun House (SH) of housing complex “young corner”
- Version 3: Scenario Low-Tech-Building (LTB) of housing complex “young corner”

5.1 Version 1 - actual building: Housing complex ‘young corner’ in Passive House standard (PH)

As already mentioned in chapter 3.1.2, the PH ‘young corner’ was designed by ‘Treberspurg & Partner’ and is the world’s largest construction with phenolic foam insulation (see Figure 23). The constructed area is 1,272 m^2 (gross floor area$_{conditioned}$ = 8,452 m^2) and the building has a heated volume of 25,352 m^3. The following description is based on a publication (Treberspurg et al., 2011) and additional information of the planning team.

Figure 23: South/west and west/east facade of the building ‘young corner’
(Source: Treberspurg & Partner Architekten (2011); Photographer: Treberspurg & Partner)

5.1.1 Urban construction conditions

The apartment building is located at the zone of Vienna’s former ‘Nordbahnhof’ (Engl. northern train station) in the second district. This area is one of Vienna’s most important developing centers for the future: Until 2025 the area shall get 20,000 residents and 10,000 working places. In regard to a sustainable development, several builder competitions were hold in which the concept of ‘young corner’ demonstrated its vigorousness. The basic idea of the building is to combine a youthful designed concept with a cost-effective but also a high quality approach. In a further contemplation, the conditions of urban construction are based on the principle of transmissibility and an open minded relationship towards public spaces as well as towards its neighborhood. Nevertheless, beside the connection to the growing area of the northern train station, the building is also situated in a good connection to the city. Public transport is available within a five minute walking distance and also Vienna's top leisure areas 'Danube Island' and 'Prater' can be easily reached due to its close proximity. Additionally, the city center can be reached within a 20 minute journey. All these urban construction conditions can be seen as a prerequisite for an ecological development. Furthermore, they reflect the former explained meta-dimension (see chapter 2.2) of a sustainable construction concept.

5.1.2 Architectural concept

The housing complex comprises 6,965 m^2 of usable area, which is allocated in 61 apartments (4,407 m^2), 10 dormitories (1,274 m^2), 19 small business offices (639 m^2) and 1 kindergarten (644 m^2). The complex is divided into two 10-floor buildings, whereas 7 floors are appareled with apartments. The other 3 floors have different functions: The basement floor has a car garage with 72 parking lots and provides rooms for building service equipment; the ground floor is functioning as a puffer zone and has storage rooms for the tenants; the 10th floor gives access to the roof terrace and –gardening areas[7]. The main house has a long shaped layout which is orientated to the south-west (see Figure 24 till Figure 29), so the building or rather the living areas have a distinct solar alignment. The shadowing is given by recessed balconies, which further separate the living quarters with wood lamellas and semitransparent colored acryl glass. To the greatest possible extent, the sleeping rooms and working areas are situated towards east and towards the tranquil courtyard. In return living rooms (e.g. parlor and kitchen) are situated towards south/west to gain a maximum of passive solar radiation, especially during the winter. The smaller building is located in the north and has a cube-shaped body. The shifted mini balconies are a characterizing design feature, which give the building a ludic atmosphere and reduces the optical building height. Another design feature is given by the planted flat roof, which reflects the principles of transmissibility and open minded relationship due to the installed community roof terraces.

Attributable to the objective of 'youthful living', the general floor plan was designed in a corresponding manner, which is reflected by a flexible and compact apartment design, a music rehearsal room and open, constructed entrance to the public surroundings. Nevertheless, necessities for elderly people and young families were also considered. Barrier-free accesses, due to the at ground level situated entrances, robust and easy to care facilities, as well as a semi-private playground are only a few aspects which cope with accompanying demands. The aspect of cost effective housing for all interest groups had been prior focus during the entire planning and construction process of the building. The result is remarkable: Due to the 'KALLCO-Baurechtsmodell' (Engl. KALLCO building rights model) and Vienna's housing subsidy program, a 60 m^2 apartment comes to a net rent of 300 € plus own funds of to 3,450 € in advance. This offer is further supplemented for young people and families by the dormitory establishments.

[7] Detailed plans of the building are added in Appendix 17

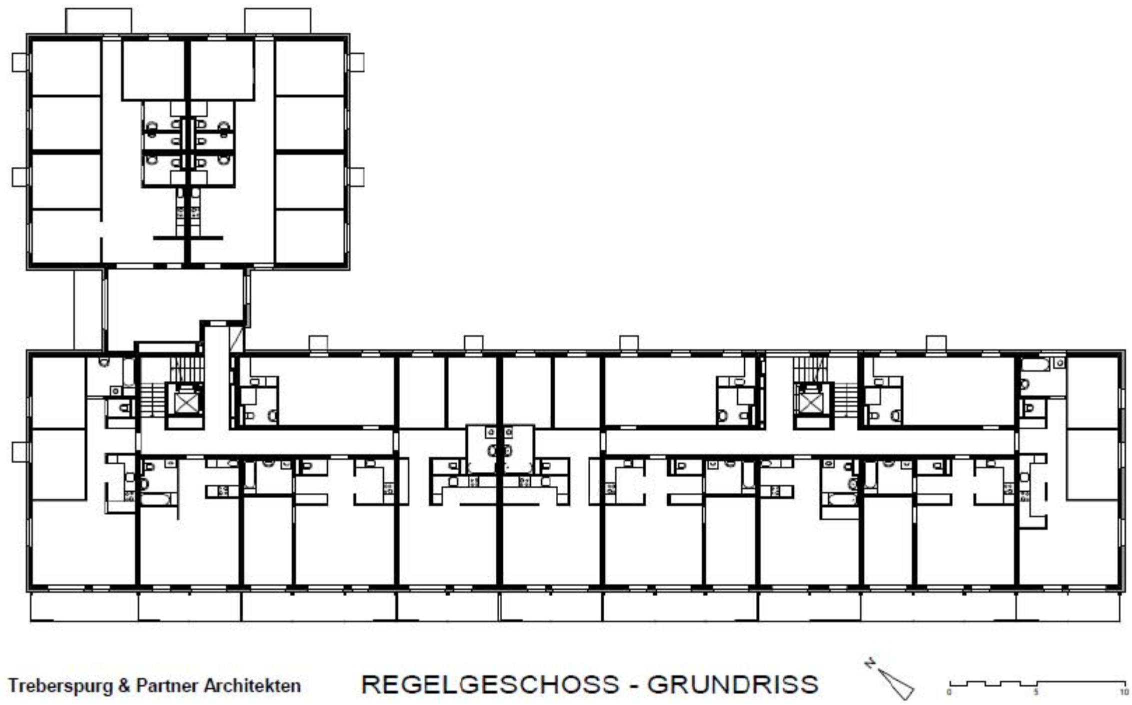


Figure 24: Standard floor plan of the building 'young corner'
(Source: Treberspurg & Partner Architekten (2009))

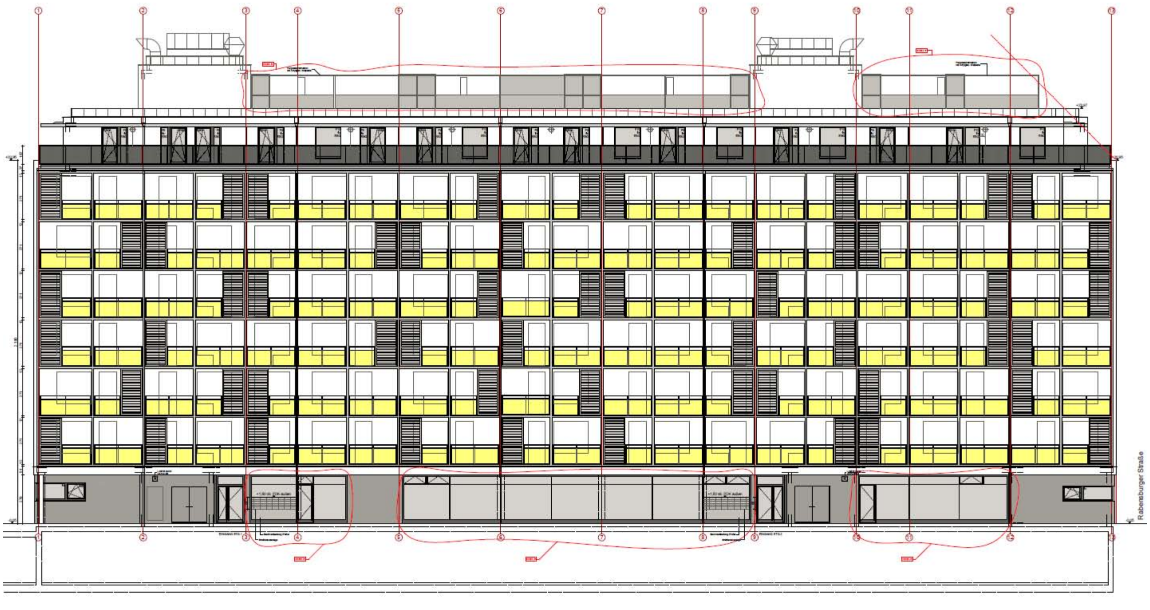


Figure 25: South/west facade of the building 'young corner'
(Source: Treberspurg & Partner Architekten (2009))

Figure 26: North/west facade of the building ‘young corner’
(Source: Treberspurg & Partner Architekten (2009))

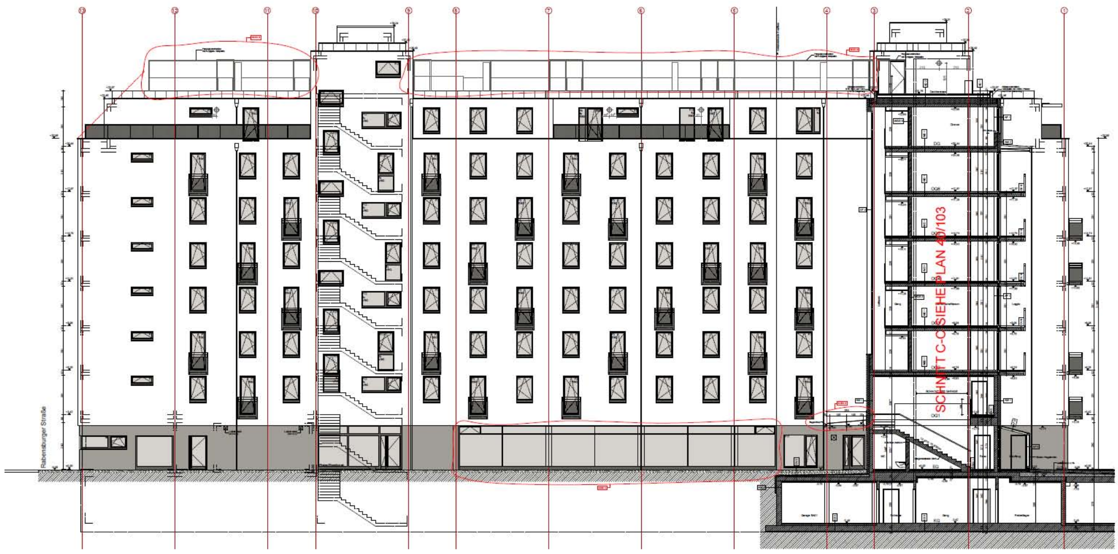


Figure 27: North/east facade of the building ‘young corner’ (I)
(Source: Treberspurg & Partner Architekten (2009))

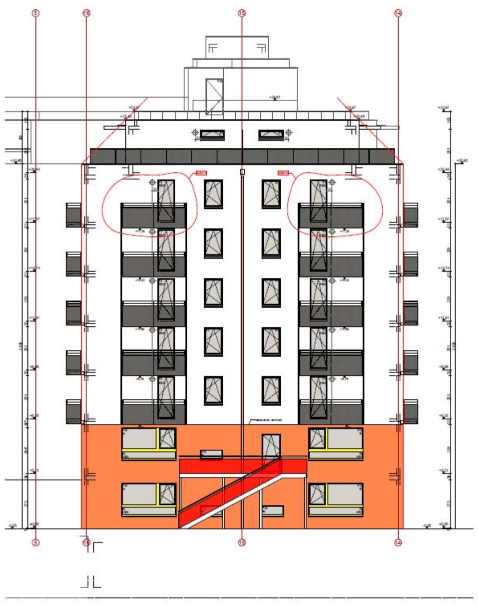


Figure 28: North/east facade of the building ‘young corner’ (II)
(Source: Treberspurg & Partner Architekten (2009))

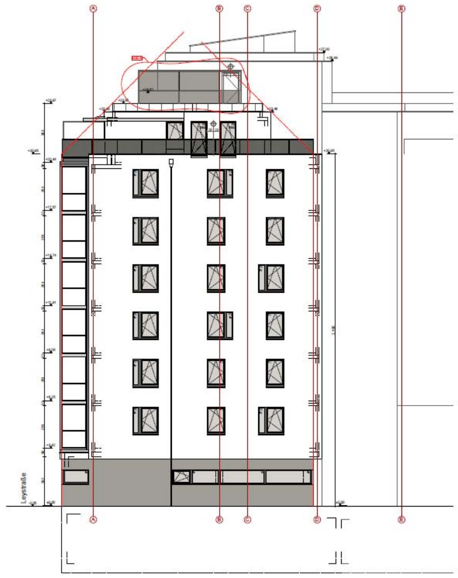


Figure 29: South/east facade of the building ‘young corner’
(Source: Treberspurg & Partner Architekten (2009))

5.1.3 Building construction

The construction process was conducted by the company ‘Porr Projekt und Hochbau AG’. Central goals had been the prevention from potential harmful substances and a high grade of quality assurance. These objectives were consequently honored with the ‘IBO-Ökopass’, which is a certificate from the ‘Austrian Institute for Healthy and Ecological Building’. The building achieved an excellent quality in 6 criteria and superior quality in 3 further fields of the assessment. Particularly stressed out results are the qualities of natural light (even during low sun standing periods) as well as marginal concentrations of solvents and formaldehyde. They were less than 10, respectively 100 times below the maximum criteria. The building has a massive construction and is made of reinforced concrete and brick-aerated concrete masonry. Further attention had been put on the insulation. As mentioned above, another distinctive feature of the building is the thermal insulation system which is based on resol hard foam (Treberspurg et al., s.a.). Resol hard foam is a thermosetting plastic material and made of resol resin. The foam is produced by a web of glass fleece and is featured by a small meshed structure, which affects a very low thermal conductivity (Schober, s.a.). The default value for thermal conductivity is 0.22 W/(m.K) according to ÖN B 8110-7:2013. Due to this characteristic feature, it was possible to gain more floor space by keeping a defined standard of insulation. In spite of the extra costs (+ 43 €/m^2), compared to a common EPS insulation, attributable to the greater floor space a higher rental income could be achieved. These circumstances lead to a positive present value, which is mirrored by a plus of 145 €/m^2 net facade area within the first 25 years and threefold result after 40 years. Additionally, with an increased utilization of resol hard foam during the last few years, a price drop occurred, which makes an application even more feasible.

5.1.4 Energy concept

The principle energy concept of ‘young corner‘ relates to a solar aligned building construction. The compact (A/V = 0.29 m^{-1}) and solar orientated body of the building has a clearly thermal division from heated to unheated sectors (see Figure 30). The living areas are facing south or west, and feature thermic separeted free zones, as well as shadowing elements made out of wood and metal. The spleeping and working areas are largly situated to the east and north. An increasing efficiency element for this part of the building is the concept of compact orifices and large proportion of oqapue walls. Therefore, the window-wall ratio to the north/east is around 0.18 whereas 0.35 on south/west are almost twice as high.

Signifying installed insulation concecpts and materials are:

- Exterior walls: 0.18 m thick resol hard foam panels, U-value 0.117 W/(m^2.K)
- Flat roof: 0.08 m thick greened humus layer + 0.40 m thick EPS panels, U-value 0.087 W/(m^2.K)
- Lowest thermic floor ceiling: 0.09 m thick cladded mineral wool panels on the underside + 0.13 m thick EPS panels on the upside, U-value 0.126 W/(m^2.K)
- Exterior Windows: 3 paned thermal insulation glazing set in a wooden frame and installed in the insulated outer wall, U-value 0.80 W/(m^2.K)
- Puffer zone: The ground floor is functioning as seen as a thermal puffer zone

Summerizing all installed compenents of the buildings envelope, it comes to an average U-value of 25 W/(m^2.K). The building services are adapted to the variability of the interior fittings and aims a high level of residential comfort. The benefits are an easy operation as well as an excellent room air quality. This is the result of a two component system:

- A semi centralized ventilation system with a larger unit (4,300 m^3/h) on the main building and a smaller one (3,700 m^3/h) on the adjacent house. Both of them have a plate heat exchanger (η = 0.80). The supply- and exhaust air dispersion is provided by vertical standpipes in the staircase shaft, as well as by horizontal distribution lines in each floor which are placed in suspended ceilings. Both units are on the top floor of each building. This makes maintenance and air filter change easy and cost effective. The air flow can be controlled from each apartment which allows an optimal customized utilization. A differential pressure speed regulating ventilator is installed in each of both machines and guarantees a sufficient supply of heated fresh air.
- An additional space and water heating preparation is provided by district heating from the local energy supplier ‘Fernwärme Wien’ or rather ‘Wien Energie’, which is also responsible for electricity supply. The connected load is accounted for 310 kW. Heat dissipation for space heating is given by steel panel plate radiators, which are placed below or in front of external windows. The heat load can be adjusted in each room. Instead of small radiators, all common rooms are equipped by ceiling radiators.

The interaction of all components result in heating demand of 6.36 kWh/(m^2.a) (PHPP: 13 kWh/(m^2.a)) and a calculated primary energy demand of 32.39 kWh/(m^2.a).

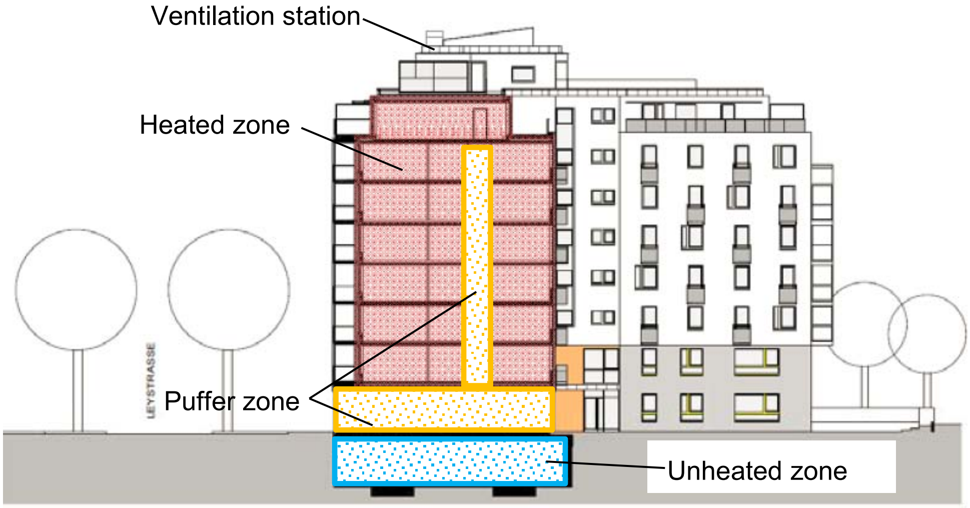


Figure 30: Zoning of heated and unheated areas in the building 'young corner'
(Source: Treberspurg & Partner Architekten (2009) adapted by Armin Holdschick)

5.2 Version 2: Scenario Sun House (SH)

On the basis of the actual building 'young corner' several elementary characteristics of the SH concept were chosen and modelled in a scenario. Hence, the geometry and the greatest part of constructions as well as building services of the scenario building is based on the actual and above demonstrated PH. In order to fulfill the requirements and characteristics of a SH, several specific adaptations were made for building envelope and building services, which are primarily referring to heating appliances and are partly derived from the SH in Freistadt (see chapter 3.2.2).

5.2.1 Adaptation of exterior walls and ceilings

One very obvious adaptation of the scenario SH is the heating demand. Whereas the PH has a value of ~6 kWh/(m^2.a) the SH has ~30 kWh/(m^2.a). To address this difference, seven of the most important exterior layer structures (relating to their overall application in m^2) were adapted. This means their dimension of insulation were reduced or removed. Nevertheless, the overall performance of each particular component still meets the requirements of OIB 6. The changed elements are:

- AW1 (exterior wall 18 Ultra with reinforced concrete) = 1,805 m^2:
  The phenolic foam insulation layer was reduced by 12.3 cm to 5.7 cm. This results in an increase of the U-value from 0.118 W/(m^2.K) to 0.35 W/(m^2.K).
- AW2 (exterior wall 18 Ultra Macuphon) = 2,928 m^2:
  The phenolic foam insulation layer was reduced by 12.6 cm to 5.4 cm. This results in an increase of the U-value from 0.116 W/(m^2.K) to 0.35 W/(m^2.K).
- AD1 (planted flat roof) = 533 m^2:
  The EPS insulation layer was reduced by 23.2 cm to 12.8 cm. This results in an increase of the U-value from 0.087 W/(m^2.K) to 0.2 W/(m^2.K).
- AD2 (wooden grated flat roof) = 295 m2:
  The EPS insulation layer was reduced by 23.2 cm to 12.8 cm. This results in an increase of the U-value from 0.087 W/(m^2.K) to 0.2 W/(m^2.K).

- AD3 (terrace with concrete slab) = 293 m^2:
  The EPS insulation layer was reduced by 11.4 cm to 10.6 cm. This results in an increase of the U-value from 0.114 W/(m^2.K) to 0.2 W/(m^2.K).
- DGUo 6 (ceiling staircase at the ground floor) = 54.84 m^2:
  The EPS insulation layer was removed and the mineral wool was reduced by 6.8 cm to 2.2 cm. This results in an increase of the U-value from 0.127 W/(m^2.K) to 0.4 W/(m^2.K).
- DGUo 13 (ceiling over common room at the ground floor) = 114.30 m^2:
  The EPS insulation layer was removed and the mineral wool was reduced by 5.8 cm to 1.5 cm. This results in an increase of the U-value from 0.143 W/(m^2.K) to 0.4 W/(m^2.K).

5.2.2 Adaptation of the heating system

Additional to the wall and ceiling constructions the building services are also adjusted to the SH concept. As an adaptation in the heating system, the plate radiators were replaced by a floor heating system. This results in a removal of all radiators from the LCA and a reduction of their connection lines by 20 % to 1,869 meters. The floor heating system is thereby considered as a floor screed installation. The tube material is a composite of PEX and aluminum. It has an outer diameter of 20 mm. The tubes are arranged in a helical manner and with an average tube distance of 150 mm the tube-lengths comes to 6.67 meters per floor square meter. Thereby, the total area of installed floor heating comes to a total 6,964 m^2. This already includes all living (inclusive wet rooms) and working areas as well as the dormitory and the kindergarten in the building. An adaptation of the particular floor coverings is not conducted in this analysis. The reason lies in the circumstance that the concentration is on the building service. A replacement of the floor coverings could force a remarkable change in the LCA and consequently a dilution of the original focus. Only the screed with 60 mm is slightly adapted to 70 mm because of the integrated floor heating system. However, the material is kept as in the initial concept. When it comes to the durability of the system, specific numbers are difficult to find. It seems that a common range is between 40 to 60 years. For the reason, that no specific figures are given and a replacement comes with considerable expenses a life span of 50 years is assumed. Consequently, the process of replacement does not play a role in this thesis. The floor heating system is then fed with heat from the solar thermal plant of the building. This accounts for 50.9 %[8] of the demanded heat. The rest is provided, as it already exists in the PH concept, with district heating. As a simplification the connected load had not been modified.

5.2.3 Adaptation of the solar thermal plant

Another aspect, which is also related to the heating facilities, is the solar thermal system. It represents the heart of every SH. For an appropriate transmission of the original conditions of the SH in Freistadt to the scenario SH of the ‘young corner’ building in Vienna, several calculations and assumptions had been made. A helpful and elementary tool for this process was the free available demo version of ‘Polysun’ (URL 6). Even demo versions usually come with a number of restrictions, this free accessible tool is most likely to meet the fundamental requirements. Resulting from these restrictions, the below listed aspects are outlining two major problems and their approach for dealing with their bias:

- Climate data: The software works only with one climate data-set. The fixed data-set is Rapperswil (CH), which is in a direct proximity to Zürich (CH). Even to its central European provenance, and alpine influenced character, there are several differences to the Austrian relevant locations Freistadt and Vienna (see Table 3). It is assumed, that the effects are marginal. The accompanying discrepancy is therefore not further considered in this thesis.

[8] The deviation of 0.9 % compared tot he energy certificate is given in chapter 5.2.3.

Table 3: Climate data of Zurich, Freistadt and Vienna
(Source: URL 7)

	H_h	H_{opt}	H(90)	I_{opt}	T_{24h}	N_{DD}
Zurich	3390	3900	2630	35	10.60	2981
Freistadt	3140	3580	2440	35	8.30	3629
Vienna, Vorgartenstraße	3330	3820	2580	35	10.60	2968

H_h: Irradiation on horizontal plane (Wh/m^2/day)
H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)
H(90): Irradiation on plane at angle: 90deg. (Wh/m^2/day)
I_{opt}: Optimal inclination (deg.)
T_{24h}: 24 hour average of temperature (°C)
N_{DD}: Number of heating degree-days (-)

- Design, respectively reporting restrictions: By trying to calculate a large object (e.g. ‘young corner’), the listed components do not suffice to represent a proper result. This specific point counts for the storage elements. With an increasing number of solar panels, a well-functioning concept relies on an increasing volume of puffer storage. However, the software does not provide suitable components. This in turn, requires manual design adaption. But as soon as a manual adaption had been made, the already restricted reporting tool does not function (with respect to its result reporting mode) anymore.

  The chosen approach of handling this problem was by downsizing the SH with all its relevant components (solar panel area, volume of puffer storage, floor space, residents, supplement furnace, heating demand and loss). As mentioned above, the restricting factor is the storage facility. As a consequence that the largest suitable tank has a volume of 20,000 liters, the chosen downsizing factor (by an original size of 40,000 liters) is two.

To sum it up, the demo version ‘Polysun’ is in this case by far the best tool compared to all other available online calculators. But due to its restriction, it only provides a basic assistance for the given task. Nevertheless the data situation shows, that the modeled concept can be conducted. Merely for a further and deeper evaluation, it would be necessary to acquire the full and actual version.

The applied data for ‘Polysun’ comes mainly from the energy certificate of the SH in Freistadt. Thus the building's energy performance, as well as specifications of the solar thermal plant (e.g. setting angle, orientation, heating demand and loss, etc.), is taken from this document. However, due to the circumstance that the available energy certificate relates to an early point of the planning process, some details are not correct and thus supplemented from other (internet-) sources. Therefore, further information is provided by the planner of building services (Forstenlechner, s.a.), as well as by the Austrian Sun House association (Stockreiter, 2015). Furthermore, to cope with the demanded data by the software, a few assumptions are made:

- Water consumption: A low medium usage of 50 liters is assumed per person and day.
- Residents: According to Statistic Austria (2013) average living space per person in Vienna amounts up to 41.2 m^2. Based on this, with an average apartment size in the basic model of ~70 m^2 it comes to 1.7 people per apartment.
- Water temperature: The supposed water temperature is 50°C.
- Room temperature: An average temperature of 20°C is assumed.

With the help of this data the calculation process via the Polysun software could be conducted. The following paragraphs, as well as their linked appendices demonstrate the particular calculation steps.

The first calculation step (see Appendix 10) was to accomplish an exact reconstruction of the solar thermal plant in Freistadt. The perfectly south orientated and in a 45° angel positioned panels are representing the basis. However, with respect to the incorrect size of the puffer storage, the calculated solar cover ratio of 45 % does not coincide with the predetermined figures.

Acting on this assumption, a 'reduced' approach for the basic model was conducted as a second step (see Appendix 11). This implies the already mentioned reduction of factor two, which neutralizes the bias from step one. Furthermore, the result of a solar ratio of 50.9 % (original value from the energy certificate = 51.8 %) was taken as a verification of the entire Polysun methodology. Central outcomes and an outline of the system are depicted in Appendix 14 and Appendix 15.

The problem of modelling large solar plants came much more into perspective, when looking at trails to simulate the actual housing complex 'young corner'. Thus the third step in this calculation process is about the adaption of the SH in Freistadt to the 'young corner' characteristics (see Appendix 12). The focus is thereby based on the assumption, that solar panels are integrated in the south/west respectively south/east facing (+45°/-45°) façade. By means of comparing the option of roof mounted and perfectly south facing panels with façade mounted panels which are facing more west and east, a difference in the received specific solar gain could be documented. Based on this, the second option is less effective, establishing the need of a larger number of panels to be installed as this will ensure the initial solar cover ratio is being reached. In other words, it was calculated how many additional panels are needed to compensate the deficit and finally to reach the original solar ratio. For this task a simplified linear correlation was taken as a representative approach.

The transformation of Freistadt linked figures to the scenario SH of housing complex 'young corner' in Vienna was necessary as a final step. For this task two approaches had been available. The first is an extrapolation of all Freistadt related figures to a larger extend, based on the gross floor area. The second one refers to a comparison of scientific evaluated approximations for the solar collector area per gross floor area [m²/m²] and the storage volume per solar collector area [l/m²]. Because of the lack of detailed data as well as inaccuracies, both approaches entail uncertainties to a particular extent. Nevertheless, in regard to an easier calculation and consequently higher transparency the second option was chosen. After screening several studies and information brochures (Kobelt et. al, 2015; Oliva, 2015; Stockreiter, s.a.) subsequent established parameter ranges could be determined for:

- solar collector area per gross floor area = 0.12 – 0.20 [m²/m²]
- storage volume per solar collector area = 150 – 220 [l/m²]

Depending on particular building characteristics, such as energy standard, orientation, solar ratio and occupation consumption patterns of the values vary highly. An interesting correlation of solar collector area and storage size is given in Figure 31. In accordance to the usable area of 160 m² of a detached house, Kobelt et. al (2015) demonstrate which combination should be strived for to achieve a certain solar ratio.

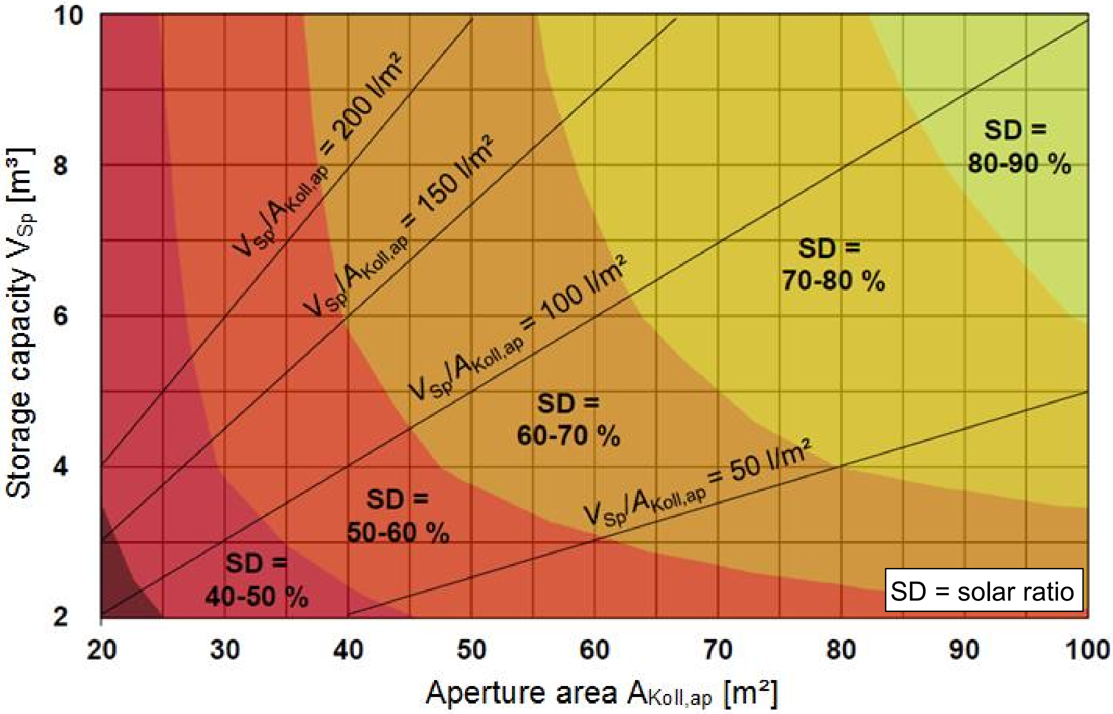


Figure 31: Variation of storage volume and collector area
(Source: Kobel, S., Bestenlehner, D. and Drück H. (2015). Modellierung des dynamischen Verhaltens von SolarAktivHäusern. SWT Technology, Stuttgart. Adapted by Armin Holdschick)

As calculated in Appendix 11, the original SH in Freistadt has a panel-gross floor ratio of 0.12 [m²/m²] and storage-panel ratio of 317 [l/m²]. Compared to the common figures above, the panel-gross floor ratio is on the lower end and the storage panel ratio is far above the upper limit. By calculating the alternative collector position (see Appendix 12), the parameters change: the panel-gross floor ratio comes to 0.18 [m²/m²] and the storage-panel ratio has 213 [l/m²].

During the modelling process of scenario SH several aspects had to be considered. First of all, it was tried to bring as many solar panels as possible to an optimal alignment (south orientation). This means, the roof top was considered first. To get a maximal application of the roof it was assumed, that the whole space of the standard floor can be used, which results in the fact that terraces from the top floor are canopied with solar panels. The rest of required panels were placed on the south/west, respectively on the south/east facade of the building. Thus, for the modelled SH the total collector dimensioning refers to the mean value (0.15 [m²/m²]) of both aligned panel options:

Total solar collector area = panel-gross floor ratio * NEW gross floor area

1,268 [m²] = 0.15 [m²/m²] * 8,451.55 [m²]

In case of the storage dimensioning, a mean value approach seemed not reasonable. In respect to the huge plant size it has to be assumed, that a simultaneous-effect occurs. Therefore, the volume was set below the Freistadt figures, but also on a common value of 175 [l/m²]. As far as the chart from Kobel et. al is representative in this case, after a recalculation with his values a solar ratio of approximately 50 % to 55 % could be reached.

Total storage volume = storage-panel ratio * NEW solar collector area

221,900 [l] = 175 [l/m²] * 1,268 [m²]

Furthermore, also the extrapolation (see Appendix 13), which represents the other calculation approach, comes to a similar solution. In conclusion it can be said, that a solar collector area of 1268 m², as well as a storage volume of 220,000 l seem reasonable for the scenario building in Vienna.

Summarizing, all relevant solar plant related details depicted below:

- total solar panel area: 1,268 m^2
  - south facing panels on the roof top: 560 m^2
  - south/west and south/east facing panels at the façade: 773 m^2
- studding made with angle steel (100/50/6 mm): 2,200 m
- pipe lengths made of stainless steel (diameter 20 mm): 2,000 m
- pipe insulation with mineral wool: 314 m^2
- stainless steel for puffer storages (220,000 liters)[9]: 242,000 kg

5.2.4 Adaptation of the ventilation system

As a last measurement, the complete ventilation system has been removed from the life cycle inventory of scenario SH. This means, the two centralized ventilation units, air canals, insulation and controlling elements are not further considered. Nevertheless, relying on OIB Directive 3 (2015), every bathroom must be equipped with window ventilation or mechanical ventilation. Hence, 71 fans were taken into consideration of the LCA. The material for the vertical air canals were estimated to 640 m^2.

5.2.5 Complementary aspects

With all these adaptations the scenario SH comes close to the concept of the SH in Freistadt. For instance, the heating demand (30.15 kWh/(m^2.a)) is only 1.3 % below the original value and almost reaches the indication as low-energy building (29.53 kWh/(m^2.a)). An analog situation comes with the solar ratio. With 50.9 %, the difference is marginal, which finally verifies the scenario SH.

Nevertheless, as a supplement it shall be mentioned, that there are some specific differences between the building bodies. The most distinctive contrast relates to the building size: Whereas the SH in Freistadt has a conditioned volume of ~3,400 m^3, the housing complex “young corner” in Vienna adds up to 25,350 m^3, which is about a factor of 7.5 larger. The different A/V-ratio is also significant. As a simplification, only linear calculations and hence correlations (except those, which have been mentioned) were considered. Nonlinear correlations are not discussed in this instance.

5.3 Version 3: Scenario Low-tech building (LTB)

On the basis of the actual building ‘young corner’ several elementary characteristics of the LTB concept were chosen and modelled in a scenario. Many elementary approaches, relating to the process of adaptation, are being identical with the already above described SH. Analogical to the scenario SH, also the scenario LTB is only applied in a few specific and considerable aspects, whereas the main concept of the actual housing complex “young corner” remains unchanged. The scenario LTB comes with two remarkable features: double arrayed honeycomb bricks for all outward facing walls and a forgoing of a conventional heating system. As far as possible, it followed the approach to meet all crucial characteristics of the LTB “2226” (see chapter 3.3.2). Due to a different utilization of the building (residential building instead of office building), it is not realistic to use the heating concept of “2226” for this scenario. Firstly, the reason lies on a quantitative lack of alternative heat sources of office equipment and lighting. With a higher density of occupation and many heat releasing facilities (e.g. computers, light bulbs,

[9] In accordance to a linear calculation of the puffer storage related to a buildings gross floor area, it comes to an over sizing of the tanks. The reason lies in a simultaneity factor. Thus an assumption was made that the required volume should sum up to the half of the linear calculated volume.

etc.) it would become easier to provide the demanded load. As a second aspect, the time of occupation can be mentioned. Due to a primarily morning and evening occupation (when no sun is shining), the room temperature is negatively affected, especially during the heating period. As a consequence, the actual supply with district heating had been kept as the only heat source for room conditioning and hot water heating. Floor heating has been chosen instead of radiator heating, according to basic principles of LTB (Streicher, 2104).

5.3.1 Adaptation of exterior walls

However, the aspect of the double brick layer was implemented in the vertical building components AW1 and AW2. The major change lies in the replacement of the reinforced concrete layer and its belonging insulation by the arrayed honeycomb bricks:

- <u>AW1 (exterior wall 18 Ultra STB) = 1,805 m^2:</u>
  The walls thickness increases by 0.2 m to 0.78 m and the U-value increases from 0.118 W/(m^2.K) to 0.14 W/(m^2.K).
- <u>AW2 (exterior wall 18 Ultra Macuphon) = 2,928 m^2:</u>
  The walls thickness increases by 0.38 m to 0.79 m and the U-value increases from 0.116 W/(m^2.K) to 0.14 W/(m^2.K).

The rest of the exterior walls remain (due their insignificance) in their initial state. Because of a conventional EPS ceiling structure of the LTB, also the ceilings of the original PH are kept the same. Supplementary it should be mentioned, that the difference as a whole, related to the ratio of the bricks, do not find any consideration. The reason lies in the circumstance that no gross density is given in the declared datasheet.

5.3.2 Adaptation of the heating system

Resulting from the quotation about the heating system above, it is clear, that the major compilation of building services is kept the same. Nevertheless, as already in the SH presented, the plate radiators are replaced by a floor heating system. Streicher (2014) stresses the self-regulating effect of floor heating and allocate their perfect fitting in a LTB. The considered characteristics are kept exactly as in the SH:

- Removal of all plate radiators
- Cutback of connection lines from 2,336 m to 1,869 m
- Heating tube consists of PEX aluminum and has an outer diameter of 20 mm
- Tube distance is about 150 mm which results in a tube lengths of 6.67 m/m^2
- Relevant floor area comes to 6,964 m^2
- Life span equals to 50 years

5.3.3 Adaptation of the ventilation system

Also the ventilation system of scenario LTB is designed as in scenario SH. The complete mechanical system (including ventilation units, air canals and controlling elements) had been removed and partly replaced be 71 fans in all wet rooms. The material for the required air canals were estimated to 640 m^2.

5.3.4 Complementary aspects

Finally, it can be said that the scenario LTB is a combination of the ‘2226’ building (exterior wall construction and relinquishment of mechanical ventilation) and the concept of Streicher which features among others, the idea of a self-regulating floor heating. By summarizing all changed components, the scenario LTB comes to a heating demand of 20.57 kWh/(m^2.a). This equals the category of a low-energy building and almost reaches the standard of a nearly zero-energy building (Niedrigstenergiehaus) with 18.84 kWh/(m^2.a). Nevertheless, compared to the requirements of chapter 3.3 it neither reaches the standard of a PH (~8 kWh/(m^2.a)) nor the performance of LTB ‘2226’ in Lustenau. The most relevant reasons for this circumstance can be found in the higher heat losses due to manually operated window ventilation. However, for the reason, that no energy certificate was accessible for ‘2226’, the fact could not be deeper investigated. It needs to be stressed that different considerations were made to evade window ventilation: For instance a decentralized (wall- or window-) installed ventilation system with a heat recovery unit could help to reduce energy losses. The problem of this idea lies in three aspects: First of all, Rojas (et al., 2015) is pointing out, that the idea is still in an early process of testing and no specific results are available. Secondly it needs to be questioned, if decentral ventilation units replace a conventional ventilation efficiently? Consequently, the last question/aspect evolves by asking how far such a system (with 95 units or more) fits to a LTB? Resulting from that, it was decided to fulfill the concept of low-tech above the endeavor of reaching a PH standard.

5.4 Overview of the investigated versions and scenarios

Before starting with an evaluation of the LCA results, Table 4 gives an overview of the specific characterizations of each concept.

Table 4: Characteristics of the particular building concepts

	Passive House (actual building)	**Sun House (scenario building)**	**Low-tech Building (scenario building)**
Exterior wall and ceiling construction	Representing a 'high-end' standard, which results in a **heating demand of 6.36 kWh/(m².a)**	Reduced insulation layers of AW1, AW2, AD1, AD2, AD3, DGUo6 and DGUo13 (average increasing U-Value by factor 3), which results in a **heating demand of 30.15 kWh/(m².a)**	Replaced steel inforced concrete and aerated concret walls as well as their insulation layer (AW1 and AW2) by a double arrayed honey comb brick wall (wall strength: 76 cm), which results in a **heating demand of 20.57 kWh/(m².a)**
Ventilation system	Representing common centralized ventilation system: 2 ventilation units (~4.000 m3/h), air canals (sheet steel ~2.100 m2), insulation (mineral wool ~118 m2) and control units	Abandonment of the centralized system and installation of 71 fans units in all bathrooms of the building (-> including sheet steel for air canals: 640 m²)	Abandonment of the centralized system and installation of 71 fans units in all bathrooms of the building (-> including sheet steel for air canals: 640 m²)
Heating system	Representing convential heat facilities by plate radiators (228 units ≈ 150 m²), which are supplied by a connection to the local district heating (310 kW)	Replacement of the plate radiators by a floor heating system: - Removal of all plate radiators - Cutback of connection lines from 2,336 m to 1,869 m - Pex-Alu as heating tube material - Tube lenghts is 6.67 m/m² - Relevant floor area is 6964 m² - Life span equals to 50 years	Replacement of the plate radiators by a floor heating system: - Removal of all plate radiators - Cutback of connection lines from 2,336 m to 1,869 m - Pex-Alu as heating tube material - Tube lenghts is 6.67 m/m² - Relevant floor area is 6964 m² - Life span equals to 50 years
Renewable energy facility	none	Solar thermal plant: For receiving a solar ratio of 51.53 % the following components are integrated - Total solar panel area is 1268 m² - Studding (stainless steel) 2.200 m - Pipes (stainless steel) 2.000 m - Pipe instulation (mineral wool) 314 m² - Puffer storage (steel) 24.200 kg	none

6 Results

This chapter deals with LCA results from the different building concepts. In a first subchapter the reader shall gain an overview of the conducted analysis. Therefore central graphics and figures of the building concepts in total are represented. Secondly, the particular constructive adaptations in the building envelope and in the building services are considered in a more detailed manner. Furthermore, it is depicted what influence the changes have on the respective energy consumption. Additionally, in between the showed results an additional analysis in accordance to the aspect of sensitivity is conducted. This means that specific component changes are related to their effect on the already mentioned construction and consumption phases.

6.1 General results

The above depicted features force changes in the LCA in each examined concept. As a first step Figure 32 outlines these changes in a general manner. This means all in the LCA relevant categories of each concept are considered respectively represented in relative figures and based on the actual Passive House (PH) (Vers. 1) which represents the basic scenario with 100 %.

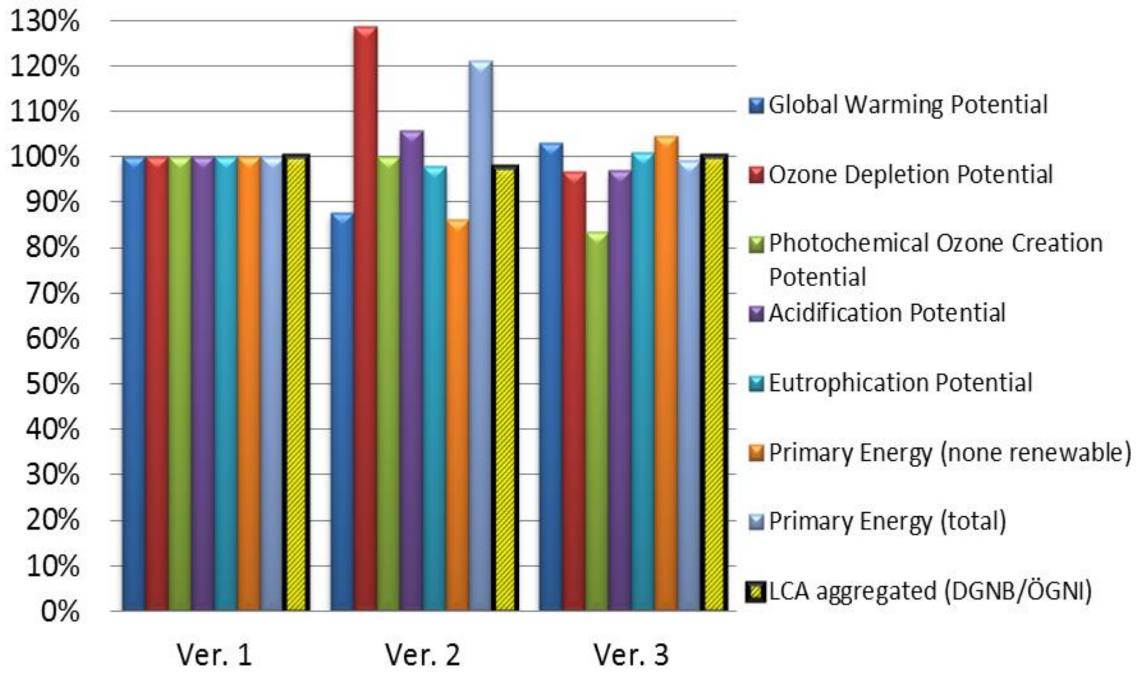


Figure 32: Comparison of overall LCA results for impact indicators. Relative results of the scenarios in relation to the actual housing complex 'young corner'.
Version 1: Actual building in Passive House Standard
Version 2: Scenario Sun House
Version 3: Scenario Low-tech building

Reinforcing the first impression, it becomes obvious that each concept has its strengths and weaknesses. Scenario Sun House (SH) (Vers. 2) is characterized by very contrary levels of the particular categories. The concept combines the best but also the poorest performances results. Specifically striking is the Ozone Depletion Potential (ODP) with 129 % which is the highest value over all categories. But also the Primary Energy in total (PE), climb up to a conspicuous level of 121 %. On the other hand, there are striking categories such as the Global Warming Potential (GWP) and Primary Energy demand of non-renewable sources (PE-NR), which feature with 88 % respectively 86 % a remarkable superiority compared to the actual PH and scenario Low-tech Building (LTB). The other categories of the SH find themselves in between. With

98 %, the Eutrophication Potential (EP) shows the smallest improvements scenario SH. However, as the figure depicts, all concepts perform very similar in the impact factor. The Photochemical Ozone Creation Potential (POCP) of scenario SH equals with the figure of the actual PH (100 %). The Acidification Potential (AP) is the last category. This factor ranges, as well as the EP, on a similar level in all concepts. But in contrast to the EP, where scenario SH performs best, the scenario SH with its 106 % AP shows the poorest result of all concepts[10].

Regarding scenario Low-tech Building (Vers. 3) the impossibility of a clear and overall distinction to Version 1 needs to be particularly stressed. Whilst some categories are above (GWP – 103 %; EP – 101 %; PE-NR – 105 %), others are below the given benchmark (ODP – 97 %; POCP – 83 %; AP – 97 %; PE – 99 %). It has to be indicated that scenario LTB is at its lowest in the category of POCP, whilst it is as its highest in GWP, EP and PE-NR.

To gain a better insight of the idea how each concept performs overall, the last adduced category 'LCA aggregated (DGNB/ÖGNI)' helps the reader to get a general view. The information is based on a weighted calculation, which appears to the fact that different categories have diverse emphases: GWP and PE-NR are weighted with the factor 3, whereas all other categories are considered by factor 1. According to this, scenario SH has with 2.2 % a lower impact than the basic model (PH). Compared to this, scenario LTB remains with 100.1 % on the same level as the actual PH house. Summarizing, it needs to be said, that all three concepts perform, despite their different approaches, very similar from an ecological point of view.

However, for the upcoming paragraphs and subchapters the focus lies set more on the GWP, PE-NR. The other LCA relevant categories are only applied in a supplementary manner especially as far as a certain position shows a significant influence on a particular concept respectively material or component. Based on this, Table 5 represents absolute and relative figures of GWP and PE-NR in relation to the functional unit (m^2 per gross floor area) and life cycle phase of the particular building concept.

Table 5: Phase orientated LCA-results of sustainable building concepts

	Passive House (actual building)		**Sun House** (scenario)		**Low-tech building** (scenario)	
	GWP kg/(m².a)	**PE-NR** kWh/(m².a)	**GWP** kg/(m².a)	**PE-NR** kWh/(m².a)	**GWP** kg/(m².a)	**PE-NR** kWh/(m².a)
Production	4.9	17.5	5.2	18.2	5.0	17.2
Replacement	1.1	3.9	1.5	5.4	0.8	2.6
End of Life	1.3	-3.4	1.2	-3.2	1.3	-3.0
Operational Energy	8.0	28.6	5.4	19.8	8.7	31.9
Sum	**15.2**	**46.6**	**13.4**	**40.2**	**15.7**	**48.7**
Referred to Version 1	100%	100%	88%	86%	103%	105%

Compared to Figure 32, the table reveals the advantages and disadvantages of each concept related to a particular life cycle phase. As it becomes obvious, scenario SH and scenario LTB perform in absolute figures very similar to the actual PH in the first three phases. Larger differences are only given during the last already listed operational phase. But going a little bit more into detail, as it can be seen in the first and second column of Version 2, the GWP respectively PE-NR of scenario SH performs in a relative manner very similar compared to the actual object. The reason lies in the compulsive dependence. Therefore, scenario SH has in the phase of production and replacement disadvantages in both categories compared to the actual PH. The other two phases, 'End of Life' and 'Operational Energy', come of better. As already examined,

[10] The particular effects which cause these results are be closer investigated in the next subchapters.

scenario LTB is generally performing on a similar standard as the actual PH. Even it features an asset in the category of 'Production' and 'Replacement', the overall performance is slightly worse compared to the actual building. In the 'End of Life phase' it performs, from a GWP related point of view, equally to the actual PH but inferior than the SH. Nevertheless, in the category of PE-NR the phase of 'Operational Energy' entails a drawback of 12 % compared to the PH and 61 % compared to the SH. When these figures are compared to the evaluation above (Figure 32) it becomes obvious that the result remains almost the same: scenario SH has the best performance, but due to the chosen category the scenario LTB is worse than the actual PH. Hence, the above mentioned and simultaneously selected categories are a crucial aspect for ranking different concepts.

Figure 33 outlines the major differences in the phase of operation in a more specific manner. Furthermore, as it can be seen, the rest differs only in a small dimension. If only the phases 'Production', 'Replacement' and 'End of Life' are compared to each other, the results would be turned around. This means, scenario SH would perform with 2.1 kWh/(m².a) (+ 12 %) worse than the actual PH. Scenario LTB on the contrary would be the prevailing option. With 16.8 kWh/(m².a) it would perform 8 % better than the actual PH and 17 % than scenario SH. Still, it has to be considered that the PE-NR of the first three phases, based on the PH, does only represent 39 % of the entire outcome. As a consequence, the operational phase counts for 61 % in the LCA and has therefore the most significant influence on the total performance of a building concept. Hence, several considerations relating to operational energy influencing aspects should be made in an early stage of planning (König et al, 2009)[11].

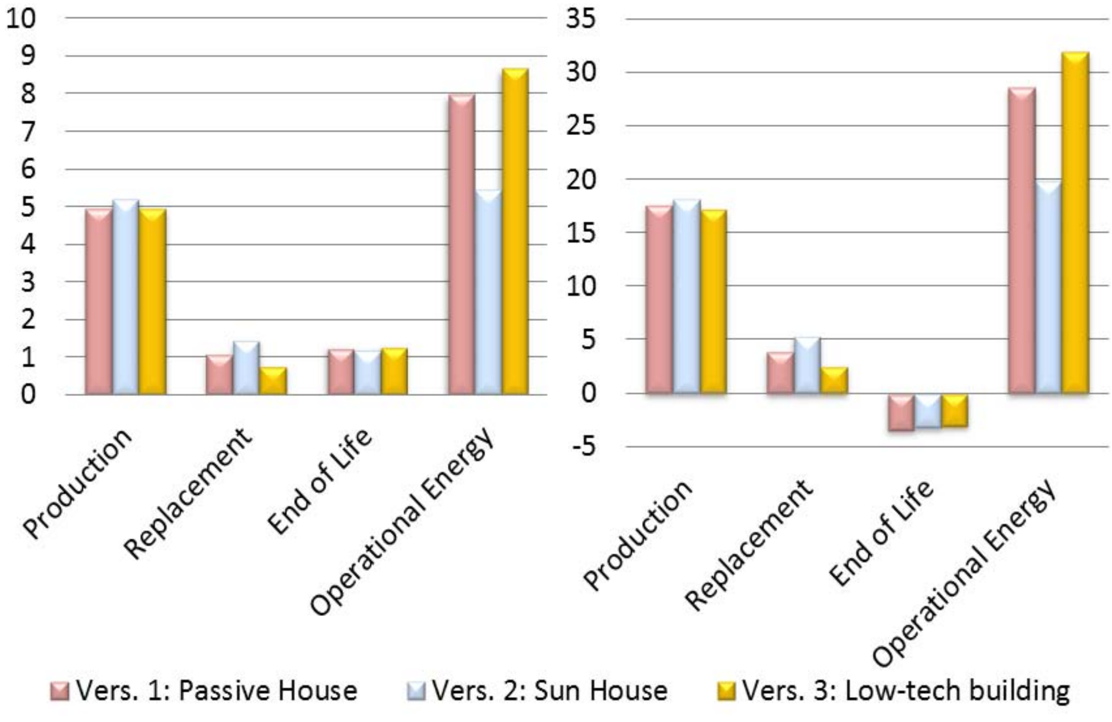


Figure 33: Comparison of GWP in kg/(m^2.a) (left) and PE-NR in kWh/(m^2.a) (right) of sustainable building concepts related to the different phases of a LCA

To get an idea how the PE and PE-NR are relating to each other, Figure 34 represents the total 'Primary Energy' consumption. This means the fossil fuel based provision is complemented by renewable sources. Obviously, the disparities towards the PE-NR are partly very different. This counts especially for scenario SH. As mentioned above, it is designed with a solar thermal

[11] A detailed analysis about these aspects can be found in chapter 6.3.

plant, which provides 50 % of the energy for hot water and room conditioning, which is about 19.3 kWh/(m².a). Nevertheless, the differences in PE reflect the lower building standard very clearly. However, also the figures of the actual PH and scenario LTB vary slightly. Whereas scenario LTB comes up with a difference of 10 %, the actual PH has a slightly higher utilization (16 %) of renewable energy utilization. Amongst other factors, this is caused by a larger electricity[12] consumption due to the higher application of building services[11].

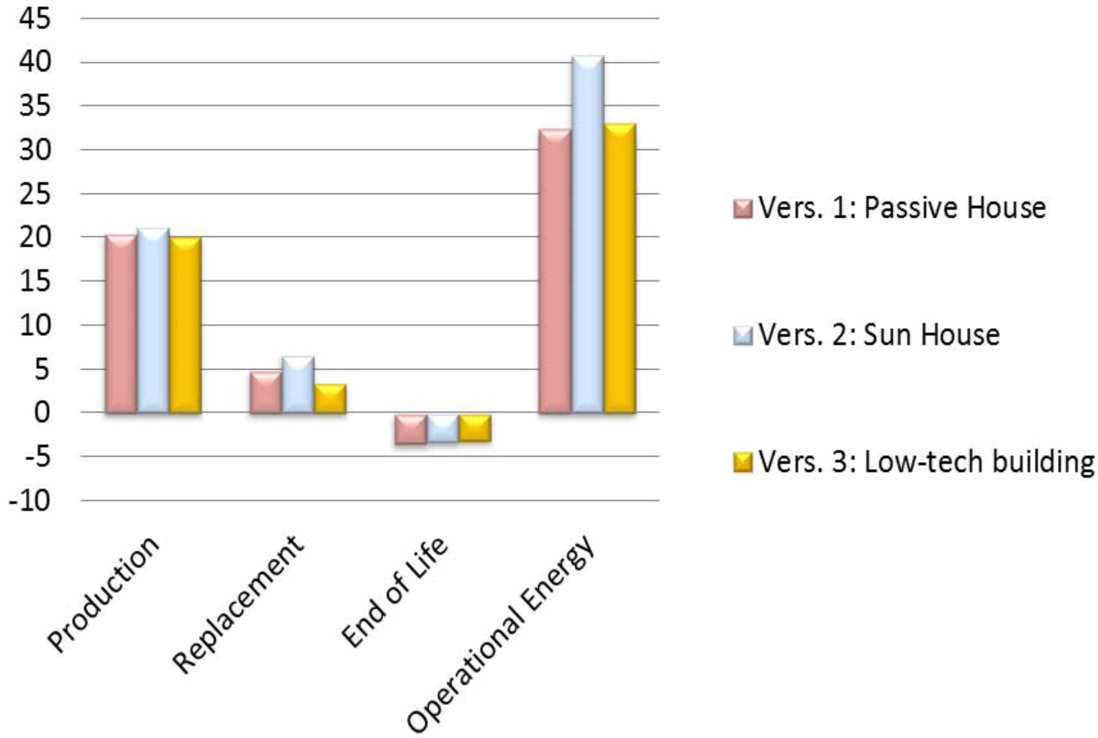


Figure 34: Primary Energy (total) in kWh/(m^2.a) related to the different phases of a LCA

In addition to all the figures of this section and a better understanding of the two next chapters, the 'End of Life' (EoL) phase shall be elucidated shortly. In contrast to all other life cycle phases, the EoL evinces with a negative result in the PE categories. This results from the aspect of thermal utilization respectively electricity generation by burning different materials. Many components like biomass or plastic can be burned and the recovered energy is considered to replace thermal and electrical energy form fossil sources. The particular heating value of each material is therefore taken as the basis and a credit is included in the balance for replaced fossil energy sources. Resulting from that, the more biomass or plastic is used in a component respectively in a whole concept, the higher the credit (= positives effects) in the EoL phase will be. However, this does not implement a suggestion for biomass or plastic at all. Before a sincere affirmation can be done, interdependences have to be closer investigated. As depicted in Figure 33, the negative credit does not count for the GWP. They are still positive, which results from the greenhouse gas emissions of the burning process. This approach or rather effect is controversial discussed and might even underlie certain adaptations in the future. Due to the lack of an uniform approach, this effect is considered, with respect to this analysis, in a conventional way.

[12] According to the ÖGNI, the Primary Energy Factor of electricity contains 52 % renewable energy.

Recapitulating from this chapter, it has to be assumed that within the context of an environmental LCA the Sun House concept represents best option for this case. The Low-tech Building concept represents the intermediate solution whereas the differences compared to the PH are marginal. Nevertheless, it has to be considered that none of the discussed concepts provides an overall superiority. Whereas scenario Sun House scores with low ‘Primary Energy (non-renewable)’ demand and consequently low ‘Global Warming Potential’, it fails badly in category of ‘Ozone Depletion Potentials’. A similar situation is given for scenario Low-tech Building, even the concept has some disadvantages, on the contrary it also has the lowest ‘Photochemical Ozone Creation Potential’ and ‘Ozone Depletion Potential’ at the same time. In many cases, the actual Passive House established itself in between the other two concepts, but it cannot attain the lowest value in any category. Certainly it should be taken that the ‘Operational Energy’ has the highest influence of all phases in a LCA.

6.2 Constructive and service related results

By putting the focus into more details, this section is looking at all important adaptations which were chosen for this study. As an assistant, the content from Table 4 can be taken for orientation. In the same order as the aforementioned table is structured, the different components are analyzed. Alongside with the buildings envelop it is primarily necessary to understand it as a representative of constructive elements. Afterwards the focus will shift to the different building services, including the ventilation and heating system, as well as the solar thermal plant as a renewable energy facility.

6.2.1 Constructive components

The examined Passive House in Vienna is renowned for being the world largest construction with phenolic foam insulation (see chapter 5.1). Due to an implementation of this cost-intensive, but very effective insulation material (λ = 0.21 W/(m.K)), it was possible to keep wall structures thin and consequently the usable area at a maximum. Despite or especially because of these remarkable features, it becomes important to compare and analyze different wall and ceiling structures of the particular building concepts. As a matter of fact the evaluation is based on three different concepts with three different aspirations of heating values and in consequence of various U-values, a direct material comparison is not reasonable. But instead of giving a comparable and material based evidence about efficiency and effectiveness in the manner of a LCA, it is more likely to get an idea how the wall structures of the discussed concepts perform and what differences exist. Furthermore it shall help to understand the differences of particular fields (e.g. exterior wall and ceiling constructions) in the LCA. In respect to this one particular construction chosen: AW1 in the PH concept is an exterior wall and implemented in 1,800 m^2. The construction is built by seven different layers and represents an U-value of 0.12 W/(m^2.K):

1) Double exterior coating
2) Exterior plaster (1 cm)
3) Insulation – resol hard foam (18 cm)
4) Reinforced concrete (14 cm)
5) Expanded clay (6 cm)
6) Filler (0.5 cm)
7) Singe interior coating

With this structure it leads to PE-NR of 1.1 kWh/(m^2.a) and consequently to emissions relating to the GWP of 0.4 kg/(m^2.a). Even this value is, compared to the above presented and summed figures (from Table 5: Phase orientated LCA-results of sustainable building concepts), very low but due to the large implementation AW1 is one of the largest constructional elements in this LCA.

By adapting this construction according to the Sun House concept, the insulation layer gets reduced to 5.7 cm, whereas the rest remains at the same. This results in a higher U-value (0.4 W/(m^2.K)), but also into lower GWP emissions (0.3 kg/(m^2.a)) and a lower demand of PE-NR (0.8 kWh/(m^2.a)). By comparing the structure of scenario LTB, the difference relating to the LCA is similar to scenario SH. With the low-tech concept, layers 3 to 6 are exchanged by a double arrayed brick construction plus an additional layer of interior plaster. This change leads to an increase of the total thickness (+ 20 cm), an increase of the U-value (+ 0.02 W/(m^2.K)) and in the same time to a lower constructional based energy demand (PE-NR = 0.8 kWh/m^2.a). This applies as well to greenhouse gases (= 0.3 kWh/(m^2.a)).

The reasons for this data situation arise because of the different implemented materials as well as in their different applied thicknesses. To get a better insight into the mostly affecting components regarding the life cycle, the focus needs to be primarily on the different materials. If the PH is taken as a sample, the relations of the integrated materials in terms of PE-NR are:

- priming material = 1 %
- interior painting = 2 %
- exterior painting = 3 %
- expanded clay = 8 %
- steel (of the concrete) = 8 %
- concrete = 14 %
- synthetic resin plaster = 26 %
- resol hard foam = 37 %

Especially the portion of the plaster and insulation seems unusually high, but with the consideration of maintenance, which entails a replacement after 30 years, it gets more reasonable[13]. Putting the components into functional groups, the bearing construction would count for 30 %[14], the insulation for 37 % and outer coatings for 33 %. Comparing this with scenario LTB the relation becomes slightly different. For the fact that bearing construction and insulation are featured in the same material, these functional groups are put together. Thus, one brick layer counts for 40 % of the PE, the insulation and bearing construction add up to 80 %, whereas the outer coatings have a share of 20 %. By comparing these functional groups in absolute figures the difference just reaches up to 0.1 kWh/(m^2.a). This entails that from a life cycle point of view the components, and hence the construction itself, does not determine reasonable differences in this particular case. Furthermore, it needs to be considered that the construction of scenario LTB provides with a higher U-value, which relativizes the slight advantage a little bit further. The great (relative) difference of these two options relates to the functional group of coating or rather in the plaster material. Whereas the plaster of scenario LTB has only 0.1 kWh/(m^2.a), the synthetic resin plaster has a PE demand of 0.3 kWh/(m^2.a). This opens a potential for improvement of factor three. By taking into consideration, that this material is used for all exterior plastered walls an improvement is easily detected. A discussion about advantages and disadvantage becomes therefore reasonable and is further analyzed in chapter 7.

After a closer view of a specific wall construction, the analysis gets back to a more integrated perspective. The above discussed aspects can also be summarized over all adapted components of the different concepts. Therefore, Figure 35 outlines the different construction related component assemblies. As showed above, the exterior walls feature differences in each concept. But in contrast to the representative AW1 of this component assembly, scenario LTB has not the lowest value. Finally, scenario SH features with 1.1 kg/(m^2.a) respectively

[13] Moreover, the resin based screed of AW1 + AW2 it is also responsible for 13 % of the total POCP. Due to abandonment in the LTB the value correspondingly decreases.

[14] Expanded clay is not in particular a bearing structure but it enqueuers in the category of concrete and hence is counted as a factor of stability.

3.3 kWh/(m^2.a) the smallest value of all concepts. With 1.2 kg/(m^2.a) and 3.4 kWh/(m^2.a) scenario LTB comes next and the actual PH has the highest environmental impact (1.4 kg/(m^2.a); 4.0 (kWh/m^2.a)). The reason for the benefit of scenario SH lies in the construction of AW2 or rather in its implemented light concrete bricks. Their performance is better than the reinforced concrete and thus performs slightly better than the brick concept of scenario LTB. The roof of scenario LTB remains the same like the actual PH (1.2 kg/(m^2.a) and 2.8 kWh/(m^2.a)). Only scenario SH comes with an insulation reduction (DGUo6 and DGUo13) and consequently with a smaller GWP of 1.2 kg/(m^2.a) and a smaller PE-NR of 2.6 kWh/(m^2.a). Interior ceiling structures are partly changed in relation to the implemented floor heating in scenario SH and scenario LTB. As a consequence, cement screed layers in conditioned rooms had to be increased by 0.01 m. Hence, the GWP rose by 2.3 % to 2.3 kg/(m^2.a) and PE-NR by 2.5 % to 4.4 kWh/(m^2.a) in both buildings. Attributable to the fact, that no adaptions were made at the base plate or indoor walls, these assemblies do not feature any differences.

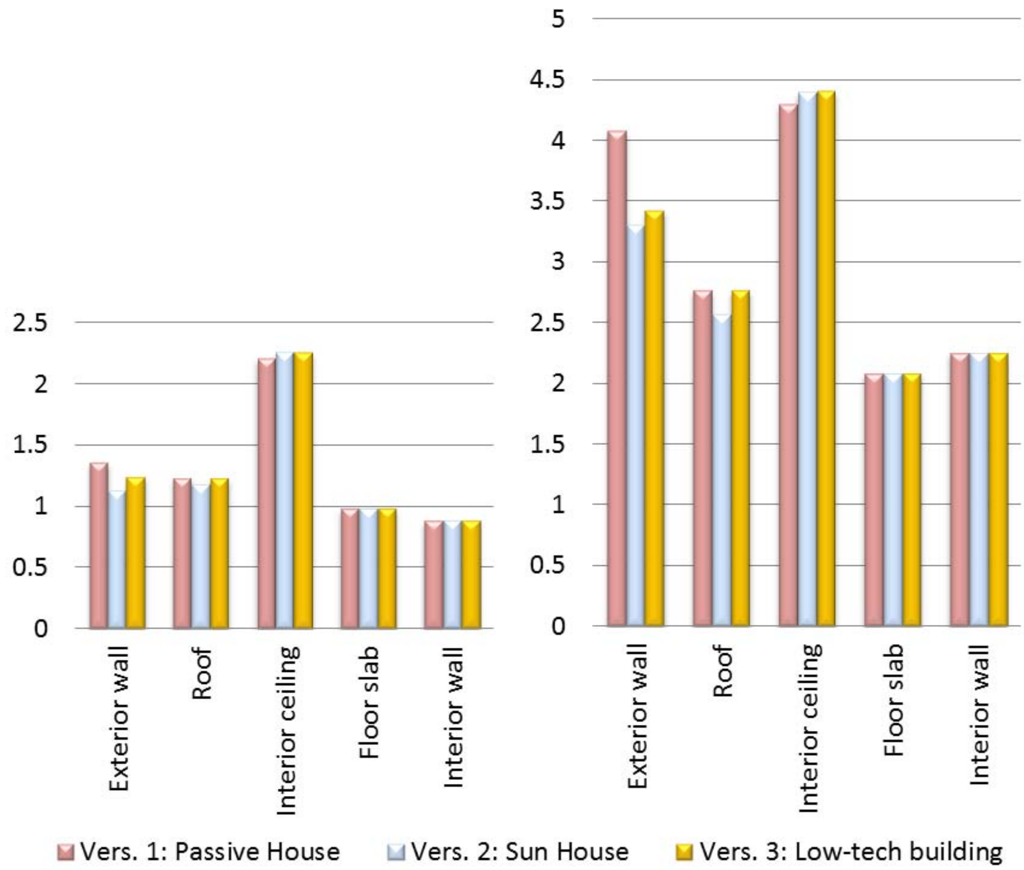


Figure 35: Comparison of GWP in kg/(m^2.a) (left) and PE-NR in kWh/(m^2.a) (right) of sustainable building concepts related to their component assemblies

Putting it in a nutshell, because of the lowest insulation standard, scenario SH has the best performance in this specific aspect, whilst the actual PH has the worst. Nevertheless, this singular aspect cannot be taken as a confirmation for a specific building concept. The entire operation energy is, so far, not included. And with the increasing U-Value of the different constructions it leads to an increasing energy demand during the utilization phase. Furthermore, if the constructive part is summed up with all its components, the improvement for the conducted adaptions in scenario SH would only count with 0.9 kWh/(m^2.a), which is 1.8 % of the total PE-NR.

According to this analysis, Figure 36 gives an additional and even more detailed perspective relating to certain materials of each component assembly. As the image depicts, the minerals are the material group of each assembly. The second largest group (in average) is given by the metals. They are mainly influenced by the steel from the reinforced concrete. A very similar level is given for plastics in roof and ceiling structures. However, in total insulation materials have a slightly higher impact. Especially the actual PH is equipped with a great extent of insulation material and consequently features a larger demand of fossil fuels. The last two material groups are coatings and biogenic materials. Coatings are mostly relevant in the context of interior and exterior walls as well as ceilings. Biogenic materials held a special role. Due to their caloric value, they get a credit for energy recovery and have a consequently positive effect on the LCA.

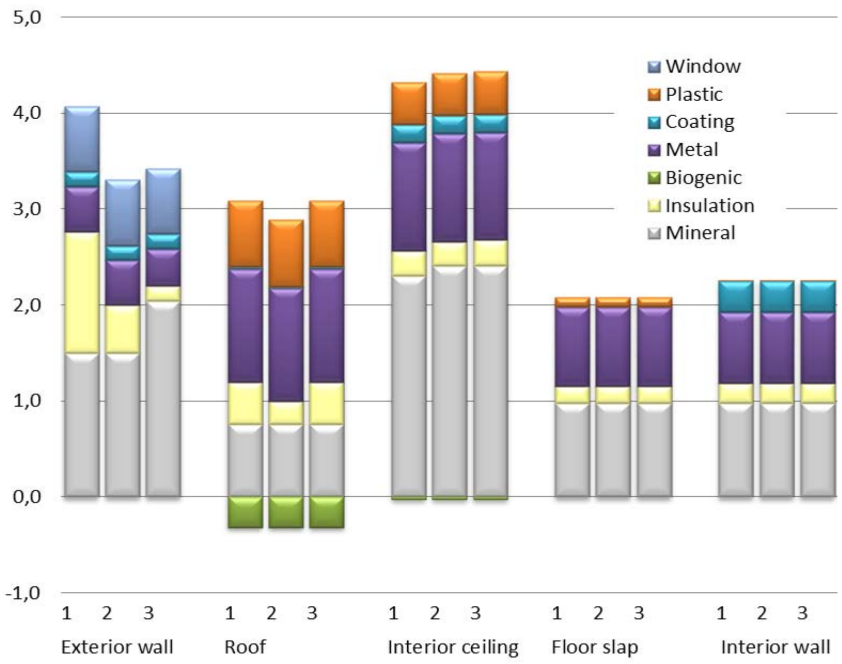


Figure 36: Materials related to particular component assemblies – measured in PE-NR (kWh/(m^2.a))

1: Actual building "young corner" in Passive House Standard

2: Scenario Sun House

3: Scenario Low-tech building

On the basis of these considerations, Figure 37 represents, independently on the component assembly, the amount of implemented materials. Therefore, it becomes clear which material is used in a certain quantity for a certain building concept. Moreover, differences of the particular concepts are depicted also within the image. The largest disparity is given for insulation materials. With regard to PE-NR scenario SH differs by 1.0 kWh/(m^2.a) (- 34 %). The same needs to be stressed regarding to scenario LTB, which has a disparity of 1.1 kWh/(m^2.a) (- 38 %). In aspiration for being precise, it has to be pointed out that a clear distinction between minerals and insulation cannot be made for scenario LTB. The reason lies in the bias of the implemented brick construction. It does not only represent the category of minerals, but also the class of insulation. However, even considering the surcharge in minerals of 0.6 kWh/(m^2.a) (+ 10 %), a small enhancement of 0.5 kWh/(m^2.a) still remains. This applies to 2.6 % of the PH related PE-NR. Beside the extended brick construction the surcharge of scenario LTB also relates on the heightened screed layer because of the floor heating. This also affects mineral values of scenario SH by 0.1 kWh/(m^2.a). The smallest differences, based on the actual PH, are given in the category of metals. The major reason for a reduction (0.1 kWh/(m^2.a)) in the low-tech concept is the replacement of reinforced concrete in AW1 with bricks. The addition within scenario SH (0.1 kWh/(m^2.a)) is due to the implemented studding system of solar thermal collectors on the façade and on the roof. Owing to the fact that no changes were made in the categories of biogenic materials, coatings[15], windows and plastics, they remain the same in each concept. This means biogenic materials representing with -0.6 kWh/(m^2.a) positive effect on the life cycle performance. For instance, plastics add up to 1.2 kWh/(m^2.a), whilst windows as well as coatings count 0.7 kWh/(m^2.a) and are therefore the smallest group of those with positive figures.

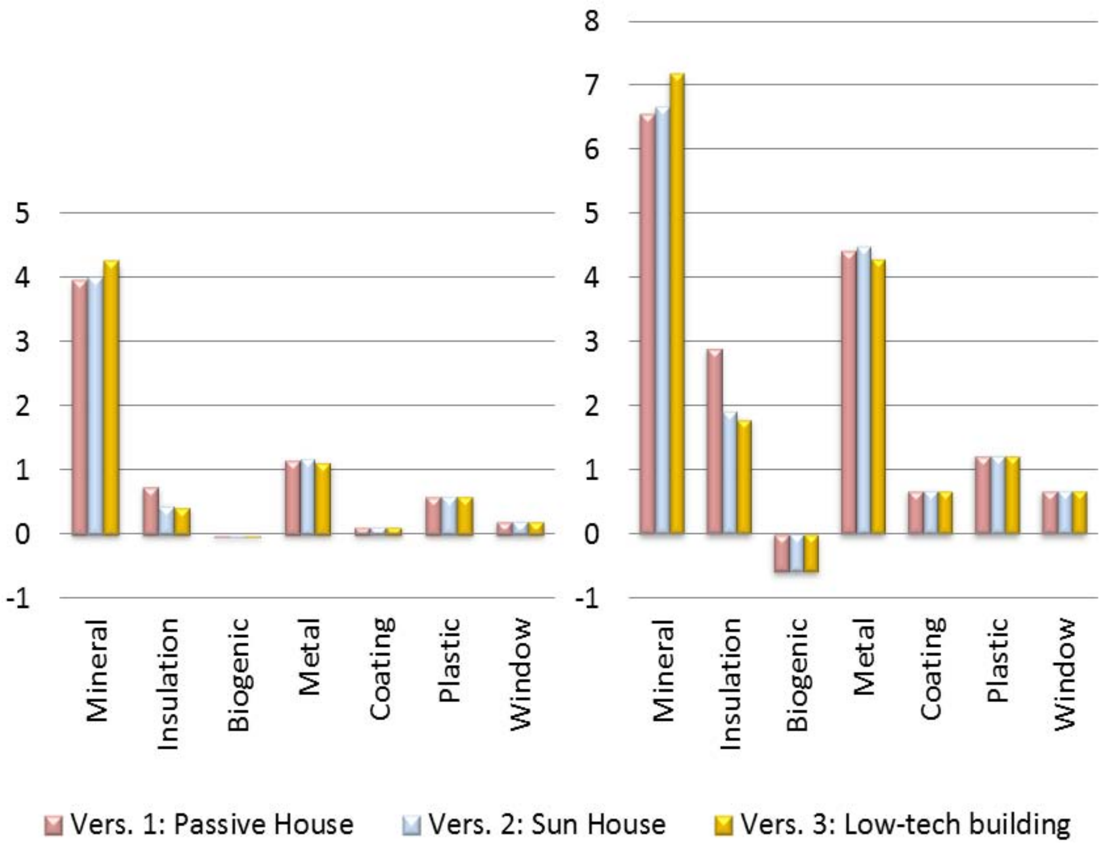


Figure 37: Comparison of GWP in kg/(m^2.a) (left) and PE-NR in kWh/(m^2.a) (right) of sustainable building concepts related to their constructive materials

After all, all concepts of each group feature at least a similar level regarding their absolute numbers. This means, even if the percentage deviation (e.g. insulation) might be high, the absolute deviation appears marginal. Hence, in a total perspective of PE-NR, minerals represent with ~41 % the largest category of constructive related materials. This is followed by metals (~27 %) and insulation materials (~18 %). As a matter of fact, the three largest groups already mount up to 86 %. Therefore, 14 % are divided into plastics (~8 %), coatings (~5 %), windows (~4 %) and biogenic (~ -3 %). Adherence to these facts it becomes remarkable, that important parts for an efficient building envelope like insulation and windows have a relatively small influence on the total material based LCA performance. Consequently, it needs to be considered carefully, especially from a life cycle based point of view, which elements should be decreased respectively which elements might get a little bit more attention related to their ensuing influence on operational energy.

A closer look towards the already mentioned aspects of building services is given by the next chapter. This especially deals with adapted ventilation and heating systems as well as an integrated solar thermal system for scenario SH.

[15] Coatings remain the same over all three concepts. Just the varnishing of radiator related pipes is not applicable for the floor heating of scenarios SH and LTB. However, the difference of 0.0002 kWh/(m².a) is negligible.

6.2.2 Service components

To increase the understanding according to the categories relevance as well as to complement the previous discussed component groups, Figure 38 entails the addiotnal divison of building services.

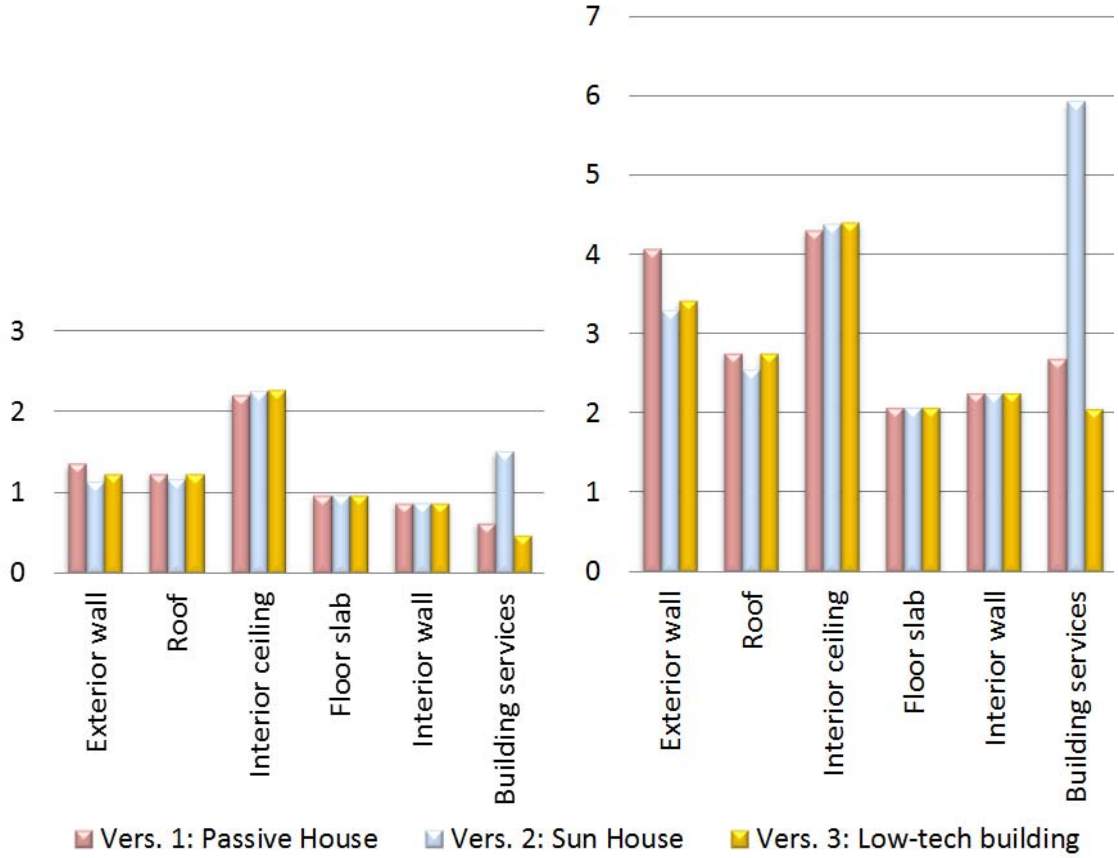


Figure 38: Comparison of GWP in kg/(m^2.a) (left) and PE-NR in kWh/(m^2.a) (right) of sustainable building concepts related to their constructive and service components

As shown in Figure 38, with respect to GWP as well as PE-NR the group Building Services is in average one of the smallest categories. However, by considering the Building Services of scenario SH, it belongs to the most influencing component groups. In the actual PH the Building Services count with 2.7 kWh/(m^2.a) for 15 % of the demanded fossil fuel based primary energy. Due to the renunciation of technical appliances in scenario LTB, which is represented in an abandonment of the ventilation system, the demand is smaller compared to the actual PH. Scenario LTB comes to 2.1 kWh/(m^2.a), which is a reduction of 22 % none-renewable primary energy of all building materials. However, the abandonment of the mechanical ventilation system brings a net-reduction (after counting up the small ventilation units in all wet rooms) of 0.5 kWh/(m^2.a). But it has to be considered, without an application of a ventilation system the air exchange results into conventional window ventilation. As a consequence of a missing heat recovery, scenario LTB as well as scenario SH come up with a higher rate of ventilation losses, which carry weight in the operational energy. But this will be is discussed in more detail in the next chapter. In this context, it has to be mentioned that a total abandonment of every ventilation component is not practical, especially when it comes to wet rooms. Therefore, every bath got a fan in the modelled buildings. With an exhausting air duct, this component approaches a PE-NR of 0.1 kWh/(m^2.a).

In contrast to scenario LTB, scenario SH has with its solar thermal system (including collectors, pipes and storage facilities) a higher demand of energy in manufacturing, maintenance and end-of life. Hence, it comes to a PE-NR of 5.9 kWh/(m^2.a) which is 2.2 times the PE-NR of the actual PH. The entire solar thermal system counts with 3.9 kWh/(m^2.a) for about 66 % of the building service demanded fossil energy and 21 % of the whole building construction. This makes a more precise investigation reasonable. With 2.7 kWh/(m^2.a) the implemented solar collectors do have a share of 70 %. A remarkable effect does not only apply to the PE-NR or GWP, especially the ODP is highly affected by solar collectors. Altogether, the ODP adds up to $2.5*10^{-7}$ in the initial building and exceeds by 29 % in scenario SH. Consequently, the collectors have a share of 26 % of all considered components (> 600) within this analysis. Regarding to PE-NR puffer storages result as the second largest position and count for 23 % of the solar system. Further elements are collector studding (3 %), pipes (3 %) and insulation materials (1 %). Resulting from the application of a solar thermal system and a self-regulating effect, another distinguishing element between the actual PH and the scenario concepts is the heating system.

Whereas the plate radiator based system at the actual PH counts with 0.8 kWh/(m^2.a), scenarios LTB and SH achieve a smaller value of 0.6 kWh/(m^2.a) on the contrary and is because of their floor heating system. This advantage is mainly explained by metal free, and therefore less energy intensive heat emitters. The plate radiators add up to 0.4 kWh/(m^2.a) and are consequently the largest position in this context. Opposing to this, the floor integrated pipes add up to 0.2 kWh/(m^2.a). The remaining positions are almost kept at the same level. Only the reduction of apartment internal distribution pipes, were considered by a drawback of 20 %, which leads to a decrease of 0.005 kWh/(m^2.a). Thus, even with the consideration of a screed extension (+0.1 kWh/(m^2.a)) the floor heating system remains as the better opportunity, at least from this perspective. Nevertheless, beside ventilation, heat and solar system, there are further building services implemented in the building. The remaining building services do not differ in the particular concepts and are divided into the following positions:

- elevators (2): 0.2 kWh/(m^2.a)
- sanitary facilities (including: pumps, pipes and insulation): 0.4 kWh/(m^2.a)
- electric facilities (including: switches, sockets, cables and pipes): 0.7 kWh/(m^2.a)

Beside a component based consideration, the building services can also be put in the context of implemented building materials. A crucial aspect in this case refers to the circumstance, that building service components are not divided into its singular parts. Thus, they are considered, next to minerals, metals etc. (see Figure 37), as an own material group. From this point of view, building services in the actual PH add up to 0.5 kg/(m^2.a) respectively 2.1 kWh/(m^2.a), and has therefore a small to medium ranging influence on the result. However, compared to the component consideration the resulting difference of 0.2 kg/(m^2.a) respectively 0.8 kWh/(m^2.a), is based on attributional discrepancies. Hence, the automatic attribution of materials does not always comply with the manual added component group. More precisely, some to the component attributed building services, this applies especially for insulation (group 2) and according to piping relevant metals (group 4), do not correspond with the automatically sorted groups of substances. Nevertheless, according to this information, a material based consideration of building services remains interesting especially in the context of the different life cycle phases.

In dependence to Figure 34, and as supplemented consideration for bringing the building service more into relation to the constructive components, the last image (Figure 39) of this chapter relates to PE demand in total. But in contrast to the previous diagram, this figure responds to the particular material groups in each life cycle phase. In the phase of production, minerals have with ~ 34 % (+/- 3 %) over all three concepts the highest share and with approximately 21 % (+/- 2 %) metal is ranging as the second largest position. The lowest proportions are given in the group of coating and windows, each with about 3 %. However, the group comparison between the different phases is much more noteworthy. Therefore, it is interesting that the largest position of replacement belongs to the group of building services. Whereas it counts only between 6 % (LTB) and 10 % (SH) in the phase of production, it adds up to 17 % (LTB) respectively 35 % (SH). Also in terms of replacement, the minerals on the contrary only play an inferior role due to their long life span. A similar situation is given for biogenic materials, this is the only group which does not have any replacement at all during the life span of 50 years. Simultaneously, an extreme situation is given for coatings as well: Whereas they have the smallest share in production (~ 1 %), their proportion rises up to ~13 % with respect to the category of replacement. The major reason for this development lies in the regularly refurbishment at 15 yearly intervals. The last considered phase within the context of materials refers to the 'End of Life'. The most notable fact is that every material group, except of minerals (~0.3 kWh/(m^2.a)) and coating (0.0 kWh/(m^2.a)) has, due to their caloric value, a negative result. The quantitative lowest value (-1.5 kWh/(m^2.a)) is given for plastic. This results mainly from the copious implementation in the building. The last section of Figure 39 represents the total energy demand during all phases. Even this section represents, more or less, similar proportions as in the phase of production, it is remarkable, that the group of biogenic materials have a small negative value (0.05 kWh/(m^2.a)). This means, energy extraction (EoL), based on the gross caloric value, is larger than the energy input for making this resource applicable. By considering this, it becomes obvious why this accreditation, as mentioned above, is controversial discussed. Nevertheless, by considering the total figures during all phases the production with almost 90 % plays the most influencing role. The replacement can be summed up to approximately 20 %. Additional to these sections, the 'End of Life' phase neutralize it with -10 %.

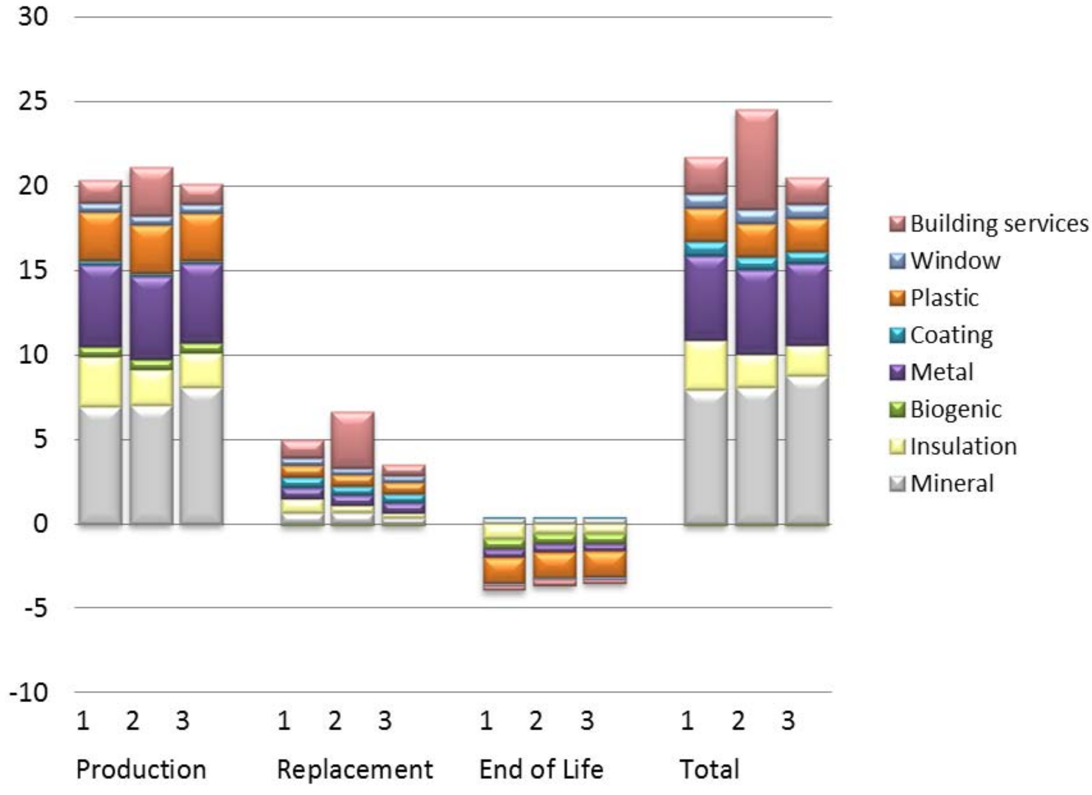


Figure 39: Primary Energy (total) in kWh/(m^2.a) related to the different phases of a LCA

1: Actual building "young corner" in Passive House Standard

2: Scenario Sun House

3: Scenario Low-tech building

By summing up the central outcomes, it has to be stressed that building services have a much larger difference between the concepts than the construction related components do. The major causing factor therefore can be assigned to the solar system. But also by considering only the ventilation and floor heating system, the differences are even higher than the category of exterior walls. In spite of the fact, that the building services of scenario SH almost feature the most important elements from a component based view, when it comes to a distinction between the implemented materials they lose their importance against minerals and metal. When embedded into a life cycle point of view, they have the largest relative relevance with respect to the phase of replacement.

6.3 Operation related results

In chapter 6.1 it was already mentioned that operational energy is the major influencing factor of this LCA. The actual PH for example, features a construction and service component based PE-NR of 18.2 kWh/(m^2.a) (= 39 %) and an operation based PE-NR of 28.6 kWh/(m^2.a) (= 61 %). This varies a little bit for the other options. Hence, scenario SH features 19.8 kWh/(m^2.a) (= 49 %) and scenario LTB 31.9 kWh/(m^2.a) (= 66 %) of operational energy (PE-NR). Even the results are just based on calculations instead of measured values, with respect of these absolute and relative differences it is worth to take a closer look on this particular issue.

The evinced differences of each concept relate to the particular building specifications (energy standard and building services) of each concept. Table 6 gives therefore an overview over all related energy consuming positions. It breaks down heat- and electricity related figures in accordance to their occurrence, which is either space heating, water heating or auxiliary energy for humidification[16].

Table 6: Operational energy demand of the actual Passvie House and the scenarios sun House and Low-tech Building

Energy Services	**Energy demand factors**	Passive House		Sun House		Low-tech Building	
		Energy demand	Energy source	Energy demand	Energy source	Energy demand	Energy source
Room heating	Heating demand (useful energy)	6.82	-	31.33	-	21.50	-
	Thermal losses	2.33	-	-4.00	-	-3.63	-
	Subtotal - Thermal energy demand	**9.15**	**District Heating**	**13.66**	**District Heating**	**17.86**	**District Heating**
	Auxiliary energy (e.g. pumps, etc.)	**0.50**	**Electricity**	**0.50**	**Electricity**	**0.50**	**Electricity**
Hot water	Hot water demand (useful energy)	12.78	-	12.78	-	12.78	-
	Thermal losses	15.57	-	14.77	-	15.57	-
	Subtotal - Thermal energy demand	**28.35**	**District Heating**	**13.77**	**District Heating**	**28.35**	**District Heating**
	Auxiliary energy (e.g. pumps, etc.)	**1.00**	**Electricity**	**1.80**	**Electricity**	**1.00**	**Electricity**
Auxiliary energy for humidification	**Auxiliary energy (e.g. air streaming, etc.)**	**4.01**	**Electricity**	**0.00**	**Electricity**	**0.00**	**Electricity**
	Ventilation (humidification)	0.00	Electricity	0.00	Electricity	0.00	Electricity
	Ventilation (dehumidification)	0.00		0.00		0.00	
Total energy demand - District Heating		37.50	kWh/(m².a)	27.44	kWh/(m².a)	46.21	kWh/(m².a)
Total energy demand - Electricity		5.51	kWh/(m².a)	2.30	kWh/(m².a)	1.50	kWh/(m².a)
Total energy demand - Solar energy		0.00	kWh/(m².a)	27.44	kWh/(m².a)	0.00	kWh/(m².a)
Final energy demand		**43.01**	**kWh/(m².a)**	**57.20**	**kWh/(m².a)**	**47.71**	**kWh/(m².a)**

As the table shows, the major part of energy (87 %) is caused by heating related energy. For the actual PH 21 % relate to space heating, 66 % to hot water services and another 13 % are used as auxiliary energy for pumps, fans or similar facilities. The reason why hot water service features a relatively high share compared to the space heating, is due to the high building standard and consequently low heating energy demand of 6.8 kWh/(m^2.a)[17]. Furthermore, with

[16] The differences between the table listed figures are based on several conversions which stand in relation to the conditioned and unconditioned floor area of the building as well as to conversion factors of the primary energy. A derivation of this conversion is adduced in Appendix 18.

[17] Figure relates to final and therefore not to primary (PE-NR) energy demand.

a low energy supply for heating, the linked losses remain small as well. Even scenario SH has the highest final energy demand, on the contrary it also features the lowest demand in district heating and has the second lowest value in electricity. The reason lies in the contribution of solar based energy for space heating and hot water supply. Because the solar plant is designed to produce 50 % of the heat related energy, it comes to a solar yield of 27.44 kWh/(m^2.a)[18]. Consequently this results, as already instanced in the first paragraph, in the lowest operational based PE-NR and lowest GWP (5.5 kg/(m^2.a)). Scenario LTB has the highest demand of energy from district heating but also the smallest in electricity. Finally, it comes to a final energy demand (related to the unconditioned gross floor area) of 47.7 kWh/(m^2.a) which is 11 % higher compared to the actual PH.

After a short overview with respect to derivation of the operational energy the effects of adaptations between the options shall be further contemplated. An overview of operation energy (PE-NR) and its correlating GWP of all major concepts, but also of additional special variants are depicted in Figure 40 and Figure 41.

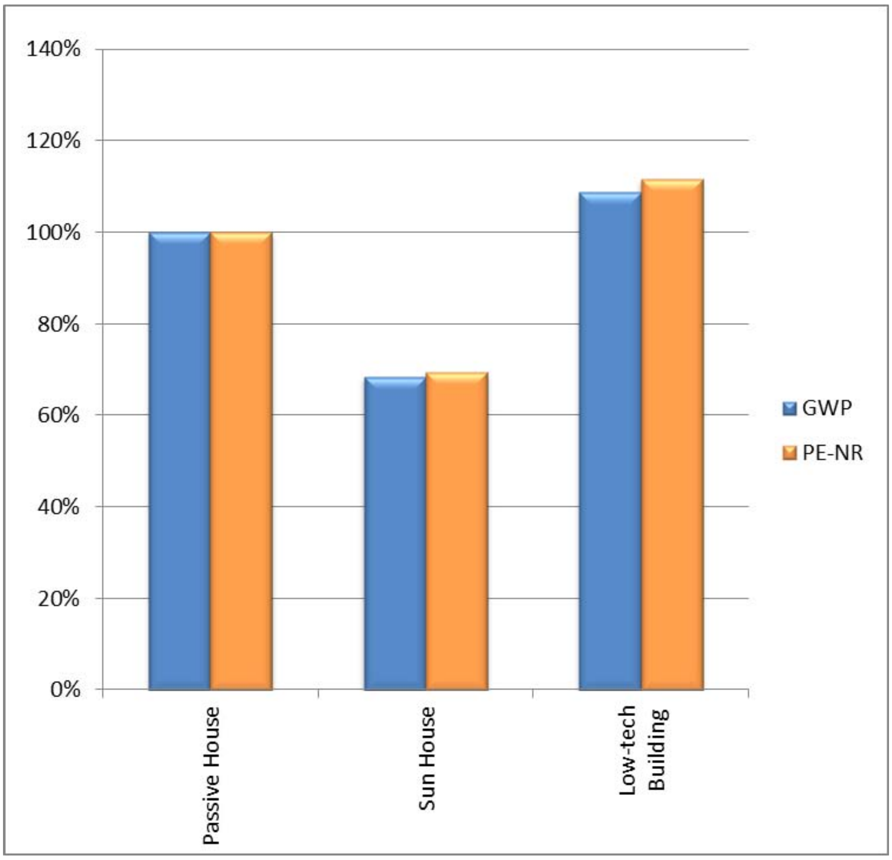


Figure 40: Global warming potential and non-renewable primary energy demand of the operational phase. Relative results of the scenarios in relation to the actual housing complex ‘young corner’ (= 100%).

[18] Figure relates to final and therefore not to primary (PE-NR) energy demand.

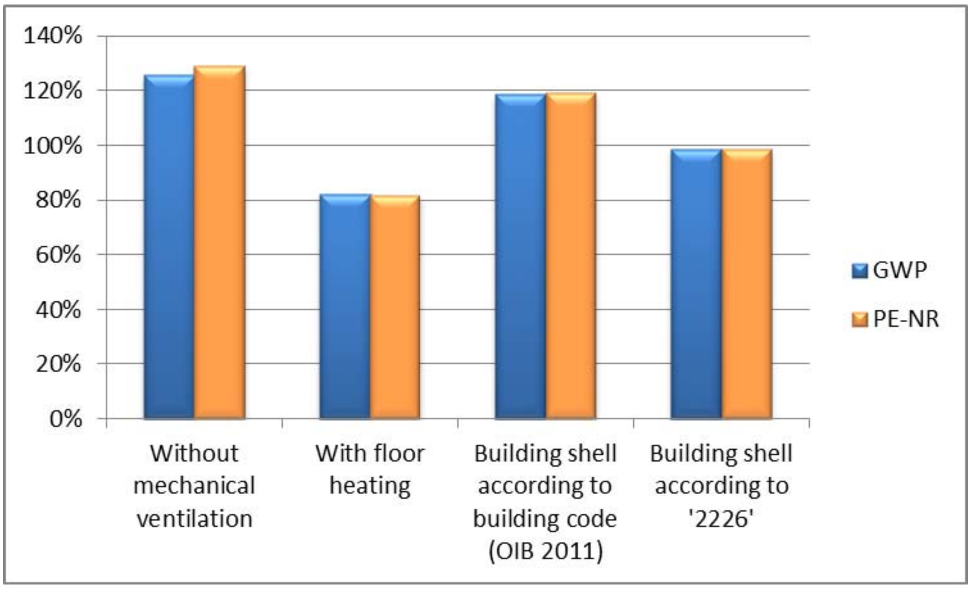


Figure 41: Effect of specific measures on the global warming potential and non-renewable primary energy demand of the operational phase. Relative results in relation to the values of the actual housing complex ‘young corner’ (= 100%).

The actual demand for space heating results highly from the heating demand of the building and its linked positions, such as thermal loses and auxiliary energy in form of electricity. Thus, as already mentioned above, according to a buildings efficiency standard (e.g. thermal envelope), the energy demand is correspondingly lower or higher. Arising from the three given concepts, the actual PH is performing best. It comes to a space heating performance (including auxiliary energy) of 9.7 kWh/(m^2.a). The second position is held by scenario LTB. It has with 21.5 kWh/(m^2.a) the second highest heating demand, and consequently a total space heating related energy demand of 18.4 kWh/(m^2.a)[19]. The lowest building standard is associated to the SH. With a heating demand of 31.3 kWh/(m^2.a) it comes, under consideration of negative thermal losses, to a demand of 27.8 kWh/(m^2.a). Thus, even the scenario concepts assigned with negative thermal losses, they perform worse than a building with a higher standard of insulation. However, it is interesting enough that both concepts (SH and LTB) which are equipped with floor heating feature a negative thermal loss in the category of space heating. The calculation processes in the energy certificate sheet, which lead to this result, are complex. The general mechanism of action is caused due to lower flow temperatures of the floor heating system on the one hand. On the other hand, it is because of thermal gains in space heating caused by thermal losses of water heating. Hence, because of lower flow temperatures (flow 40°C; return 30°C), a floor heating system has not to deal with the same high losses like a radiator based system. The effect of heat gain from hot water filled pipes within the thermal envelope of the building, especially during the heating period, is an additional result beside the already lower balanced losses in the heating system. These hot water based losses are so high, that even the positive losses from the heating system become negative. Hence, the energy software tool balances loses between two categories. The reason why the PH does not have negative losses lies in their larger heating losses compared to floor heating systems. For assessing these effects, an additional analysis of the floor heating system is implemented. Based on the original PH concept, the exchange of radiator by floor heating system is examined. Hence, only the system is changed in the energy certificate, whereas the rest is kept the same. According to this analysis a reduction of 1.4 kg/(m^2.a) GWP is the result. This is a relative decrease of 18 % compared to the initial operational energy. A similar situation is given for the PE-NR, it decreases also by 18 % and thus by 5.2 kWh/(m^2.a). These figures appear quite high, especially by comparing them with results from other research operations such as Lettner et al. (2014) and Lüdemann (2002). According to these research results, the floor heating system performs, related to the primary energy demand in utilization, performs only by 1-3 % better than a conventional radiator heating system. Moreover, others experts like Laasch et al. (2013) assume even non-existing differences between both systems. Nevertheless, the evaluated result in this thesis has its legitimacy. The significant difference of nearly 15 % results mainly from an integrated approach, and not from the floor heating system alone. This means, there is a synergy between smaller pipeline loses, caused by lower flow temperatures, and gained heat from hot water carrying pipes. This circumstance followed by a negative thermal loss of 5.5 kWh/(m^2.a) [19]. Simultaneously, a drop in the space heating demanded energy (final energy) from 9.7 kWh/(m^2.a)[19] to 1.85 kWh/(m^2.a)[19] can be recognized.

Whereas scenarios SH and LTB perform worse in the context of space heating, they gain advantage of 4 kWh/(m^2.a)[19] with respect of auxiliary electricity related to air streaming. The reason obviously lies in the abandonment of the ventilation system. On the contrary it has to be considered, that only with mechanical ventilation and an integrated heat recovery, aeration losses, which are caused by window ventilation, can be minimized. Consequently, the mentioned losses play a role for space heating and thus are credited in the energy certificate calculation to the heating demand of a building. In case of the initial PH version the aeration losses (minus the savings from auxiliary energy), by omitting the ventilation system, counts with 2 kg/(m^2.a) in GWP and 8.3 kWh/(m^2.a) in PE-NR. Thus it would increase the heating demand from 6.82 kWh/(m^2.a) to 20.7 kWh/(m^2.a), which is almost as high as the heating demand from scenario LTB (21.5 kWh/(m^2.a)). In consequence to this fact, it becomes clear, what influence an abandonment of a ventilation system has.

The last adaptation in building services relates to the solar system of scenario SH. As outlined above, the main advantage compared to the other two concepts is a solar based energy gain of 27.44 kWh/(m^2.a)[20]. This leads to the lowest demand of external energy services (e.g. district heating and electricity). The additional power for pumps is credited in the auxiliary energy of hot water services. But with an addition of 0.8 kWh/(m^2.a), it has an inferior role. Especially in considering environmental impact factors like GWP, renewable energy facilities are an important factor. Even with their own production related PE-NR of 518.6 kWh/m^2 and GWP of 120 kg/m^2, over a life span of 20 years one square meter produces 5,300 kWh, and features consequently an energetic payback period of approximately 2 years[21].

However, the last not evinced adaption is the buildings envelope. Due to a similar U-Value in average, the differences from PH to LTB are very small. In GWP they differ only by 0.1 kg/(m^2.a), and in PE-NR only by 0.4 kWh/(m^2.a). The situation differs in the case of scenario SH. Because of its lower performance in exterior wall and ceiling constructions, the values increase by 1.5 kg/(m^2.a) and 5.5 kWh/(m^2.a) compared to the actual PH.

To put it in a nutshell, it can be said that the operational energy, especially in relation to PE-NR, is in this specific case highly influenced by three factors: renewable energy facilities, ventilation system and heating system. Especially the solar thermal plant influences the demand from energy services at most. With a solar cover ratio of 50 %, it reduces the external delivered energy (district heating and electricity) by 48 % respectively by 27.4 kWh/(m^2.a) of final energy. The ventilation system shows to be a little bit less significant. Yet, with a saving of 12 kWh/(m^2.a) in final energy it still holds a remarkable improving potential. The floor heating system can count approximately with 8 kWh/(m^2.a) of final energy. The fourth point, building envelope, highly relates to the adapted components, but is also from significant influence. Whereas, scenario LTB has only a negligible disadvantage (~ 1 %) scenario SHs envelope is approximately responsible for an increase of 20 % of the PE-NR.

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[19] Figure relates to final and therefore not to primary (PE-NR) energy demand.
[20] Figure relates to final and therefore not to primary (PE-NR) energy demand
[21] Even by considering the total solar plant the energetic payback period must be less than 4 years.

7 Discussion

The Life Cycle Assessment represents ‘a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle’ (EN ISO 14040, 2006). The previous chapter (6) attends this approach by considering several aspects of environmental impact factors in relation to different building concepts, respectively to their particular characteristics. Thus, it was the thesis aim, to determine the least environmental harming version and identify respective and responsible causalities. Whilst the chapter of results follows mainly an interrelation based approach and a material point of view, the discussion intends more to outline the absolute figures of each building concept and summarize them. Furthermore, with instancing variabilities of the calculated figures it shall be shown how sensitive the results are. The focus still lies on the aggregated impact values, Global Warming potential (GWP) and non-renewable primary energy demand (PE-NR). This shall help, to get an overview of the most relevant building components and their particular impact characteristics. This numerical analysis is followed by a more qualitative consideration. Firstly, this includes a concept comparison, related to their practicability with respect of apartment buildings, and is followed by a more holistic point of view, in which the gained findings are put together with the concept of sustainable building in general.

7.1 Quantitative analysis

According to the aggregated results (Figure 32) scenario Sun House (SH) had the lowest environmental impact (97.8 %). The actual Passive House ‘young corner’ (PH) and scenario Low-tech Building (LTB) are ranging on the same level (~ 100 %). This is a central outcome of the implemented analysis and is thus quoted in one of the first result pages. Nevertheless, its significance and validity should be further considered and must not be taken as an indisputable fact. This argument refers mainly to two aspects. The first relates to solar ratio determination of the modelled scenario SH. As already outlined in chapter 5.2.3 the solar ratio is rather based on an extrapolation than on a detailed and exact calculation. Thus, the evaluated figures only result from the conversion of the SH in Freistadt and deals consequently with inaccuracies to a certain extent[22]. The second aspect refers to the weighted factors of the aggregated results. They can have, according to local or regional circumstances and respective environmental issues, different emphases. Certainly, the impact factors such as GWP or Ozone Depletion Potential (ODP) effect, for sure, on a global scale. Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP) and Eutrophication Potential (EP) on the contrary are more related to small scale structures. Hence, it might be crucial to think of different approaches with respect of factor weighting. Moreover, reconsideration in general is not preposterous. As taking the following dimensioning as an example: If all categories are weighted with the same factor (e.g. 1), the ranking would change in so far, that scenario LTB (97.9 %) would be the most and scenario SH (103.9 %) the least preferable option. A more intensifying situation is given as far as the ODP is raised to the factor three. This would entail a further slip of scenario SH to 109.4 %. Scenario SH in contrast could gain a further asset of 0.3 %. Moreover, the overall assessed outcome can be arranged very diversely and has to be considered carefully.

However, by considering the major factors of this thesis (GWP and PE-NR) and consequently their exact figures, the picture is different again:

- The actual PH has a GWP of 15.2 kg/(m².a) and a PE-NR of 46.6 kWh/(m².a)
- Scenario SH has a GWP of 13.4 kg/(m².a) and a PE-NR of 40.2 kWh/(m².a)
- Scenario LTB has a GWP of 15.7 kg/(m².a) and a PE-NR of 48.7 kWh/(m².a)

[22] This applies also in a similar way to relevant adaptation for scenario LTB

The largest differences lie, relating to this consideration, between scenario SH and scenario LTB. Compared to scenario LTB, scenario SH has 2.3 kg/(m².a) less GWP and 8.5 kWh/(m².a) less PE-NR. Again, the ranking is the same as in the initial aggregated consideration. The only difference is that the results are more distinctive and the differences are more significant.

7.1.1 Quantitative analysis of building components

A detailed outline of component related differences can be found in Figure 35 and its preliminary paragraph. Nevertheless, supplementary to the already elucidated facts, the image gives an overview over all adapted building components and services, related to their particular concept. The actual PH is therefore taken as a basic version, whilst scenarios SH and LTB are described regarding their differences towards the actual PH.

Table 7: Building component based differences of scenario Sun House (SH) and scenario Low-tech Building (LTB) compared to the actual Passive House 'young corner' (PH)

	Passive House (actual building)		**Sun House** (scenario building)		**Low-tech building** (scenario building)	
	GWP kg/(m².a)	PE-NR kWh/(m².a)	Δ GWP kg/(m².a)	Δ PE-NR kWh/(m².a)	Δ GWP kg/(m².a)	Δ PE-NR kWh/(m².a)
AW 1	0.36	1.07	-0.08	-0.28	-0.08	-0.32
AW 2	0.46	1.51	-0.14	-0.48	-0.04	-0.33
AD 1	0.24	0.69	-0.02	-0.08	0.00	0.00
AD 2	0.40	0.74	-0.03	-0.09	0.00	0.00
AD 3	0.12	0.33	-0.01	-0.03	0.00	0.00
DGUo6	0.02	0.04	0.00	-0.01	0.00	0.00
DGUo7	0.13	0.26	0.00	0.00	0.00	0.00
Ventilation	0.18	0.62	-0.14	-0.49	-0.14	-0.49
Heating	0.18	0.76	-0.02	-0.15	-0.02	-0.15
Solar	0.00	0.00	1.03	3.88	0.00	0.00
Total	**2.07**	**6.02**	**0.59**	**2.27**	**-0.28**	**-1.29**

By considering, that all green marked figures represent a lower and all red marked figures a higher value, it becomes obvious that in total the building components of scenario SH cause a slightly higher and scenario LTB a smaller environmental impact compared to the actual PH. According to the building components and services, the ranking is just the opposite compared to the above listed bullet points. Hence, it can be concluded, that building components have an influence indeed, but they do not represent the critical factors. This applies to the fact that it has to be the operational energy. But before discussing this in more detail, the differences in components shall be further illuminated. One of the largest savings in both categories (GWP as well as PE-NR) can be reached in quantitative large exterior wall constructions e.g. AW 1 (1370 m^2) and AW 2 (2283 m^2). This particularly applies to scenario SH and is primarily based on material reduction[23]. Building service related adaptations follow similarly within both concepts: there are small changes in GWP but relatively high changes in PE-NR. This even counts for the solar plant of scenario SH.

According to the contrary situation in the building components, compared to the overall outcome, the operational energy must be further significant as may suggested in the beginning. This is also represented in Figure 33. By looking at the differences between the concepts in the first three life cycle phases, it is apparent that in sum the differences are by far smaller than in the phase of operation. Another perspective of this aspect is given by Figure 42:

[23] A consideration of the effects regarding to the space of living caused by the different wall thicknesses is further discussed in 7.2.

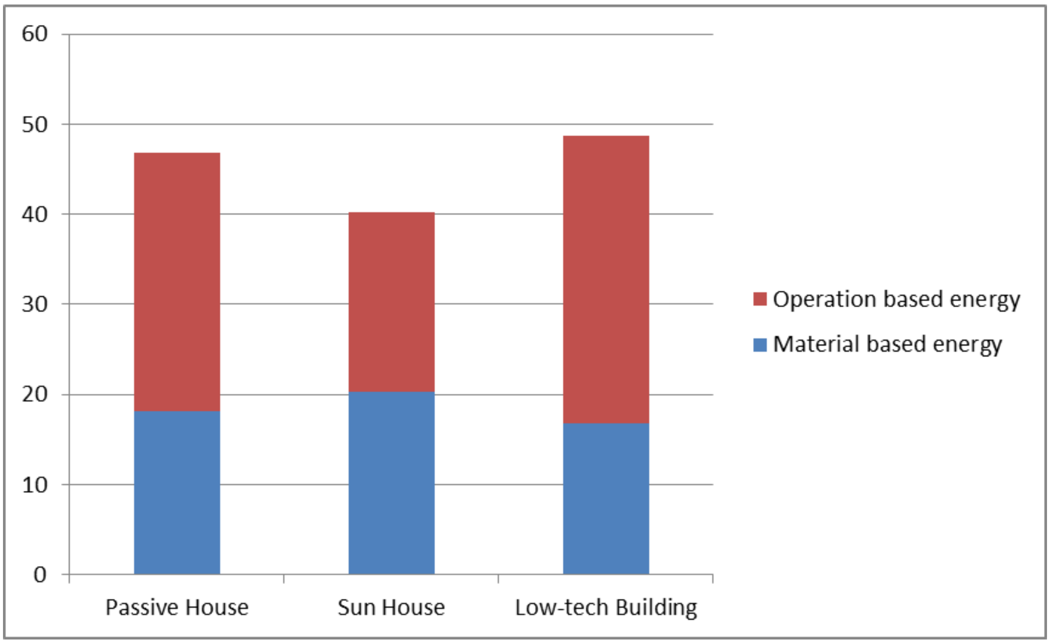

Figure 42: Comparison of material and operation based energy over the three building concepts in non-renewable primary energy

This illustration further depicts the distinctive difference of operation and material based energy. But it also reveals that the dominant phase of operation does not comply with scenario SH. Normally, the operation phase (based on the PE-NR) applies to the concept with the lowest building standard at most. However, this rule of thumb does not apply as far as other components (e.g. renewable energy facilities) are largely replaced or added. Therefore, scenario SH has about 20.3 kWh/(m².a) of material based energy and 19.8 kWh/(m².a) of operational based energy. Thus it can be said a 50:50 share. For the actual PH (4:6) and scenario LTB (3:7) the predominant character of the operation phase remains.

7.1.2 Quantitative analysis of operational energy

As already explained in chapter 6.3, the operational energy relates to certain aspects[24]:

Scenario SH has, with its renewable energy facility, the best result in PE-NR. Because the solar system provides 50 % of the heat related energy demand, scenario SH has only to be supplied with 18.4 kWh/(m².a) heat from district heating and with 1.4 kWh/(m².a) of auxiliary electricity. Furthermore, it also gains an advantage from utilizing a floor heating system (~ -5 kWh/(m².a)). Negative influences for the building performance result from an absence of the ventilation system (~ 8 kWh/(m².a)) and a lower insulation standard (~ 5.5 kWh/(m².a)).

The PH ranks second. With the highest standard of insulation and a ventilation system, which lowers the losses due to its heat exchanger compared to a window ventilation, it has a PE-NR demand of 28.6 kWh/(m².a). But, due to a missing solar thermal facility the entire energy (related to PE-NR) has to be provided from an external supplier (heat = 25.2 kWh/(m².a); electricity 3.5 kWh/(m².a)).

Scenario LTB has, because of its missing ventilation and renewable energy system as well as its slightly lower insulation standard, the highest demand on PE-NR. Even though it has the lowest value in auxiliary energy (0.9 kWh/(m².a)), due to the high heating demand to 31.9 kWh/(m².a).

[24] The below listed figures are related to the functional unit of conditioned gross floor area.

7.1.3 Quantitative analysis in a summarizing manner over the entire life cycle

The evinced differences between the three concepts arise from various origins. Whereas scenario SH achieves its asset during the phase of operation, scenario LTB scores during the production phase. Its smaller impact especially with respect to ODP, POCP but also ACP remains from material reduction respectively material exchange. This even lasts over the operational phase, where scenario LTB has the largest drawback. Taken the POCP as one example, in which scenario LTB features the best performance, it becomes clear that the most important is not only played by the GWP and PE-NR. The actual PH, as well as scenario SH, are equipped with a synthetic resin plaster at the exterior walls (AW 1 and AW 2). This position in these concepts causes approximately 14 % of the entire POCP. Thus these components represent the highest values of this parameter. Scenario LTB on the contrary is supplied by lime plaster (< 1 %). Even though the absolute differences remain very small, the sensitivity of this parameter should not be underestimated. In contrast to the protective function of ozone in the stratosphere as soon as it comes closer to the earth surface it has many hazards. According to scientific evaluations, POCP is suspected of causing damage to vegetation and also to materials. Moreover, it is toxic for humans (König et al., 2009). However, the reason for an application of synthetic resin plaster is not directly comprehensible and a controversial discussion about its benefits exists. Perennially pro and contra arguments are (Source: URL 11 and URL 12):

Advantages:	Disadvantages:
- easier processing	- lower temperature resistance
- faster curing	- application only on outer surfaces
- better shaping potential	- synthetic and oil based product
- thinner plaster layers	- disadvantages in waste disposal

Nevertheless, the main discussion refers to the aspect of tear resistance. On the one hand, it is said, that this characteristic is fulfilled especially by the resin plaster because of its viscosity, on the other hand many practical experiences but also expert appraisals criticize embrittlement of the synthetic material (enius, s.a.; Kolb, 2015). Even, the reason for it application results from the concept of minimizing the construction of exterior walls, concluding from an environmental point of view, it seems more reasonable to apply a mineral plaster instead. Still, the resin plaster is not the only reasonable difference for a lower outcome of POCP. Also the varnishing from plate radiators counts for 9 %. With the application of floor heating in scenarios SH and LTB, this component gets redundant and causes a further asset for both concepts regarding to this parameter.

Alongside with this last written elaboration it shall be shown, that effects are interrelated and do not always function in a correlated manner. Even with an increasing GWP and PE-NR during the operation phase, scenario LTB took over the advantages of material exchange in production and replacement during the whole life cycle. In a more specific related examination the different components could be further and deeper discussed about their life cycle performance compared to their reasonable application. But as far as it is not a matter of subject in this thesis, it will not be further considered in this context.

After all, it shall be mentioned, that all three evaluated concepts, even there are partially significant differences, already feature a high performance according to the concept of sustainability. This statement especially applies in consideration of comparing them with the average building inventory as well as with the objects which are currently built after the legal standards. To verify this statement an additional scenario was compiled and evaluated. This scenario fulfills the building code (OIB directive 6, 2011) and is therefore indicated as scenario OIB-House (OIBH). Scenario OIBH has in general the same structure like scenario SH. Only in respect to the implemented building services some changes occur. For this reason, the solar thermal system was removed and therefore complemented by a greater demand towards the district heating, whilst the floor heating was replaced by a conventional radiator based heating system.

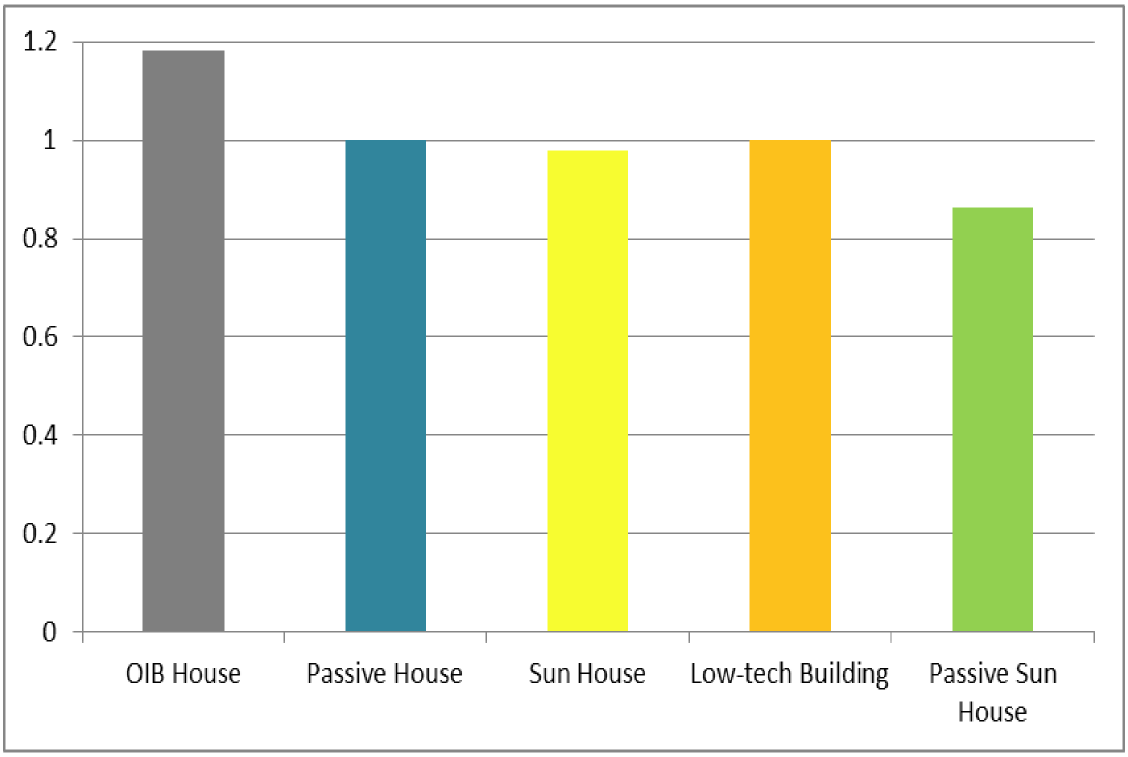

Figure 43: Comparison of overall aggregated LCA results. Relative results of the scenarios in relation to the actual housing complex ‘young corner’ in Passive House Standard. Additional scenario ‘OIB house’ represents the minimal requirements of the building code and scenario ‘Passive Sun House’ represents the combination of Passive House Standard and Sun House concept.

As Figure 43 reveals (related to Figure 32), the 118 % of scenario OIBH is by far above the major evaluated concepts. It has an overall GWP of 18.5 kg/(m².a) and a PE-NR of 59.7 kWh/(m².a). As far as these values are divided into a material and an operational based contemplation, it can be said, that 37 % of the GWP are emitted for materials and 63 % during the operational phase. A similar, but also more distinctive picture is given for PE-NR, 28 % are used for materials and the rest for the operation. It needs to be stressed, that even though it shows better performance in some categories (e.g. ODP and PE) for at least one of the major concepts, its performance in each category is worse compared to the actual PH. This evidence illustrates the influence of a low building standard, which entails a poorer building envelope and less building services. It becomes even more significant when the major impact factors are compared with the sustainable concepts.

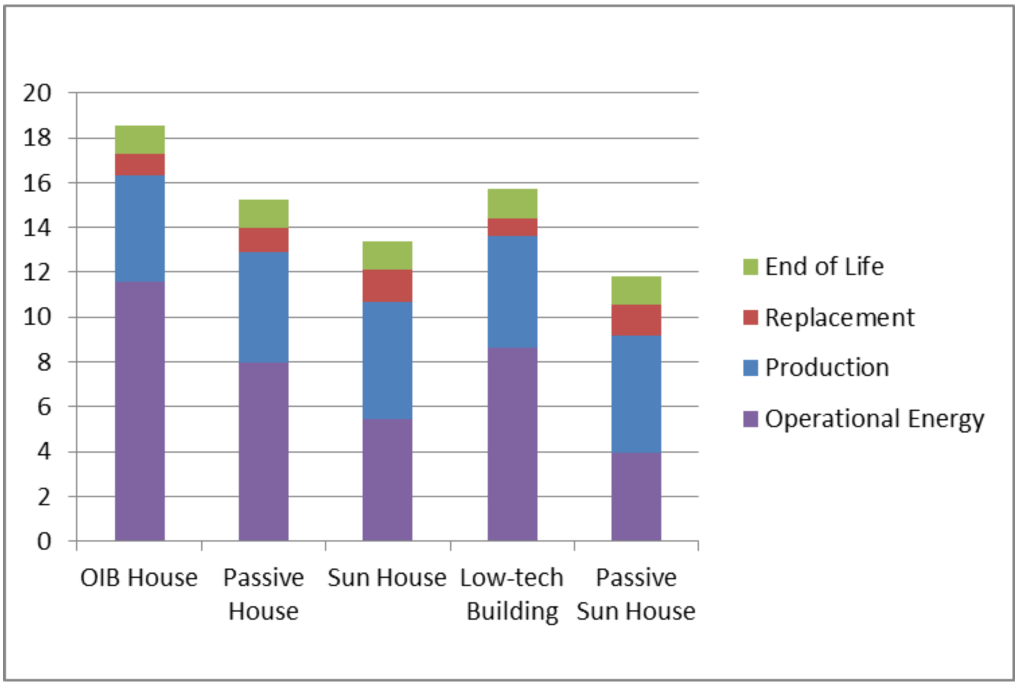

Figure 44: Global Warming Potential (kg/(m².a)) of the actual Passive House and different scenarios over the entire life cycle. Additional scenario ‘OIB house’ represents the minimal requirements of the building code and scenario ‘Passive Sun House’ represents the combination of Passive House Standard and Sun House concept.

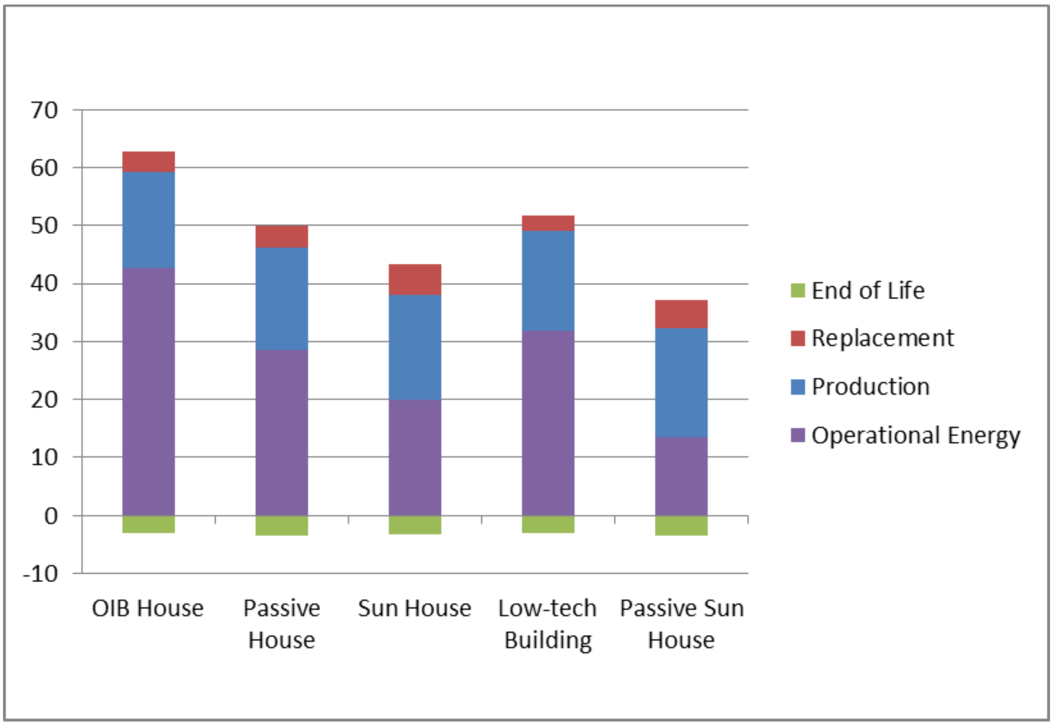

Figure 45: Non-renewable Primary Energy (kWh/(m².a)) of the actual Passive House and different scenarios over the entire life cycle. Additional scenario ‘OIB house’ represents the minimal requirements of the building code and scenario ‘Passive Sun House’ represents the combination of Passive House Standard and Sun House concept.

In a contrasting manner to scenario OIB house, a fifth scenario is also already listed in the last three figures. This scenario is called Passive Sun House (PSH) and represents the most efficient building standard of all considered scenario. It actually combines scenario PH with scenario SH and features the best characteristics of each concept. This means scenario PSH is built with:

- a PH building envelope (HWB 6.82 kWh/(m².a))
- a mechanical ventilation system with a heat recovery unit
- a floor heating system
- a solar thermal system

Based on these characteristics, scenario PSH has the best performance of all evaluated concepts. In an overall assessment (see Figure 43) scenario PSH undercuts the actual building by 13.7 % and scenario SH by 11.5 %. Furthermore, in four out of seven categories scenario PSH has the overall benefit and is not in any category the worst option. Its best parameters are even better, in response to the GWP it comes to a value of 77 % and 72 % in case of the PE-NR. ODP (114 %) and PE (104 %) are the only parameters, which exceed the value of the actual building. The proportion between material based and operation based energy lies about 34 to 66. But its striking result relates not only to the particular implemented features, a major contribution comes from the downsized solar plant as well. Due to the reduced demand for space heating, the solar collectors could be reduced by 47.35 %[25] down to 668 m². This value is furthermore confirmed by an analysis of 'Initiative Sonnenhaus Österreich' (see Figure 46). According to these findings, the solar collector area can be reduced by a factor of two, by keeping the same solar cover ratio, as soon as the building standard goes from HWB 27 (similar to scenario SH) down to HWB 10 (similar to PH respectively PSH). Consequently, on a solar cover ratio of 50 %, the 10 m² solar collector can be downsized to approximately 5 m² as soon as the building standard moves from the HWB 27 standard to HWB 10 standard.

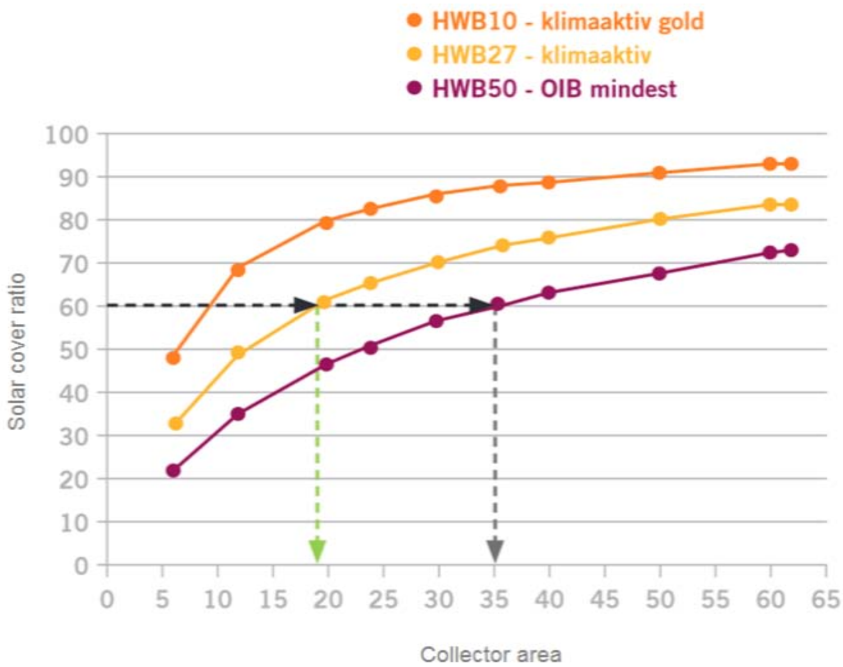

Figure 46: Relation between different building standards, solar cover ratio and collector area (Source: URL 4)

[25] The building standard of the SH has an energy demand, regarding to space heating and hot water, of 54.9 kWh/(m².a). The PSH has an energy demand of 28.9 kWh/(m².a), which is a reduction of 47.35 %. As a result, the solar gained energy can be reduced by the same ratio.

This leads to a reduced number of solar collectors, decreased size of the solar plant facility and lower requirements for studding, pipes and storage tanks associated with the construction. Thus it seems that the new concept benefits from many aspects of the entire construction. Furthermore, it can be concluded, firstly on a numerical basis, that the best performance lies neither in the PH, SH nor LTB, it goes back to a reasonable combination of two or maybe even three different concepts in which each can be profitable as a whole respecting its particular strengths.

7.2 Qualitative analysis

After a detailed description of diverse quantitative aspects with respect to the LCA, in this chapter the focus is set back again on a more general point of view. For this reason the general illustrated building concepts from chapter 3 are related to the respective LCA outcome. Additionally, results are not only compared to the six dimensions of sustainable building (see chapter 2.2), they are also discussed in a more holistic way which cannot properly described with numerical values.

7.2.1 Fundamental ideas and respective life cycle outcomes

As written in chapter 3, each building concept epitomized a certain idea. In a simplified manner it could be claimed: Whereas the PH has its focus on a minimization strategy, the SH for example follows, with its solar plant, more a maximization approach. The LTB is also a representative of the minimization method, even though its focus more likely put on a simple but effective functionality.

In chapter 3.2.2 the major characteristics of a LTB are defined as ‘simplicity, functionality and robustness’. But how far does the scenario building comply with these features? Talking about simplicity, it means in effect, that a certain function or state is established with a minimum of complexity. If a building is dissembled in its main components, it would be separated in constructive wall/ceiling, window/door, water supply and heating. Thus by looking first of all on constructive components, it could be said, that due to some complex structures, e.g. AD 1 with 14 layers, versus very simple kept ones, e.g. AW 1 with only 3 different components (painting, mineral plaster and bricks), simplicity could be realized persuasively. Windows and doors are kept, by considering the demand of a low heating demand, as simple as possible. Even triple glazing windows are in particular not a simple construction, but due to their multiple implementations in many nearly zero energy buildings during the last 20 years, they have become more common. Even 50 years ago, a well-insulated building had been classified as a high-tech building, but nowadays it is one of the most common things in construction (Ritter, 2014). The third aspect, water supply, is kept very simple and does not have any specialties. Also the floor heating system is a very basic method. Even though it is a little bit more complex in the aspect of installation, with respect to its production (tubes versus radiators), it represents a very low technology standard. Furthermore, with the utilization of the already existing screed it follows in the same time a multi functioning approach of one building component. Recapitulating it can be said, that the modelled LTB accomplishes its aim of striving an approach of simplicity on a wide field. As already referred to the function of providing a low heating value, it can be said that also the aspect of functionality is given over all applied components. A similar situation is given for the last aspect, the robustness. The entire building complex does not exhibit any fragile structures. The only exception is given, as far as it considered on a longer life span of 50 years, by replacing the floor integrated tubes. But exchanging the tubes would be the smallest problem, if not the entire floor covering, screed and (partly) insulation must be replaced as well. In other words, even the replacement of a single component causes lateral damage to three others. Thus, this represents a kind of weakness instead of robustness.

However, talking about life expectancy, the goal of extending this, is largely complied by the LTB. With a decreasing implementation of high tech components such as ventilation system, solar panels or wall constructions with special elements (e.g. synthetic resin plaster and phenolic foam insulation) the average life span could be further increased. One example is also given for the already discussed floor heating. Whereas plate radiators are exchanged after 25 years, the floor heating tubes last about 50 years. But also ventilation is a good example, whereas the ventilation system of the PH has to be exchanged after 25 years, the window ventilation does not need any replacement at all and features the aspect of multi functioning components as well. Moreover, a decreasing level of technology entails beside a life span extension also a minimization of maintenance and adjustment of service facilities.

In reference to the Streichers definition of LTB (see chapter 3.2.2) it can be summarized, that the modelled building (scenario) complies with the requirements to a great extent. Especially the aspect of a ‘minimum of technical installations’ is achieved without any compromises. Other aspects like ‘excellent energy performance’, utilization of ‘natural physical effects’ as well as local available resources are largely met. The ‘excellent energy performance’ for example is achieved so far, that the building accomplishes the standard of a low-energy house. But due to its heating demand of 20.57 kWh/(m^2.a) it has an approximately 2.5 fold higher energy standard than an PH, which represents the strived standard. Hence, it can be said the energy standard is good, especially compared to a standard house according to legislation, but it does not achieve an excellent level. A similar situation is given for the ‘natural physical effects’: Already the initial building features a good alignment to south/west, canopy for the sun during summer as well as effective arrangement of rooms according to their utility and sun appearance. However, unfortunately it does not face 0° south which brings a disadvantage in passive solar radiation as well as a lower performance in usage of natural light. The local available resources are also partly complied. With the focus on mineral materials, also with respect to insulation, a supply of local resources is more likely compared to synthetic substances which are highly based on oil and other chemical substances. Only the part of ‘historic building techniques’ does not find any consideration. Hence, even it is not a simple process to define a LTB, in respect to the given information it can be concluded that the modelled version is a decent representative for this type of building.

Besides talking only about defining or efficiency, there are other aspects in the context of buildings respectively ‘modern architecture’. Treberspurg (2006) points out six aspects which have to be considered (see Figure 47):

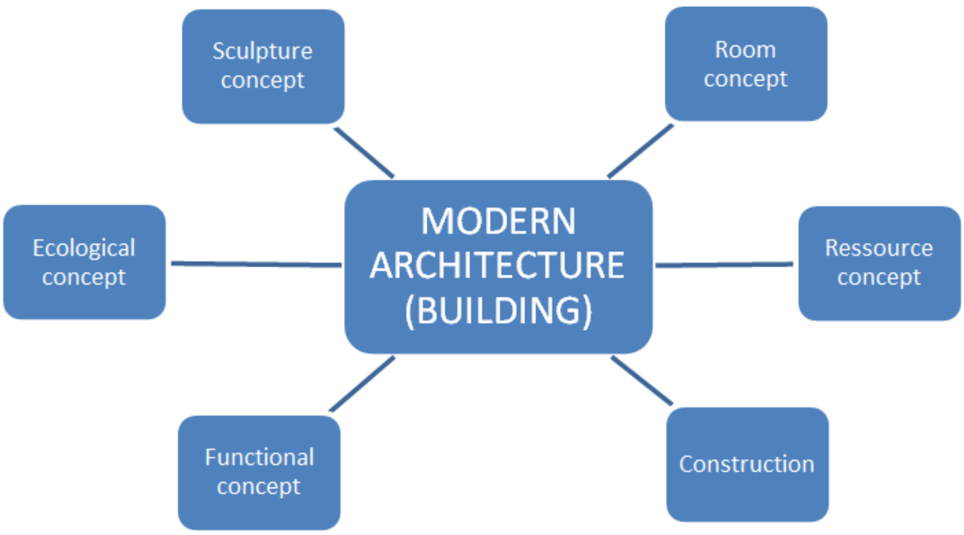

Figure 47: Concepts of modern architecture respectively building
(Source: Treberspurg (2006) adapted by Armin Holdschick)

According to this approach, there are some concepts left which have not been mentioned in this thesis so far. Even though a comprehensive consideration of architectural concepts is not object of this thesis, a short recapitulation of already discussed and non-discussed aspects seems reasonable in the matter of a holistic methodology. Thus, the main focus of this paper lies on the ecological (building based) as well as on the resource concept (usage based) and has been discussed in a very detailed manner. Also broached is the concept of rooms and construction. So far, only the sculpture and the functional concept are missing. And with respect of the second one, some additions shall be made in the following paragraphs.

In terms of still discussing the LTB concept it comes to an important consideration of the chosen wall structure. As already shown, the double brick wall has a similar U-value (= similar energy demand) and significant lower emissions relating to POCP than the wall from the actual PH. A real virtue sources itself from an ecological and a resource point of view. Certainly, this construction has not only benefits when it comes to the functional concept of the wall or of its influencing surrounding. Compared to the initial construction, which was built with the idea of minimizing the structure for gaining a maximum of useful area, it represents just the opposite. With 80 cm it is 65 % thicker than the exterior wall of the actual PH with 48.5 cm. This in turn reduces the useful area by 2 m^2 in an apartment of ~40 m^2 and up to 8 m^2 in an apartment of ~70 m^2. Hence, the function of using a maximal floor area would be negatively affected. In the matter of the utilization and entire concept of a building it has to be asked how important several factors are. Therefore, with respect of a multi-storey apartment building the useful area becomes a very important concept and has been designed very carefully. Summarizing it can be said, that this type of exterior wall construction is not suitable to the given utilization of the building and fits properly and better to detached houses or office complexes such as '2226' in Lustenau.

In a comprehensive contemplation the question is: How practical is a LTB? In general it has to be said, that the idea of reducing technology, if a high and well-functioning building standard is kept, represents an excellent approach. The outcomes from the conducted LCA achieve a very beneficial outcome especially compared to the scenario OIB House. This means the performance is at its peak within the concept of resources as well as in ecology matter. But also the aspects construction and room conceptualizing are not negatively affected. There are only two things, which lower the overall performance. The first one is the already discussed aspect of functionality; in terms of a multi-storey apartment complex the losses of useful area are too striking. Furthermore with respect of a comfortable living environment it comes, due to the manual operation in ventilation and cold breezes in winter, to adverse implementation compared to the PH. The second aspect deals with the costs. Even though they are not discussed in this thesis they also play an important role regarding the realization of building constructions. The LTB is confronted, as all other sustainable building concepts with higher initial costs, to be get paid back as far as the savings from lower energy expenditures are calculated. Nevertheless, these higher initial costs often discourage constructors and investors from choosing the 'better' one. However, as written in the previous paragraph, the building concept seems to fit more precisely to a detached/multiple dwelling or offices complex. Still, it needs to be stressed that, from the current perspective it should be worth putting more investigation into this kind of building concept. This applies specifically for regions with a constant climate, which even might entail an abandonment of a large heating facility.

After discussing the LTB the next section deals with the other two concepts. During the last few years, since SH became more popular (till recent days), a partly heated discussion arose about the differences between PH and SH and their practicability. The PH was already established in the end of the 90ies. The SH in contrary got more popular during the last 10 years and found many advocates during this time. Generally, the reason lies primarily in the changed focus of energy consumption. Whereas the PH refers mainly to the heating demand, the SH focusses on an approach, which relates to a primary energy demand of non-renewable resources. The argument is reasonable: Only a low heating demand does not prevent automatically from high energy consumption. Even, the primary energy demand is at 120 kWh/(m^2.a) (including also household electricity consumption) supplementary considered in the PH concept, there are many SH concepts which achieve a much smaller value due to their installed solar energy facilities. However, the particular dis-/advantages are discussed more in detail in the next few paragraphs.

First of all, it shall be shown that both concepts meet their particular standards. The realized PH has in general, compared to the minimal requirements of the PH-standard, a very good performance. With a heating demand of 6.82 kWh/(m^2.a) it is about 2 kWh/(m^2.a) (~ 20 %) below the PH criteria. Moreover, all elements of the building envelope (exterior walls/ceilings, windows, etc.) comply with the requirements. Only compliance of PE-NR (< 120 kWh/(m^2.a)) cannot be verified because of missing data of utilization energy respectively household electricity. But because of the energy allocation in a household (see chapter 3.3.2) and a low PE demand of 32.4 kWh/(m^2.a), which is just based on the heating demand, it can be assumed, that the threshold will not be exceeded. A similar situation is given for the SH. Besides of meeting all mandatory specifications according to the envelope it also complies with standards relating to PE and heating demand. The PE adds up to 21 kWh/(m^2.a) and is caused by its non-renewable energy supply (district heating) below the threshold of 30 kWh/(m^2.a). Thus implies, that the modelled SH is marked with an 'f' which stands for fossil fuel. Also the most remarkable feature of the SH, the solar ratio, is met by its minimum standard of 50 %. As it can be seen, due to the specific requirements it is easier to determine if the standards are accomplished or not. Nevertheless, the before instanced architectural concepts and therefore qualitative factors, have also here, in context of PH and SH, their relevance. As described in chapter 5.1.2 (and 5.1.3) the construction, as well as the room concept are already fulfilled by the initial construction. But, when it comes to the ecological and resource concept it is worth, with respect to the topic of this thesis, to go into more detail.

Because of the current importance, but also growing interest of the topic, the comparison between PH and SH have already been object of several research activities. One of the most popular scientific papers in this context is the diploma thesis by Katrin Koch (2008). Her major purpose was the comparison of both building concepts with respect to their building services. The energy consumption thereby is the crucial evaluation factor. According to Kochs paper the PH achieves, according to its excellent insulation standard, lower results in useful and final energy. Speaking of the ecological relevant category, which is represented by PE-NR, the SH has a significant asset. Koch (ibidem) determined, by considering four different PH concepts, that the PE-NR of the SH is at least four times lower than the PH. This result is mainly owed to the application of a solar plant (solar ratio 66.5 %) and a biomass furnace. In her thesis the SH features a specific PE-NR of 8.14 kWh/(m^2.a), whereas the modelled PH ranges between 30.2 kWh/(m^2.a) and 55.7 kWh/(m^2.a). The adherent dissimilarities are mainly caused by different specifications in the matter of building geometry, insulation standards and applied building services. Especially the last aspect plays probably the most important role. Whereas the PH in this research is heated by district heating, the PH in Kochs version is only heated by a heating register in the mechanical ventilation and consequently only provided with electricity. In addition to this, the variation in the primary energy factors between Austria (1.8) and Germany (3.0) is also a factor of distortion. Nevertheless, even the results differ in quantity from this LCA, the basic message remains: In terms of energy and from an ecological point of view, the SH is the better option.

But designating a singular building concept as a better or even the best option in general is not practical. Too many factors such as utilization, climate or surrounding specifications like other buildings or environmental obstacles have a great influence on the most suitable concept. As a result building specifications have to be adapted from case to case (Sölkner et al., 2014). And even by considering only the PH and SH, one of the most sustainable building concepts, none of them has the overall virtue. Moreover it seems, according to the carried out analysis, that a mixture of both concepts, hence minimization of thermal loss plus mechanical ventilation based ventilation (PH) and renewable energy utilization plus floor heating (SH), achieves the best results. In total it comes to a net saving in PE-NR of 13 kWh/(m^2.a) compared to the actual PH which is more than two times higher compared to the effect from scenario SH alone. This conclusion is shared by Koch (2007). She points out, that an aggregation of a high insulation standard and the utility of renewable energies (including biomass) are not mutually exclusive. Especially in terms of increasing energy prices and maybe insecure energy supply, the 'new' concept could score with its benefits. However, during times of decreasing oil prices[26], this concept will not find many advocates. This is mainly owed to the high initial prices. The lower the energy prices the longer the payback period and people respectively investors are not interested anymore. This seems to remain, even in times when government sets legal basis for energy efficiency objectives (Energy Performance of Buildings Directive (2010/31/EU)) and sustainable buildings should get more importance, respectively a higher value. In the best case the legal setting absorbs the decline of energy efficient buildings a bit. Nevertheless, it can be assumed, that in a long run and with respect to a decentralizing energy economy these examined building drafts will become more important.

Still remaining the cost aspect, the concept of functionality opens a supplementary perspective. In the Oxford Dictionary (Stevenson et al., 2010) the term of functionality is defined as 'the quality being suited to serve a purpose well'. Thus, the term does not refer only to technical subjects it is more a general concept of a suitable and well working system. With respect to costs, the term functionality can therefore be used to describe whether the expenses comply with investor's aspirations. In the context of the actual housing complex 'young corner'one of the central aspirations had been 'cost effective housing' (see chapter 5.1.2). This strategic goal was the result from public funds. If the costs had exceeded a certain level, the project would not have been possible to conduct. Thus, the idea came up to maximize floor area by implementing one of the most efficient insulation materials and after its economic benefits, the resol hard foam material was installed in the building's façade. However, the intention of this argument aims to clarify, that the 'young corner' project had a limit of expenses. This means a symbiosis of PH and SH had not been possible because it would have exceeded the cost limit and had therefore no compliance regarding its specific functionality. Beside the non-disputed fact, that a combination of SH and PH would cause additional costs, it is also controversially discussed if the SH is more expensive than the PH. The crucial factor is that the savings from insulation reduction and a lower external energy demand must be higher compared to the expenses from installing a large solar thermal plant. Owed to the circumstance that no consistent and reliable data about the costs of all four adaptions (exterior wall change, ventilation system, floor heating, roof mounted and façade integrated solar thermal facility) were available, it was decided to waive a detailed cost analysis for all concepts.

Nevertheless, as a last aspect of this section and with respect to the concept of functionality, the implementation of a SH based solar system in a multi-storey complex shall be discussed in detail. As evinced in chapter 5.2.3, it was possible to achieve a solar ratio ~51 %. This possibility results from the installation of solar panels on the entire roof and on the entire south/east and south/west façade. Only windows on south-east and initial aperture of the loggias on the south-west façade kept open. This implies an elaborated installation but also a complex procedure for maintenance which entails probably higher cost than a normal solar plant on a detached house which can be seen in Figure 9. Furthermore, a SH in form of a single-family house appears to be especially in terms of a higher proportion of floor-/roof area per dweller more feasible. Another point relates to the room for puffer storages. In the modelled scenario SH it would be nec-

[26] After a continuous increasing oil price after 2008 the price dropped at the second half of 2014 from 100 $ per Barrel to less than 50 $. Even a rise followed, the price kept below 70 $ in the first half of 2015 and decreased after all in July and August even below the level from January 2015 (finanzen.net, 2015).

essary to install 16 tanks with a height of 7.88 meters. The demanded space for this facility was neglected in the LCA, but in reality this room must firstly be established. Nevertheless, this should not mean that any multi-storey buildings in PH standard should be waive a solar plant or should not try to achieve a high solar ratio from the beginning. Because of the unambiguous positive effects of a solar plant, even buildings like 'young corner' with a semi-optimal orientation should consider the installation of a roof mounted system. And as far as a perfect alignment to south is given, loggia and therefore façade integrated solar panels could be considered as well. That this idea is not only a theoretical approach can be seen on the increasing number of PH, which gain hot water as well as room heat from solar radiation. By following this approach, the PH at Mühlweg (Part C) in Vienna is a good representative (see Figure 48). The architects Dietrich and Untertrifaller constructed a building with a heating demand of 14.3 kWh/(m^2.a) and a solar thermal facility which provides about 50 % of hot water supply (Treberspurg et al., 2009). Even, it does not provide a similar contribution of solar energy as the SH, these objects are already following the displayed concept.

Figure 48: Passive House at Mühlweg (Part C) in Vienna
(Source: URL 13; Photographer: Bruno Klomfar)

However, considering the combined approach of a PSH, this would entail a reduction of the total solar collector area from 1268 m² down to 668 m². Moreover, with such a decrease it is almost possible to install the entire solar collectors on the roof. Only about 100 m² had to be installed on the façade, which makes an implementation further feasible.

7.2.2 Sustainability of building concepts

Determining something as sustainable, it presumes that all three dimensions (ecological, economic and social quality) have to be complied (Ritter, 2014). Otherwise, an imbalance and unilateral contemplation would be created. Even though this thesis has its focus on the environmental point of view, by considering the under chapter 2.2 listed principals respectively qualities of sustainable building, the aim of this chapter is to discuss the examined concepts under an integrated point of view.

The concept of low and nearly zero energy buildings is based on the idea of minimizing energy consumption over the utilization phase. Thus, all examined concepts comply with this aspect and firstly fulfill a central and important aspect of sustainability regarding to the ecological quality. However, a low heating or primary energy demand, which is related only to the consumption, is just one aspect which does not necessarily give a significant indication. Depending on the local conjuncture many other factors may play an important role as well. One possible example therefore is the land usage. Especially in cities but also on rural sites or environmental-sensitive locations it is important that sealing is kept on a minimum level. Likewise this aspect is, due to the intelligent initial construction, complied by all three buildings. By taking into consideration, that a person living in a detached house has in average 50 m^2 usable floor area and person who lives in a (rented) apartment has 37 m^2, a relative divergence of 25 % is the result (Statistik Austria, 2014). Hence, in other words could be said, that apartments are in average 25 % more efficient, especially in relation to floor usage. This effect gets further multiplied, as far as the reference value is land usage and the building is constructed as a multi-storey object. As a matter of fact, the sustainable factors, such as land usage and minimal energy consumption, count for all three concepts. It could be criticized that the LTB is in context of energy consumption less sustainable than the PH or SH, but due to the fact of an advancement of at least 25 %, further grading is neglected. Slight differences occur in the aspects of life extension and application of renewable energy sources. The first one is linked to the LTB. With a missing mechanical ventilation and a longer lasting floor heat system, respectively no renewable energy facility, it already provides a benefit in building services. In addition to this, the longer lasting exterior wall construction (insulation layer) also has to be credited for the LTB. Instead of replacing the resin plaster after 40 years in the PH, as well as in the SH, the double brick wall remains (at least) for 50 years. The PH and the SH loose further points with their complex building services and their respective maintenance and replacement efforts. Even though all concepts are built in a way, that passive solar energy can be used, the SH benefits in a special way of applying renewable energy technologies (solar thermal) and reducing its (non-renewable) primary energy demand. Then again, all concepts have in common that they are not especially constructed to reuse implemented building components. Thus they do not differ from a standard house and consequently cannot gain any virtue with respect of sustainability. This also applies on the substance repatriation into the natural substance flow. According to this aspect, it cannot be said, that the concepts performing worth than other buildings, but on the contrary they neither held a special positive position[27].

The economic quality is, with the given data basis, difficult to describe. Nevertheless, by considering that many of the ecological aspects are satisfied, it can be assumed, that in a long run and therefore in life cycle point of view, the costs are optimized in all three buildings. The only constraint comes with the respective strength and weaknesses of each type. The PH for example is built with expensive insulation. Even though it assets in an overall consideration because of its gain of useable area and therefore additional income potential. The SH is built with an expensive and costly in maintenance solar system. On the contrary, expenses for external energy supplies can be saved. And with a payback period of approximately five years, over its life span of 25 years, it achieves a big surplus. The LTB as a third aspect builds on simple and robust technologies. This entails longevity and therefore small expenses with respect to adjustment, maintenance and replacement in the future. On the contrary, it is facing higher utilization costs. How far each specification may assets or outweighs contrary costs (initial vs. running costs), cannot be exactly answered. However, especially with capital- as well as value preservation, an important contribution is achieved by all three concepts. The reason lies primarily in the energy efficient building construction. As far as energy costs further increase in the future, low and nearly zero energy buildings will be confronted by a large demand and therefore long lasting value enhancement.

[27] Neither the aspect of reducing transportation processes nor reducing fresh water consumption are considered in respect to the ecological sustainability.

The third pillar of sustainable development relates to social quality. This aspect is defined by upholding the buildings functionality, (re-) creation security, providing residents safety and user satisfaction. All four aspects are already complied by the initial building construction and are also given in the other two concepts. The main reason lies in the already provided structure of a high living standard inside of the building. This relates especially to the already mentioned aspects from 5.1.1 and 5.1.2 like a good connection to city attractions, flexible and compact apartment design and many more. Hence, no changes were conducted by modelling the alternatives the initial facts are still valid. The only drawback could be determined in the SH respectively PSH. With the installation of solar panels on the roof, the entire community roof top garden gets lost and consequently the ‘community spirit'. Ultimately, the social quality is inevitably set on a very high level, mainly because the building is built in one of the most livable cities in the world.

The horizontal aligned qualities are not further influenced by the modelling process. The technology performance provides aspects like fire, heat and moisture protection without restriction of any kind. This also applies to structural integrity and resistance towards environmental influences, according to the particular concept the capability of dismantling does not change either.

For the reason, that neither the process of planning nor building or operating itself is object of the LCA, it is not reflected in the evaluation and stays, as the technical quality does, on the same level of each building concept. Nevertheless, it is still an interesting aspect for further, and not already mentioned, trains of thought. Examples are influences of early integrated planning approaches and consumer based responsibility during the utilization phase and coherent rebound effects. Taking the aspects of early and integrated planning approaches into consideration, one example needs to be particularly stressed: Many different factors with different interests are involved when it comes to buildings, as well as to other constructions. This is a consequence due to their long lasting lifespan. Bringing all these interests together is a central task for the planning committee. But with old and linear approaches it is getting hard to fulfill this function. Due to circular evolving information progresses during the building (but also life cycle) process, the matter of planning gets diversified. Furthermore, caused by a variety of dimensioning and rating procedures, which are not coordinated in practice, it comes to isolated applications and solutions. The consequence is inconsistency and mutually dependencies like environmental impacts, durability and flexibility cannot be recognized. Hence, important synergy effects get lost. Striking examples are the operation phase restricted verification of energy efficiency as well as capped consideration of construction costs during the planning and erection phase (bmub, 2014). Therefore, König (2009) claims for a multidimensional solution space, which comprises all solutions and achieve the predefined objectives and thresholds over the entire life cycle. Even this represents a complex endeavor, König (ibidem) introduces several methods, which can be applied in this context:

- life cycle orientated building description which relates to a connections between element structure, construction works as well as energy and substance balancing
- scenario technology in regard of life cycle simulation
- value analysis in regard of obsolescence
- option theory in regard of real and virtual options
- risk analyses

The other point relates to the responsibility of consumers: It is not only the task of architects, planers, engineers and finally construction workers to establish an excellent building, which complies with all aspects of sustainability, it is also the residents task to keep it as efficient as it was built for. As long as the residents do not adapt their behavior on new circumstances, caused by the building technology, they will not necessarily save any energy and the performance gets worse than initially calculated. Representative examples for this circumstance are

- window ventillation during the winter in low energy building with mechanical ventilation
- no shading of eastern and western transparent building components during the summer
- no purge ventillation during night in hot weather periods
- and many more…

However, with respect to a life cycle point of view, the caused losses from a ‘wrong’ and not adapted user mentality is not the only problem. The so called ‘Rebound Effect’ and therefore gained energy savings often resolve in new consuming habitats. The most popular example is the ‘VW Beetle’. After 60 years of technological improvements and increasing efficiency the ‘Beetle’ of 2005 still needs as much energy (7.5 liter/100 km) as its predecessor model from 1945. The increasing engine power and weight used up the entire advancement in automotive technology (Santarius, 2012). This applies also within the building industry. Even the energy demand for space heating could be decreased due to more efficient boilers by 9 %, the entire heating demand rose in total by 2.8 % during 1995 to 2005. The reason can be finally found in the increasing living area of 13 % (ibidem). Both effects did not happen on purpose, moreover they result from an evolutionary development, which can be named as technology advancement. Anyway, according to Ritter (2014) also the exact opposite can occur. He considers, that people may afford, because of them saving energy and therefore money, additional holidays or cars. Independently to the particular reasons, it should be tried to impede this effect. Ritter (ibidem) claims that the problem is not owed to an efficient or sustainable technology itself. It is more the lacking transparency between acting and impact. Hence, he proclaims that residents should be confronted with a conscious approach of resources. Specific approaches are various but often go back to an alternative perspective: sufficiency. Sufficiency is a contrary view compared to efficiency. It is not asked, how much can be gained with a minimum input, it is more likely to ask what is redundant or in general not needed. Examples therefore are (ibidem):

- **Amenities** (Is it necessary to implement two bath rooms?):
  With an over equipped building additional constructing but also operational costs can occur.
- **Floor space** (Is it necessary to have a floor area 45 m^2/person?):
  It has to be found an optimal size of a building. Dwellings which are too small are often difficult to sell and may even not reflect the future needs. Buildings, which are too large, may cause too high costs.
- **Resource supply** (Is it necessary that each room gets supplied?):
  Utilization and supply has to be brought together. Thus, if a room (bath, sleeping room, office) is only occupied on certain times during the day, the supply could be adapted according to the usage matter.
- **Quality** (What level of building quality should be applied?):
  A higher quality standard is, in general, related to higher costs. These additional costs can be justified as far as an extended life span occurs. However, this aspect does not only count expenses, it also considers practicability and cost efficiency of each approaches.

Thus, many factors are influencing the process of a building over its life time. Hence it can be summed up, that a multidimensional planning, proper construction but also a consumer adapted application and attitude are key elements in this particular quality to achieve a sustainable building concept.

As a last, but also everything surrounding quality, the location profile has relevance for many different and already above mentioned factors. This means: A building cannot be assessed in a dissociated manner from its environment. However, the term environment is in this case not only related to the nature (e.g. climate or cataclysms), it is also linked to human resources which have a direct influence on the examined building itself. This can be caused by surrounding buildings, air and sound disturbances or other, by human caused factors. Another point of view is related to the location of the respective building and its connection to further infrastructural localities like workplace, shopping facilities and so on. Stephan (2013) pointed out that energy for transportation counts in average for 27 % of a PH. His results are based on the consideration, that buildings with a low energy demand are mainly located in rural or suburban territories. A consequence of this development is that more energy is needed for transportation and should therefore also be considered in a LCA. Therefore, it is not only the building that matters but also external factors, which can have a significant influence on the final outcome. Nevertheless, with respect to the location of the examined building, the fact must be adhered, that the object is, according to the aspect of transportation and consequently infrastructure facilities, in an excellent area.

By summarizing all discussed aspects in relation to sustainable building, it can be claimed that all three concepts comply the aspiration of being representatives of sustainable buildings. Each option has its strengths and weaknesses but overall they perform very well. However, as shown in this chapter, it is unsatisfactory to just look at quantitative materials. There are many more (qualitative) factors, which should also be considered. Finally, the question arises, how far a LCA can be seen as a useful contribution to a sustainable development for buildings. The answer is, as like as the LCA, not unidimensional and therefore cannot simply be answered with a 'Yes' or 'No'. On the one hand, it features a holistic and comprehensible method to describe complex issues and on the other hand, it is afflicted with imprecision. By bringing up a personal perspective to this point, I would say, that the LCA is a great tool for bringing certain aspects into a new perspective. As long as deficiencies are kept in mind, it can help to understand more things which strive for sustainability or in general after an implemented approach. Nevertheless, its execution calls for a great expertise with a deep knowledge in many fields.

8 Summary

Houses are centers of humankind's everyday living. Most of the time, people spend their time in buildings, respectively their homes. In these buildings people earn money to make their living, they spend a great part of their spare time cooking, watching TV or just sleeping and some are also raising their children. Apparently houses represent a parameter of people's fundamental needs. Due to this elementary importance, it becomes reasonable to make the best of it. This means, a building should be built in a way that it epitomizes a high building standard, which stands for longevity, energy and resource efficiency, a minimum of negative externalities and a maximum of comfort for the residents to an affordable extent. As soon as all the factors are brought together within a system, this system can be declared as sustainable. A central goal of sustainability relates to the longevity regarding adapting potential towards changing ecological, economical as well as social circumstances. Thus, it is not only one of these aspects which make a building sustainable; it is the collaboration of all parameters, which are able to meet these fundamental needs. However, to achieve these goals, an integrated planning process from an early stage is indispensable. This means, the concept of stand-alone solutions must be replaced by integrated and iterative planning, as well as operating processes from the beginning of a planning process. To accomplish this task, many instruments are available and the Life Cycle Analysis (LCA) is one of them. It is not a universal tool solving all central problems; it is more a structured, comprehensive and international standardized method, which quantifies all relevant emissions, resources and health related issues to serve an environmental overview of a certain object. The LCA has its importance in the aspect of evaluating the whole life cycle of a product, which includes the production, replacement, operation and dismantling process of a good or service. This results in a general advantage, regarding the discussion of sustainability insofar, that not only one aspect (e.g. operation) is considered, which could cause a bias because of a disproportionate energy input or an excessive replacement. Within this study the LCA is used to compare three different sustainable building concepts. These include the concept of a Passive House (PH), a Sun House (SH) and a Low-tech Building (LTB). To obtain a uniform evaluation basis, the PH was taken as the initial building according to the actual housing complex 'young corner' in Vienna. Scenarios were modelled for SH and LTB with their particular characteristics according to the basic construction of the initial building 'young corner' (see Table 8). The purpose of the evaluation had been to find answers to the questions which of these building concepts have the lowest environmental impact, as well as to clarify, what are the most relevant components according to the overall result. The functional unit and hence the central result basis is m² (based on the gross floor area).

Table 8: Analyzed building concepts and their particular features

	Passive House (actual building)	Sun House (scenario building)	Low-tech Building (scenario building)
Building envelope	Passive House standard (Insulation material: Resol)	OIB 6 (Insulation material: Resol)	Passive House standard * (Insulation material: Bricks)
Ventilation	Mechanical ventilation	Window ventilation (mech. Ventilation in wet rooms)	Window ventilation (mech. Ventilation in wet rooms)
Heating system	Radiator heating	Floor heating	Floor heating
Renewable Energy	Not existing	Solar thermal	Not existing
Central characteristics			
Heating demand	6,36 kWh/(m².a)	30,15 kWh/(m².a)	20,57 kWh/(m².a)
Primary Energy (non-renewable)	28,60 kWh/(m².a)	19,84 kWh/(m².a)	31,93 kWh/(m².a)
Primary Energy (total)	32,39 kWh/(m².a)	40,75 kWh/(m².a)	32,98 kWh/(m².a)

The conducted LCA is evaluated by seven environmental impact factors. These include the Global Warming Potential (GWP), the Ozone Depletion Potential (ODP), the Photochemical Ozone Creation Potential (POCP), the Acidification Potential (AD), the Eutrophication Potential (EP), the non-renewable Primary Energy (PE-NR) and the total Primary Energy (PE). According to the most important parameters (GWP and PE-NR) of this thesis, the three concepts perform very similarly (especially in absolute figures) in the phases of production, replacement and End of Life. By taking the PE-NR as a representative example (GWP is directly connected to PE-NR), the actual PH comes in the phase of production to 17.5 kWh/(m².a). Scenario SH comes in slightly worse by having a plus of 0.7 %. Scenario LTB in contrast performs best in this phase and is with 17.2 kWh/(m².a) by 2 % lower compared to the actual PH. The same picture occurs in the phase of replacements. Even the absolute differences are not very high, but by considering the relative figures scenario LTB undercuts the actual PH (4.0 kWh/(m².a)) by 35 %. Scenario SH can be found in the last position due to a plus of 35%. The reasons for the differences are manifold and can be assigned to different building materials, but also to different life expectancies of the varied components. However, one elementary aspect for the lower performance of scenario SH within these phases is the installed solar plant. Even though the energetic payback period is just four years, its energetic expenditures exceed all the retrenchments, which result from the insulation reduction of exterior walls. The major advantage of scenario LTB in this case can actually be found in the reduction of building services. This does not only downsize the production expenses, it mainly reduces the complex replacements of the low lifetime affected high-tech components. Although, by installing fewer components, which can be utilized in a caloric process, the contribution to the End of Life phase decreases. Therefore, scenario LTB (+ 12 %) has the lowest contribution within this field. It is directly followed by scenario SH (+ 6 %), whilst the actual PH (- 3.4 kWh/(m².a)) has the highest rate of usable components within this sector. In the opposite of the above depicted figures, the situation changes in the phase of operation. Even though scenario SH has the poorest energy standard of all evaluated building concepts, it provides the best performance of operational energy. Accordingly, it has the lowest non-renewable Primary Energy demand. With an undercut of 31 % it has, compared to the actual PH (28.6 kWh/(m².a)), not only a large relative, but also a great absolute advantage. This impressive performance is highly linked to the solar plant, which provides a cover ratio for space heating and hot water of 50 %. It needs to be stressed, that scenario LTB shows the lowest performance of all concepts. Its lack of building services causes an energetic disadvantage of 12 % compared to the PH. Especially the mechanical ventilation system enables, despite its higher production effort, significant savings, which are otherwise lost by manual window ventilation. Summing these different results up the actual PH comes to a PE-NR of 46.8 kWh/(m².a). This is undercut by scenario SH (- 14 %) and exceeded by scenario LTB 4 %.

Besides the particular concept performance according to a certain phase, the ratio between energy (PE-NR) of construction (including the phases of production, replacement and end of life) and energy of operation indicates respective characteristics. Thus, for the actual PH the ratio comes to 39:61, which means 39 % is used for the construction and 61 % for the operation. The other two concepts have more or less a similar proportion: Scenario SH has 59:41 and scenario LTB 66:34.

So far only one, out of seven impact factors, is described in the previous paragraph. But for an easier understanding, the other six parameters can be summarized in an aggregated value. This category comprises the seven others under the consideration of a selective weighting. Therefore, all parameters are particularly weighted with a factor according to their particular importance. As a common standard, according to the DGNB/ÖGNI, GWP and PE-NR are weighted with the three whereas the other five are multiplied by factor one. In compliance with this approach, scenario SH comes out with the best result. It provides an advantage of 2.2 % compared to the actual PH, which is the basis with 100 %. Scenario LTB ranges with 100.1 % on the same level as the actual PH. As these results demonstrate, the building concepts perform, despite their partly very significant characteristics, very similar in total. Nevertheless, it shall be stressed, that a slight change in the weighting leads to a different result. As an alternative scenario, with a uniform weighting, in which all factors are set on the same level (e.g. 1), can be taken as a representative example how results can change quickly. According to this approach, two major changes can be determined. First of all, the differences between the best to the lowest performance increase from 2.3 % to 6.0 %. But the most significant fact is, that scenario SH (103.9 %) turns out to be the poorest and scenario LTB (97.9 %) to be the best option. This change makes it obvious, how small but also fragile the differences between these sustainable concepts really are. Moreover, besides these environmental impact factors related results, an interesting methodical outcome of this thesis is that the final result can be easily adapted in a positive as well as a negative manner. As a consequence the overall outcome of a life cycle evaluation cannot be brought to a single result. It is much more important to consider the evaluated data carefully and as far as possible in detail.

In an additional step two further scenarios were evaluated within this thesis. The first is scenario 'OIB house' (OIBH) representing the minimal requirements of the building code OIB directive 6:2011 and the second is scenario 'Passive Sun House' (PSH) representing the combination of Passive House Standard and Sun House concept. The intention was to set the major concepts in relation to a standard building and a building, which is implemented with the best characteristics of the two rivalling concepts. Whilst the three chosen sustainable concepts are almost showing no differences over all impact factors within the aggregated result, the two additional concepts vary greatly. Scenario OIB house features the poorest performance of all evaluated concepts. In respect to all impact factors, it performs with 18 % worse compared to the actual building (PH). Even it has some categories (e.g. ODP and PE) with a better performance of at least one of the major concepts, it performs in each category worse than the actual PH. This affects especially the categories of the GWP (122 %) and the PE-NR (128 %). In both aspects scenario OIBH has by far the poorest performance compared to the other building concepts. Scenario Passive Sun House (PSH), is just the opposite of scenario OIBH. Whilst scenario OIBH has its poorest results, scenario PSH strikes at most within this request. The remarkable feature of this concept is, as already mentioned above, the idea of combining the best components with each other. This means scenario PSH is characterized by an ideal building envelope and supplied by a solar thermal plant, which provides 50 % of the demanded energy for room and water heating. Additionally, it is equipped with a floor heating system and a mechanical ventilation facility. This combination leads to an overall result of 86 % compared to the actual building. Thus, whereas scenario OIBH has a minus of 18 %, scenario PSH can gain further 14 % compared to the already as sustainable classified concepts. In four out of seven categories, scenario PSH provides the overall virtue. The best results can be gained in the categories of the GWP (78 %) and the PE-NR (72 %) but also in aspects like the POCP (96 %) and the ODP (114 %) it gains, especially in comparison to the linked building concept, great improvements. However, these remarkable results are not only owed to the application of the particular components. It is more the combination and as a consequence the occurring synergy effects. For example, with the improved building envelope according to the actual PH, the solar collector area could be downsized to approximately 50 % of the initial area. This does not only reduce environmental impact factors (e.g. ODP), it also makes an installation, with respect to the decreasing demand of difficult facade integrated panels, more feasible. Another favorable aspect for the wall construction of the actual PH is the remaining effect of floor maximizing, which was already a central aim in the planning process of the initial building concept. A further aspect derived from the SH concept goes back to the idea of reducing the non-renewable Primary Energy demand. The low energy demand in heating and the large amount of solar energy brings these aspects perfectly together. And as a last point, the aspect of independency shall be mentioned. Both concepts, PH and SH, strive for this aim, but in two different ways. By bringing these fundamental ideas together, they complement each other and reach a very high standard. The only lagging factor, which is not considered in detail in this thesis, relates to the costs. This is due to the fact of the PH and the SH facing higher initial expenses, also the PSH is more likely to be affected by this point. This applies especially in times with low energy prices (e.g. 2015). During such periods, the payback period of additional expenditures prolongs to an extent, which has proven the tendency to be not profitable enough anymore. Nevertheless, due to the fact, that both concepts combine their technical advantages it can be assumed, that also the economic point of view is positively affected.

The idea of combining two different concepts in accordance to their particular strength is one approach of finding new and more sustainable options to cope with the imminent obstacles of the future. However, from a more general point of view it also can be said, that thinking in certain schemes does not support the progress in any subject and consequently neither in building affairs. The conventional planning of buildings was so far always limited to a certain number of individual aspects within singular life cycle phases and no interrelation or dependencies were further considered. A convincing example for this is the focus on the approach of capped initial costs of the construction phase or the operation related energy consumption. This restricted view leads to biases and as a consequence to misleading decisions. Therefore, future building projects have to be set with a holistic and integral planning approach. This means, that life cycle related solutions, in which interrelations are connected and reasonably complemented, should be further strived for and implemented. The main objective should be to achieve a reasonable and comprehensive solution. But this does not only apply to the involvement of architects, planers, engineers and finally construction workers. It is also necessary, that especially the consumers play an active role in the entire consideration. On the one hand this implies that the consumer's behavior towards ventilation or shading must be influenced in a way that the theoretical potential of sustainable buildings can be practically implemented. On the other hand this aspiration is highly connected to a higher awareness with respect to this particular potential but also to the consumption of resources and its consequences. A helpful start would also be to firstly take sufficiency and secondly the efficiency into consideration. This means the consumer should start to ask him/herself if certain amenities are necessary. It should be asked, to what extend a floor space is appropriate and reasonable, which could be directly followed by the question what supplying standard seems appropriate. This and many more questions could be asked before efficiency measures are chosen. Hence, the reason for this approach lies not only in further and often so far not considered improving potentials, it also lies in their effectiveness. Otherwise, rejecting the growing awareness about certain processes, the so called rebound effect strikes back and resolves, as often observed, the gained progress. A LCA respectively its results can also serve as a helpful tool. It does not only summarize results over all life cycle phases of a building, it also increases the awareness in response to certain implementations and constructions.

List of abbreviations

AD	Außendecke
AP	Acidification Potential
A/V	Surface-Volume ratio
AW	Außenwand
bpb	Bundeszentrale für politische Bildung
bmub	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
BREEAM	Building Research Establishment Environmental Assessment Method
CEN/TC	Comité Européen de Normalisation – Technical Committee
°C	Degree Celsius
CH	Switzerland
CO_2	Carbon Dioxide
DGNB	Deutschen Gesellschaft für Nachhaltiges Bauen
EN	Europäische Norm
EoL	End of Life
EP	Eutrophication Potential
EPD	Environmental Product Declaration
EPS	Expanded polystyrene
EU	European Union
GWP	Global Warming Potential
HVAC	Heating Ventilation and Air Conditioning
IBO	Österreichisches Institut für Bauen und Ökologie
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
LTB	Low-tech Building
ODP	Ozone Depletion Potential
ÖGNI	Österreichischen Gesellschaft für Nachhaltige Immobilienwirtschaft
OIB	Österreichisches Institut für Bautechnik
OIBH	OIB House
PE	Primary energy (total)
PE-NR	Primary energy (non-renewable)
PH	Passive House

PHI	Passive House Institute
PHPP	Passivhaus-Projektierungspaket
POCP	Photochemical Ozone Creation Potential
PSH	Passive Sun House
s.a.	sine anno
SH	Sun House
U-Value	Thermal transmittance
URL	Uniform Resource Locator
Vers.	Version

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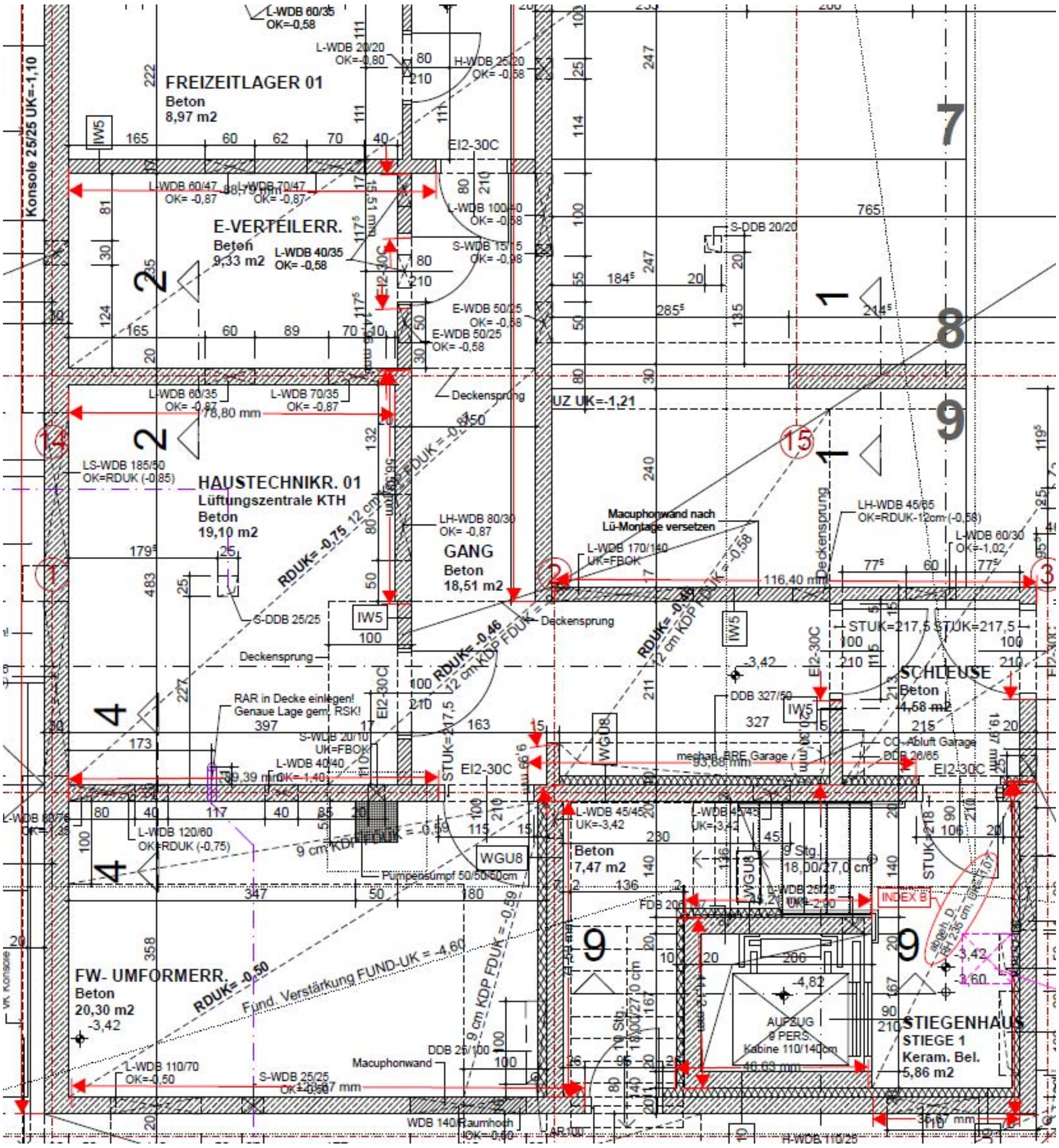
Appendix

Appendix 1: Plan Measuring



Appendix 2: Measuring Results

Vertical Building Elements				
AW	1		1805.41	m^2
AW	5		84.15	m^2
AW	6		19.00	m^2
AW	7		17.98	m^2
AW	2		2928.76	m^2
AW	3		15.37	m^2
AW	4		8.41	m^2
EWu	1		21.64	m^2
EWu	2		912.45	m^2
EWu	3		89.96	m^2
IW	1		666.62	m^2
IW	5		22.77	m^2
IW	6		139.64	m^2
IW	7		76.42	m^2
IW	10		769.59	m^2
IW	11		138.62	m^2
IW	2		475.60	m^2
IW	3		3479.86	m^2
IW	4		524.47	m^2
IW	7		38.57	m^2
IW	8		45.82	m^2
IW	9		98.46	m^2
W	1		278.40	m^2
WGs	1		16.385	m^2
WGs	2		28.12	m^2
WGs	3		23.36	m^2
WGs	4		57.855	m^2
WGs	5		21.87	m^2
WGs	10		6.45	m^2
WGs	6		1020.08	m^2
WGs	7		221.85	m^2
WGs	8		14.07	m^2
WGs	9		103.83	m^2
WGu	1		20.16	m^2
WGu	2		28.53	m^2
WGu	3		38.43	m^2
WGu	4		26.15	m^2
WGu	5		37.56	m^2
WGu	6		21.46	m^2
WGu	7		19.14	m^2
WGu	8		85.94	m^2
WGu	9		32.43	m^2
WGu	10		14.07	m^2
WGu	11		15.97	m^2
WW	1		1571.08	m^2
WW	2		142.10	m^2

Horizontal Building Elements				
Bruttogrundfläche				
EB	1		14.69	m^2
EB	2		2141.35	m^2
EB	3		243.52	m^2
Stiegenlaufplatte			17.15	m^2
DGU	1		207.39	m^2
DGU	2		171.99	m^2
DGU	3		598.63	m^2
DGU	4		20.30	m^2
DGU	5		80.04	m^2
DGU	6		133.38	m^2
DGU	7		0.00	m^2
DGU	8		0.00	m^2
WD	1		6204.93	m^2
DGU	9		675.26	m^2
DGU	10		40.99	m^2
DGU	11		74.01	m^2
DGU	12		464.46	m^2
WBD	1		0.00	m^2
DD	1		28.75	m^2
DU	1		94.48	m^2
DU	2		6.74	m^2
DU	3		185.09	m^2
DU	4		900.78	m^2
DU	5		757.46	m^2
DU	6		58.22	m^2
DU	7		39.68	m^2
AD	1		380.27	m^2
AD	2		210.07	m^2
AD	3		507.83	m^2
AD	5		49.45	m^2

Appendix 3: Building service equipment

Oberkategorie	Unterkategorie	Objekt	Anzahl	Länge (m)	Fläche (m^2)	Gewicht (kg)	spezifisches Gewicht	Hinweis
Heizungstechnik (94)	Heizkörper, Deckenstrahlplatten und Zubehör (94.07)	Plattenheizkörper (94.07.01.05M)	223	228.7	0.063	37.5	580.40	Fläche (lxb) = 228,7*,6 = 137,22
		Deckenstrahlplatten (94.07.09.01)	5	3.75	0.215	47.1	292.09	Fläche (lxb) = 3,75*4,3 = 137,23
		Heizkörperlack (94.07.10.950)		80	50.24		1210 kg/m3	Annahme: DN 20
	Sole-Erdwärmetauschersysteme (94.09)	Stahlr.nahtl. 76,1*2,9 (94.09.01.21H)		214			6,78 kg/m	
		Kunstoff Erdkollektorrohr PE-HD 32x2-PN 6 (94.09.15.25E)		3900			0,269 kg/m	
		Hocheff. Pumpe Wilo-Stratos 40/1-8 (94.09.75.40A)	2				5 kg/stk	0,18 - 0,31 kW
		Dämmschlauch Kautschuk-Schlauch 19mm DN65 (94.09.82.12G)		242	0.196656051	1427.7	30 kg/m3	47.59
		Armaturen-WD Kautschuk , ohne Mantel, DN32-DN (94.09.84.01B)	104	1.56	0.096815287	4.5	30 kg/m3	0.15
	Metallrohre und Zubehöhr (94.70)	ms GR nahtl.schw.DN15 (1/2") (94.70.01.01B)		5952			0,88 kg/m	
	Dämmung (94.82)	WW/Heizung-WD Mineralwolle (94.82.02.01C)			309		2,76 kg/m2	Dicke = 60mm; DN35
		Dämmschlauch PE-Schlauch 4mm mit Folienmantel (94.82.10.00A)		3460			30 kg/m3	Dicke = 4mm; DN20
		Dämmschlauch PE-Schlauch 4mm mit Folienmantel (94.82.10.00A)		1640			30 kg/m3	Dicke = 9mm; DN15
		Armat.WD MinWo, Alu-Pak-Mantel, DN15-DN25 (94.82.16.04A)	414	124.2			2,76 kg/m2	Dämmungsstärke 40mm bis DN25
Raumlufttechnik (95)	RLT-Zentralgeräte (95.44)	RLT-ZG, Innen, ZUL/ABL max. 4500m3/h (95.44.05.02A)	2	4.9	2.45	100.0	1200	4715 VA
		Solewärmetauscher SWT-CA 4000 (95.44.05.02C)	2				600 kg/Stück	20,5 kW
	RLT-EINZELGERÄTE (95.45)	Rohr-/Kanal-Einbauventilatoren (95.45.20.01A)	1					1,5 kW
		Rohr-/Kanal-Einbauventilatoren (95.45.20.02B)	6					100 W
		Rohr-/Kanal-Einbauventilatoren (95.45.25.01H)	1					18 kW

Raumlufttechnik (95)	LUFTKANALNETZEINBAUTEN (95.47)	Kulissen Schalldämpfer (95.47.05.01A)	10	8.8	1.332		37,4 kg/lfm	4300 m^3/h
		Rohrschalldämpfer (95.47.05.06B)	432	259.2	81.388		7850 kg/m3	
		Brandschutzklappen (95.47.10.10B)	162	8.1	20.25		7850 kg/m3	
		Volumenstrom-Regeleinrichtungen für KVS-/VVS (95.47.25.09A)	279	83.7	26.28		7850 kg/m3	
	Luftleitungen (95.54)	Wickelfalzrohre aus verz.Stahlblech (95.54.04.01C)		2038	639.932		7850 kg/m3	
		Bogen WFR (95.54.04.02C)	748	374	117.436		7850 kg/m3	
	Luftleitungen (95.54)	Luftleitungen, Stahlblech verzinkt (95.54.50.01A)			952		7850 kg/m3	
		Luftleitungen, Aluminium (95.54.55.05C)		253	317.768		2700 kg/m3	
	Dämmung (95.82)	Lüftung-Wärmedämmung (95.82.20.01C)			118		46 kg/m3	
		Brandschutz für Luftleitungen (95.83.10.01L)			183		11,25 kg/m2	
		Brandabschottungen (95.83.12.01B)	149		37.25		150 kg/m3	
Sanitärtechnik (96)	ABWASSERPUMPEN (96.33)	AW-Pumpe WILO-Drain (96.33.01.10A)	1				24,7 kg/Stück	0,37 kW
	Abwasserleitungen und Zubehör (96.37)	Abwasserrohr - Kunststoff (96.37.03.03C)		1948			0,926 kg/lfm	
	Metallrohre und Zubehöhr (96.70)	Gewinderohre - verzinkt (96.70.03.02E)		965			2,52 kg/lfm	
		Gewinderohre - verzinkt (96.70.03.02B)		575			0,88 kg/lfm	
		Kupferrohre (96.70.05.01E)		546			0,42 kg/lfm	
		Kupferrohre (96.70.05.01F)		745			0,48 kg/lfm	
	Rohre aus Verbundwerkstoff	VPE-Al-PE VerbundR (96.72.01.05E)		562			0,16 kg/lfm	
	Wärme-, Kälte-, Brandschutz-, Schalldämmung (96.82)	Dämmung Mineralwolle (96.82.04.01A)			641		46 kg/m3	
		Dämmschläuche (96.82.10.00A)		1291	80		30 kg/m3	
		Armaturen-WD Kautschuk 9mm DN 25 (96.82.16.01A)	212	31.8	0.035828025			1.13933121
		Armaturen-Mineralwolle (96.82.16.04A)	32		3.2		150 kg/m3	
	Brandschutz- Schalldämmung (96.83)	Mineralwollplatten (96.83.12.02A)	26					

Oberkategorie	Unterkategorie	Objekt	Anzahl	Länge (m)	spezifisches Gewicht
Elektrotechnik (98)	Niederspannung (06)	Schutzschalter (1312L Z)	884		0,079 kg/Stück
		Schukosteckdose (14150 Z)	3		0,077 kg/Stück
		Schalter (1422C Z)	68		0,079 kg/Stück
	KABEL F. ENERGIE- U. NACHRICHTENÜBERTR. (07)	Einleiterkabel (1201C Z)		730	0,02 kg/lfm
		Dreileiterkabel (1203B)		100	0,121 kg/fm
		Vierleiterkabel (1204I)		1140	0,145 kg/fm
		Fünfleiterkabel (1205F Z)		5275	0,168 kg/fm
		Fernmeldekabel (2252A)		1600	0,0589 kg/fm
	Isolierte Leitungen	Aderleitung Eindrähtig (0101B Z)		46690	0,02 kg/lfm
		Manteilleitung Eindrähtig - Dreiadrig (0203A Z)		8520	0,1 kg/lfm
		Manteilleitung Eindrähtig -vieradrig (0204A Z)		3550	0,1 kg/lfm
		Manteilleitung Eindrähtig - Fünfadrig (0205A)		2710	0,1 kg/lfm
		Vorspanndraht (4002B Z)		5715	
		CAT.5 (40030 Z)		3990	0,1 kg/lfm
	ROHR-, KANAL- UND TRAGESYSTEME (09)	Panzerrohr (kunststoff) biegsam (0213C Z)		34370	0,1 kg/lfm
		Installationsrohr (0301C)		5850	0,1 kg/lfm
		UP-Schalterdose/Kasten (1001A Z)	5658		
		Kabelrinne (Stahl) (17040 Z)		440	5,29 kg/lfm
		Ankerschiene (1906C)	120		2,52 kg/lfm
	SCHALT-, STEUER- UND STECKGERÄTE (10)	UP-Schalter (divers) (0101A Z)	1254		0,079 kg/Stück
		UP-Schukosteckdose	2096		0,077 kg/Stück
		Bewegungsmelder (18010 Z)	34		0,079 kg/Stück
	Erdungs- und Blitzschutzanlagen (14)	Erdleiter (0102A)		1470	0,14 kg/lfm
	ANTENNENANLAGEN (30)	Schalter (9803A Z)	27		0,079 kg/Stück
		Steckdose (98040 Z)	91		0,077 kg/Stück
	M-BUS Verkabelung	Fernmeldekabel (0201A Z)		1000	0,0589 kg/fm

Appendix 4: Energy data for ÖGNI auditors

ÖKOBAU.DAT DATENSÄTZE ENERGIE		SB01	SB02	SB03	SB04	SB05	SB10		SB11
Daten pro kWh Lieferenergie	Quelle	**GWP**	**ODP**	**POCP**	**AP**	**EP**	**PEne**	**PEe**	**PE ges**
		kg	kg	kg	kg	kg	kWh	kWh	kWh
Gas/Öl 50%/50%	PE International, Austria: Benchmarkfindung NBV	0.266	4.23E-10	3.32E-05	2.89E-04	3.35E-05	1.115	0.0009	1.116
9.2.6_Fernwaerme_Mix.xml	Ökobau.dat 2009	0.256	4.96E-10	2.46E-05	3.15E-04	3.06E-05	0.953	0.0007	0.953
9.2.1_Thermische_Energie_Erdgas.xml	Ökobau.dat 2009	0.249	3.59E-10	2.57E-05	2.12E-04	2.88E-05	1.162	0.0006	1.162
9.2.3 Thermische Energie aus Heizöl el	Ökobau.dat 2009	0.336	5.71E-10	4.73E-05	4.24E-04	4.48E-05	1.292	0.0014	1.293
9.2.5_Strom_Mix	Ökobau.dat 2009	0.655	1.03E-07	6.96E-05	9.74E-04	8.82E-05	3.070	0.3928	3.463
Strom AT	PE International, Austria: Benchmarkfindung NBV	0.308	1.45E-09	4.21E-05	4.94E-04	4.21E-05	0.890	0.9720	1.862
Fernkälte Wien*	FW-Wien	0.220	5.27E-10	2.26E-05	2.84E-04	2.69E-05	0.787	0.117	0.903

Appendix 5: Ökobau.dat Dataset

Datensatz: 1.4.01 Transportbeton C30/37; 2365 kg/m3 (de)	
Inhalt: Datensatzinformation - Modellierung und Validierung - Umweltindikatoren	
Datensatzinformation	
Kerninformation des Datensatzes	
Geographische Repräsentativität	DE
Referenzjahr	2006
Name	Basisname; Technische Kennwerte/ Eigenschaften 1.4.01 Transportbeton C30/37; 2365 kg/m3
Technisches Anwendungsgebiet	Einsatz im Straßenbau und bei der Gebäudeerrichtung sowie im Erd- und Grundbau. Genaue Anwendungsbereiche, die für Beton der Druckfestigkeitsklasse C30/37 möglich sind, werden durch die Norm DIN 1045-2 vorgegeben.
Fluss	Transportbeton (2365 kg/m3)
Kerninformation des Datensatzes	1 m3 (Volumen)
Anwendungshinweis für Datensatz	Das vorliegende Umweltprofil beinhaltet die Aufwendungen für die Lebenszyklus-Stadien "Cradle to Gate". Es basiert hauptsächlich auf Literaturrecherchen und direkten Datenerhebungen der Industrie.
Gliederung Produktgruppe ()	Klassifizierung / Ebene / Ebene / Ebene Prozesse / 1 Mineralische Baustoffe / 1.4 Mörtel und Beton / 1.4.1 Transportbeton
	Urheberrecht? Ja Eigner des Datensatzes (contact data set) BTB
Quantitative Referenz	
Referenzfluss (Name und Einheit)	Transportbeton (2365 kg/m3) - m3 (Volumen)
Zeitliche Repräsentativität	
Zeitliche Gültigkeit des Datensatzes	2011
Erläuterungen zur zeitlichen Repräsentativität	Jährlicher Durchschnitt
Technische Repräsentativität	
Technische Beschreibung inklusive der Hintergrundsysteme	Die Lebenszyklusanalyse des betrachteten Betons umfasst die Lebenswegabschnitte "Cradle to gate", d. h. die Herstellung von Roh- und Hilfsstoffen sind ebenso berücksichtigt, wie die Transportbetonherstellung. Die Systemgrenze bildet also das versandfertige Produkt am Werkstor. Transporte zur Baustelle, die typischerweise 20 km betragen, sind nicht berücksichtigt und müssen bei den Systembetrachtungen eingerechnet werden.
Modellierung und Validierung	
Angewandte Methode und Allokation	
Art des Datensatzes	EPD
Datenquellen und Repräsentativität	
Datenquellen (source data set)	GaBi4 Software und Datenbank 2006
Validierung	
Review	*Independent external review*
Reviewer (Name und Institution) (contact data set)	PE INTERNATIONAL
Administrative Information	
Dateneingabe	
Zeitpunkt der Dateneingabe	2009-08-06 09:32:36 +01:00
Datensatzeingabe durch (contact data set)	VDZ
Kennung	
UUID des Datensatzes	04d522ef-b210-4c34-8a42-0a3ac1351cb8
Letzte ÄnderungLetzte Änderung	2009-08-06T09:32:36+01:00
Eigner des Datensatzes (contact data set)	BTB

Umweltindikatoren

Indikatoren der Sachbilanz

Indikator	Richtung	Wert	Einheit	Anteile
Inputs				
Primärenergie nicht regenerierbar	Input	1200	MJ	
- Braunkohle				34 %
- Steinkohle				18 %
- Erdgas				6 %
- Erdöl				26 %
- Uran				16 %
Primärenergie regenerierbar	Input	21,8	MJ	
- Wasserkraft				50 %
- Windkraft				47 %
- Sonnennutzung (Solarenergie)				3 %
- Sonnennutzung (Biomasse)				0 %
Sekundärbrennstoffe	Input	432	MJ	
Wassernutzung	Input	1170	kg	
Outputs				
Abraum und Erzaufbereitungsrückstände	Output	742	kg	
Hausmüll und Gewerbeabfälle	Output	0,00313	kg	
Sonderabfälle	Output	0,113	kg	

Indikatoren der Wirkbilanz

Indikator		Wert	Einheit
Abiotischer Ressourcenverbrauch (ADP)	Input	0,485	kg Sb-Äqv.
Treibhauspotential (GWP 100)	Output	237	kg CO2-Äqv.
Versauerungspotential (AP)	Output	0,416	kg SO2-Äqv.
Photochem. Oxidantienbildungspot. (POCP)	Output	0,0427	kg Ethen-Äqv.
Eutrophierungspotential (EP)	Output	0,0587	kg Phosphat-Äqv.
Ozonabbaupotential (ODP)	Output	6,3E-6	kg R11-Äqv.

Appendix 6: Life span catalogue (short excerpt)

Code Nr.	KG - 2. Ebene	KG - 3. Ebene	Bauteil / Material	a	Ersatz in 50a
	320 Gründung				
	320 Gründung	**322 Flachgründungen**			
322 111			Einzel- / Streifenfundamente	≥ 50	0
322 112			Fundamentplatten	≥ 50	0
	320 Gründung	**323 Tiefgründungen**			
323 111			Bohrpfähle, Presspfähle, Rammpfähle, Pfahlwände, Schlitzwände, Spundwände, Trägerbohlwände	≥ 50	0
	320 Gründung	**324 Unterböden und Bodenplatten**			
324 111			Bodenplatte	≥ 50	0
	320 Gründung	**326 Bauwerksabdichtung**			
326 111			Abdichtung gegen nichtdrückendes Wasser	35	1
	330 Außenwände				
	330 Außenwände	**331 Tragende Außenwände**			
331 111			Mauerwerkswand	≥ 50	0
331 211			Betonwand	≥ 50	0
331 311			Holzwand	≥ 50	0
331 411			Stahlbauwand	≥ 50	0
331 511			Lehmbauwand	≥ 50	0
331 611			Formsteine mit Betonfüllung	≥ 50	0
	330 Außenwände	**333 Außenstützen**			
333 111			Mauerwerksstütze	≥ 50	0
333 211			Betonstütze	≥ 50	0
333 311			Holzstütze	≥ 50	0
333 411			Stahlstütze	≥ 50	0
	330 Außenwände	**334 Außentüren und -fenster**			
	330 Außenwände	**334 Außentüren und -fenster**	**Außentüren**		
334 111			Standardtüren: Laubholz	≥ 50	0
334 112			Standardtüren: Metall	≥ 50	0
334 113			Standardtüren: Holzwerkstoff	40	1
334 114			Standardtüren: Kunststoff	40	1
334 115			Standardtüren: Nadelholz	35	1
334 121			Brandschutztüren	≥ 50	0
334 131			Sondertüren: Schallschutztüren, Glastüren	≥ 50	0
334 132			Sondertüren: Automatiktüren	20	2
334 133			Sondertüren: Schiebetüren, Rotationstüren	30	1
	330 Außenwände	**334 Außentüren und -fenster**	**Außenfenster**		
334 211			Fenster (Rahmen und Flügel): Aluminium, Aluminium-Holz-Komposit, Aluminium-Kunststoff-Komposit, Laubholz behandelt, Stahl	≥ 50	0
334 212			Fenster (Rahmen und Flügel): Kunststoff, Nadelholz behandelt	40	1
	330 Außenwände	**334 Außentüren und -fenster**	**sonstiges**		
334 311			Beschläge: einfache Beschläge, Schiebebeschläge	30	1
334 312			Beschläge: Drehkippbeschläge, Schwingflügelbeschläge, Hebedrehkippbeschläge	25	1
334 313			Türschlösser, Türanschlagdämpfer, Panikverschlüsse	25	1
334 314			Türschließer	20	2
334 315			Türantriebe	15	3
334 316			Verglasung: Sicherheits-Isolierglas, 3-Scheiben-Wärmeschutz-Isolierglas, 2-Scheiben-Wärmeschutz-Isolierglas, Brandschutz-Isolierglas, Schallschutz-Isolierglas, Angriffhemmendes Isolierglas, Sonnenschutz-Isolierglas	30	1
334 317			Dichtungsprofile	20	2

Appendix 7: EPD Kingspan – LCA Results

5. LCA: Results

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)																
PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARYS
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement[1)]	Refurbishment[1)]	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 m2, 100mm thickness

Parameter	Unit	A1	A2	A3
Global warming potential	[kg CO_2-Eq.]	8.32	0.15	1.39
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	7.22E-10	8.85E-12	5.19E-11
Acidification potential of land and water	[kg SO_2-Eq.]	0.02	0.00	0.00
Eutrophication potential	[kg $(PO_4)^{3-}$- Eq.]	2.25E-3	2.53E-4	1.89E-4
Formation potential of tropospheric ozone photochemical oxidants	[kg Ethen Eq.]	3.31E-3	2.75E-5	6.56E-3
Abiotic depletion potential for non fossil resources	[kg Sb Eq.]	1.84E-5	5.41E-9	5.01E-8
Abiotic depletion potential for fossil resources	[MJ]	283.00	1.96	7.44

RESULTS OF THE LCA - RESOURCE USE: 1 m2, 100mm thickness

Parameter	Unit	A1	A2	A3
Renewable primary energy as energy carrier	[MJ]	3.90	0.08	0.26
Renewable primary energy resources as material utilization	[MJ]	0.00	0.00	0.00
Total use of renewable primary energy resources	[MJ]	3.90	0.08	0.26
Non renewable primary energy as energy carrier	[MJ]	160.00	1.96	7.44
Non renewable primary energy as material utilization	[MJ]	123.00	0.00	0.00
Total use of non renewable primary energy resources	[MJ]	283.00	1.96	7.44
Use of secondary material	[kg]	0.00	0.00	0.00
Use of renewable secondary fuels	[MJ]	2.89E-3	2.17E-5	3.10E-4
Use of non renewable secondary fuels	[MJ]	3.00E-2	2.28E-4	3.11E-3
Use of net fresh water	[m^3]	2.79	0.02	0.12

RESULTS OF THE LCA – OUTPUT FLOWS AND WASTE CATEGORIES: 1 m2, 100mm thickness

Parameter	Unit	A1	A2	A3
Hazardous waste disposed	[kg]	0.00	0.00	0.00
Non hazardous waste disposed	[kg]	4.86	0.04	0.24
Radioactive waste disposed	[kg]	1.61E-3	1.62E-5	8.53E-5
Components for re-use	[kg]	-	-	-
Materials for recycling	[kg]	-	-	-
Materials for energy recovery	[kg]	-	-	-
Exported electrical energy	[MJ]	-	-	-
Exported thermal energy	[MJ]	-	-	-

Appendix 8: Specimen Component Catalogue for reinforced concrete

	Bewehrungsanteil		Volums-Anteile		Masse-Anteile	
	kg/m³		Stahl	Beton	Stahl	Beton
Attikabewehrung	90	kg/m³	1.15%	98.85%	3.8%	96.2%
Bauteil bis 1 m Höhe, sonst = Wand						
Hochbaudecken/-platten:	100	kg/m³	1.27%	98.73%	4.2%	95.8%
Wände:	80	kg/m³	1.02%	98.98%	3.4%	96.6%
Wand hat unter sich wieder eine Wand, durch welche Lasten abgetragen werden.						
Scheiben:	120	kg/m³	1.53%	98.47%	5.0%	95.0%
Scheibe (= vertikaler Bauteil) leitet keine Kräfte weiter nach unten ab (d.h. darunter KEINE Wand)						
Unterzüge:	200	kg/m³	2.55%	97.45%	8.2%	91.8%
Stützen:	250	kg/m³	3.18%	96.82%	10.1%	89.9%
Schleuderbetonstützen:	300	kg/m³	3.82%	96.18%	11.9%	88.1%
Anmerkung: es ist der Betondatensatz C30/37 zu verwenden!						
Kellerwände „Weiße Wanne“:	130	kg/m³	1.66%	98.34%	5.4%	94.6%
Anmerkung: Wasserundurchlässige Ausführung mit "WU-Beton"						
Kellerwände Sonstige	100	kg/m³	1.27%	98.73%	4.2%	95.8%
Anmerkung: Wasserundurchlässige Ausführung mit "WU-Beton"						
Bodenplatte „Weiße Wanne“:	160	kg/m³	2.04%	97.96%	6.6%	93.4%
Bodenplatte Sonstige	120	kg/m³	1.53%	98.47%	5.0%	95.0%
Schlitzwände:	120	kg/m³	1.53%	98.47%	5.0%	95.0%
Bohrpfähle:	200	kg/m³	2.55%	97.45%	8.2%	91.8%
Einzelfundamente:	200	kg/m³	2.55%	97.45%	8.2%	91.8%
Streifenfundamente:	90	kg/m³	1.15%	98.85%	3.8%	96.2%
Stiegenläufe	120	kg/m³	1.53%	98.47%	5.0%	95.0%

Appendix 9: Example of one component in the LCA-tool

	Berechnung	Eingabezellen	Eingabezellen	Eingabezellen	Eingabezellen	Eingabezellen
		BAUTEIL, BAUSTOFF				
	Material		Bauteil-Untergruppe	Bauteil-Nr.	Bauteilschichten	Quellenangabe, Anmerkungen Material
	Spalte für Orientierung	Zeile frei lassen				
EINGABE GRUNDEINSTELLUNGEN			Varianten	bitte hier Kürzel und Titel eingeben und Betrieb wählen		Betriebsvariante
50	Jahre Bilanzzeitrahmen		1	Passive House		1
1.0	Sicherheitsfaktor (1,1 für vereinfachtes Verfahren)		2a	VGS Sonnenhaus (ohne HVAC-Anpassung)		2
	Bezugsfläche (meist NGFa)	12 003 m²	2	Sun House		2
	(prüfen ob ident mit Betriebsenergie)	BGF	3a	VGS LowTechHaus (ohne HVAC-Anpassung)		3
			3	Low-tech building		3
1	Passive House		Variante 1	Passive House		
1	AW-AW 1-Anstrich		STB-PF-WDVS	AW 1	Anstrich	Annahme
1	AW-AW 1-Anstrich			AW 1	Anstrich	Annahme
1	AW-AW 1-Kunstoffdünnputz			AW 1	Kunstoffdünnputz	BTK
1	AW-AW 1-Dämmung			AW 1	Dämmung	BTK
1	AW-AW 1-Stahlbeton-Wand_Beton			AW 1	Stahlbeton-Wand_Beton	BTK
1	AW-AW 1-Stahlbeton-Wand_Stahl			AW 1	Stahlbeton-Wand_Stahl	BTK
1	AW-AW 1-Blähtonbeton			AW 1	Blähtonbeton	BTK
1	AW-AW 1-Spachtel			AW 1	Spachtel	BTK
1	AW-AW 1-Anstrich			AW 1	Anstrich	Annahme

Eingabe	Eingabe	Berechnung		Berechn	K	Eingabezellen	Eingabezellen		Berechnur	Eingabe
						Ökobau.dat Daten und Nutzungsdauer				
MATERIALGRUPPEN für Auswertung						Herstellung				
Bauteil-gruppe	Bestand (x)	Öko-bau.dat-Gruppe	Roh-stoff-gruppe	EoL-gruppe		Datensatz ökobau.dat Herstellung (H)	Anmerkungen Datensatz	Kern-info Wert Ökobau.dat	Kerninfo Einheit Ökobau.dat	kg/Einheit manuell aus Ökobau.dat
	nicht nötig					Zeile frei lassen		NEU		kg --> 1
	ACHTUNG, Hinweise zur Bearbeitung:							für Kontrolle		
	Keine Leerzeilen zwischen Bauteilen einfügen sondern Zeilenhöhe vergrößern auf 25							Spalte R		
	Zellen niemals verschieben (drag&drop) sondern kopieren (copy&paste). Keine Zellen verbinden									
	Eingabe von Luftschichten und Einfügen von Zeilen vermeiden! Wenn unbedingt notwendig, dann in eingefügte Leer-Zeilen, die bestehende Zeilen (vo									
	Bei Varianten: Wenn bei Basisvariante (= oberste Variante = Variante 1) Zeilen ergänzt oder gelöscht werden gibt's Probleme! Abhilfe: Anstatt lösche									
	Bei Varianten: Daten, die im Vergleich zur Basisvariante eingegben werden (d.h. manuell überschrieben werden), bitte farblich hinterlegen.									
AW		5		Mix		5.4 Fassadenfarbe Dispersionsfarbe	Annahme: Anstrich	1	kg	1
AW		5		Mix		5.4 Fassadenfarbe Voranstrich Silikat-Disp	Annahme: Anstrich	1	kg	1
AW		1		Min		1.4.04 Kunstharzputz	EAW: Kunstoffdünnputz	1	kg	1
AW		2		Heiz		2.05 PF-Schaumplatte, Phenolharz, Kingspa	weber.therm plus ultra	1	m²	3.5
AW		1		Min		1.4.01 Transportbeton C30/37		1	m3	2365
AW		4		Met		4.1.2 Bewehrungsstahl		1	kg	1
AW		1		Min		1.3.04 Blähton LB Hohlblockstein Trennwar	EAW: Blähbeton (R=1500)	1	m3	1600
AW		1		Min		1.4.05 Kleber für Gipsplatten		1	kg	1
AW		5		Mix		5.5 Innenfarbe Dispersionsfarbe scheuerfe	Annahme: Anstrich	1	kg	1

Eingabe	K	Eingabezellen	K	ıgabezell	Berechnur	Eingabe	Eingabe	Eingabe	Eingabe	Eingabe	K	Berechr
		End-of-Life					Instandhaltung			Instandhaltung		
kg/Einheit manuell aus Ökobau.dat		Datensatz ökobau.dat End of Life (EOL)		Anmerkungen Datensatz	Einheit Ökobau. dat	kg/Einheit manuell aus Ökobau.dat	Nutzungs-dauer Baustoff	Quelle Nutzungs-dauer	Anmerkungen	Nutzungs-dauer im Bauteil		Ersatz in 50 Jahren
kg --> 1		Prüfen				kg --> 1	Anm.: 50 bedeutet mind. 50 Jahre					
		Wenn "Mineralisch", dann "Bauschuttaufbereitung" lt. NBV09					Mittlere Werte aus			Fehler		
		wenn H-Datensatz, dann EoL-Datensatz und Angabe kg/EH					Nutzungsdauerkatalog-AT			wenn größer		
							heranziehen			als Baustoff-		
ıde Zeilen (von darüber oder darunter) kopieren										nutzungsdauer		
ıstatt löschen die Werte auf Null setzen. Zeilen einfügen: Alle Varianten müssen von Admin manuell angepasst/geprüft werden												
n.												
1		9.5 Bauschutt-Deponierung			kg	1	20			20		2
1		9.5 Bauschutt-Deponierung			kg	1	20			20		2
1		9.5 Bauschuttaufbereitung			kg	1	30			30		1
3.5		6.8 Verbrennung PS in MVA incl. Gutschrift		deutsche	kg	1	30			30		1
2365		9.5 Bauschuttaufbereitung			kg	1	50			50		0
1		9.5 Bauschuttaufbereitung			kg	1	50			50		0
1600		9.5 Bauschuttaufbereitung			kg	1	50			50		0
1		9.5 Bauschuttaufbereitung			kg	1	40			40		1
1		9.5 Bauschutt-Deponierung			kg	1	15			15		3

ıung		Berechnu	Berechnung				
ÖBD	**Flächenermittlung**			**Mengenermittlung (Daten bei 1., 2. oder 3.**			
				1. Mengenermittlung mittels Bauteilschicht			
	Netto-fläche	Faktor Brutto- / Netto-Bauteil-fläche	Brutto-Fläche	Flächen-anteil	Schichtdicke	Dichte	Quelle Dichte
		1.00		% eingeben			
		bereits formel-verknüpft					
	1 370.59	1	1 370.59				
	1 370.59	1	1 370.59				
	1 370.59	1	1 370.59	100%	0.0100	1200	
	1 370.59	1	1 370.59	100%	0.1800	35	
	1 370.59	1	1 370.59	99%	0.1400	2400	
	1 370.59	1	1 370.59	1.02%	0.1400	7800	
	1 370.59	1	1 370.59	100%	0.0600	1500	
	1 370.59	1	1 370.59	100%	0.0050	1300	
	1 370.59	1	1 370.59				

							Berechnur	*Berechnung*	*K*
eingeben)								**Masse**	
2. Mengenermittlung pro Fläche				3. Mengenermittlung absolut			Kontrolle		
Menge pro Fläche	Ein-heit	Flächen-anteil	kg / Einheit	Menge absolut	Ein-heit	kg / Einheit	Flächen-gewicht	Masse	
Zeile frei lassen		% eingeben		*Zeile frei lassen*			hier nichts eintragen		
1.00	m²	100%	0.22				0.2	302	
1.00	m²	100%	0.22				0.2	302	
							12.0	16 447	
							6.3	8 635	
							332.6	455 821	
							11.1	15 266	
							90.0	123 353	
							6.5	8 909	
1.00	m²	100%	0.15				0.2	206	

Ökobilanz Herstellung pro Jahr und pro m² NGFa								Ökobilanz Herstellung pro Jahr und pro m² NGFa	**H**
kg	kg	kg	kg	kg	kWh	kWh	kWh	kWh	
GWP	ODP	POCP	AP	EP	PE-NR	PE-R	PE-S (SF)	PE-T	
16	24	20	18	22	10	12	14		
0.001	7.40E-11	0.000003	0.000020	0.000000	0.007	0.000	0.000	0.007	
0.001	3.48E-11	0.000002	0.000006	0.000000	0.003	0.000	0.000	0.003	
0.024	1.35E-09	0.000072	0.000200	0.000007	0.147	0.004	0.000	0.150	
0.041	3.22E-12	0.000041	0.000099	0.000011	0.334	0.005	0.000	0.339	
0.076	2.02E-09	0.000014	0.000134	0.000019	0.107	0.002	0.039	0.148	
0.022	2.00E-09	0.000007	0.000042	0.000004	0.088	0.007	0.000	0.095	
0.043	1.02E-09	0.000016	0.000295	0.000015	0.084	0.003	0.005	0.092	
0.002	5.70E-11	0.000000	0.000002	0.000000	0.007	0.000	0.000	0.007	
0.001	6.33E-11	0.000003	0.000014	0.000000	0.006	0.000	0.000	0.006	

Ökobilanz Instandsetzung pro Jahr und pro m² NGFa								
kg	kg	kg	kg	kg	kWh	kWh	kWh	kWh
GWP	ODP	POCP	AP	EP	PE-NR	PE-R	PE-S (SF)	PE-T
0.002	1.48E-10	0.000006	0.000041	0.000001	0.014	0.000	0.000	0.014
0.001	6.98E-11	0.000003	0.000012	0.000000	0.007	0.000	0.000	0.007
0.025	1.34E-09	0.000072	0.000202	0.000007	0.147	0.004	0.000	0.151
0.062	-1.25E-09	0.000038	0.000071	0.000009	0.207	0.003	0.000	0.211
0.000	0.00E+00	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000
0.000	0.00E+00	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000
0.000	0.00E+00	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000
0.002	5.14E-11	0.000000	0.000003	0.000000	0.008	0.000	0.000	0.008
0.003	1.90E-10	0.000008	0.000043	0.000001	0.018	0.000	0.000	0.018
0.004	2.47E-10	0.000009	0.000068	0.000001	0.023	0.000	0.000	0.023
0.002	1.16E-10	0.000005	0.000021	0.000000	0.011	0.000	0.000	0.011
0.041	2.23E-09	0.000121	0.000337	0.000012	0.245	0.006	0.000	0.251
0.103	-2.09E-09	0.000064	0.000119	0.000015	0.346	0.005	0.000	0.351

Ökobilanz End-of-Life pro Jahr und pro m² NGFa					Ökobilanz End-of-Life pro Jahr und pro m² NGFa			
kg	kg	kg	kg	kg	kWh	kWh	kWh	kWh
GWP	ODP	POCP	AP	EP	PE-NR	PE-R	PE-S (SF)	PE-T
16	24	20	18	22	10	12	14	
0.000	8.30E-14	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000
0.000	8.30E-14	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000
0.001	-1.03E-11	0.000000	0.000002	0.000000	0.000	0.000	0.000	0.000
0.021	-1.26E-09	-0.000003	-0.000027	-0.000002	-0.126	-0.002	0.000	-0.128
0.027	-2.86E-10	0.000004	0.000052	0.000008	0.010	0.000	0.000	0.010
0.001	-9.58E-12	0.000000	0.000002	0.000000	0.000	0.000	0.000	0.000
0.007	-7.74E-11	0.000001	0.000014	0.000002	0.003	0.000	0.000	0.003
0.001	-5.59E-12	0.000000	0.000001	0.000000	0.000	0.000	0.000	0.000
0.000	5.66E-14	0.000000	0.000000	0.000000	0.000	0.000	0.000	0.000

GESAMTERGEBNIS ÖKOBILANZ								
Ökobilanz GESAMT pro Jahr und pro m² NGFa								Ökobilanz End-of-Life pro Jahr und pro m² NGFa
kg	kg	kg	kg	kg	kWh	kWh	kWh	kWh
GWP	ODP	POCP	AP	EP	PE-NR	PE-R	PE-S (SF)	PE-T
0.004	2.22E-10	0.0000	0.000061	0.000001	0.020	0.000	0.000	0.021
0.002	1.05E-10	0.0000	0.000019	0.000000	0.010	0.000	0.000	0.010
0.049	2.68E-09	0.000145	0.000405	0.000014	0.294	0.007	0.000	0.301
0.124	-2.51E-09	0.0001	0.000143	0.000017	0.415	0.006	0.000	0.421
0.103	1.74E-09	0.0000	0.000185	0.000026	0.117	0.002	0.039	0.157
0.023	1.99E-09	0.0000	0.000044	0.000004	0.088	0.007	0.000	0.095
0.051	9.43E-10	0.0000	0.000309	0.000017	0.087	0.002	0.005	0.094
0.005	1.03E-10	0.0000	0.000006	0.000001	0.015	0.000	0.000	0.015
0.004	2.54E-10	0.0000	0.000057	0.000001	0.024	0.000	0.000	0.024

Appendix 10: Solar Panel Extrapolation (I)

As in detail described (4.3.1), the calculation approach for the solar moduls is (because of missing data or software restrictions) based on several extrapolation and assumption. Thus, the subsequent executions reflect the extrapolation in detail and with several comments.

Step 1: Calculation of the original object in Freistadt

Gross floor area	1 028.20	m²	*Data from the energy certificate*
Residents	17.30		*= 9 * 1.7 + 2* *= numbers of aparments * average residents per apartment + number of occupational residents*
Specific heating demand	37.38	kWh/(m²a)	*Data from the energy certificate (site climate)*
Heating demand	38 435.00	kWh/a	*Data from the energy certificate (site climate)*
Heat loss	65 865.00	kWh/a	*Data from the energy certificate (site climate)*
Solar panels*	126.00	m²	*Evaluated figure from an air picture of the building in Freistadt -> 63 panels * collector area of 2m² per panel*
Orientation (South = 0°; West = -90°; East = +90°)	0°		*Data from the energy certificate*
Alignment	45°		*Data from the energy certificate*
Puffer storage	20 000.00	l	*Original size is 40.000 litres but due to the restricted availability of pufforstorages repectively modeling option it had to be chosen a tank with 20.000 litres*
Furnance	40.00	kw	*Data from the energy certificate*
Solar ratio	**45.80**	**%**	*Calculated by Polysun-software*

Characteristic values of solar plant

Collector area per gross floor area	0.12	m²/m²
Puffer storage per collector area	158.73	l/m²

Further considerations:

In respect to the incorrect size of the puffer storage, the calculated solar ratio does not cope with the predetermined figures. In accordance to that, the next step was to adapt the real conditiones to the restricting variable, which implies a reduction of all components by factor 2.

* All calculations in the Polysun-software are modelled with 'good' quality panels. The reason lies in the fact, that (as it can be seen in the next stept) they had the closest result compared to the predetermined figures.

Appendix 11: Solar Panel Extrapolation (II)

Outgoing from the restricted variable (puffer storage). This approach claims to rectify the bias of Step 1. All components are reduced by factor 2

<u>Step 2: Calculation of the reduced object</u>

Gross floor area	514.10	m^2	*Reduced factor*
Residents	8.65		*Reduced factor*
Specific heating demand	37.38	kWh/(m^2a)	*Data from the energy certificate (site climate)*
Heating demand	19 217.50	kWh/a	*Reduced factor*
Heat loss	32 932.50	kWh/a	*Reduced factor*
Solar panels	63.00	m^2	*Reduced factor*
Orientation (South = 0°; West = -90°; East = +90°)	0°		*Data from the energy certificate*
Alignment	45°		*Data from the energy certificate*
Puffer storage	20 000.00	l	*Reduced factor*
Furnance	20.00	kw	*Reduced factor*
Solar ratio	**50.90**	**%**	*Calculated by Polysun-software*
Specific solar gain	363.00	kWh/(m^2a)	*Calculated by Polysun-software*
Solar gain	22 870.00	kWh/a	*Calculated by Polysun-software*
Energy demand in total	44 962.90	kWh/a	*Evaluated figure from summing up the total solar gain and the other energy sources for heating purposes*

<u>Characteristic values of solar plant</u>

Collector area per gross floor area	0.12	m^2/m^2
Puffer storage per collector area	317.46	l/m^2

<u>Further considerations:</u>

The calculated solar ratio is not even the same as in the predetermined data. However, with a deviation of 0.9 % it comes close and can be seen as a reference value. Because of the possibility (and finally necessity) of installing panels at the builing facade, the next step was to adapt and calculate the solar plant for the new model.

Appendix 12: Solar Panel Extrapolation (III)

In accordance to modell a south-west (45°) facing and facade mounted solar plant, the following assumptions and calculations were made:

Step 3: Calculation of a facade (orientation: south-west) integrated solar plant -> reduced object scale

Gross floor area	514.10	m²		*Reduced factor*
Residents	8.65			*Reduced factor*
Specific heating demand	37.38	kWh/(m²a)		*Data from the energy certificate (site climate)*
Heating demand	19 217.50	kWh/a		*Reduced factor*
Heat loss	32 932.50	kWh/a		*Reduced factor*
Solar panels	63.00	m²		*Reduced factor*
Orientation (South = 0°; West = -90°; East = +90°)	-45°			*Data from the energy certificate*
Alignment	90°			*Data from the energy certificate*
Puffer storage	20 000.00	l		*Reduced factor*
Furnance	20.00	kW		*Reduced factor*
Solar ratio	**34.10**	**%**	-33%	*Calculated by Polysun-software and compared to the figures from step 2*
Specific solar gain	236.40	kWh/(m²a)	-35%	*Calculated by Polysun-software and compared to the figures from step 2*
Solar gain	14 892.90	kWh/a	-35%	*Calculated by Polysun-software and compared to the figures from step 2*
Energy demand in total	43 653.90	kWh/a	-3%	*Evaluated figure from summing up the total solar gain and the other energy sources for heating purposes*
Solar panels NEW	**93.99**	**m²**		*By a linear extrapolation (=43653.9*0.509/236.4) 94 m^2 are necessary to achive the initially solar ratio of 50.9%*
Solar ratio NEW	**50.9**	**%**		*As far as this value is calculated by the software of Polysun the solar ratio only comes to 39.8%. This value is not even close to the strived value. Nevertheless, also by doubling the solar area to 120 m^2 the solar ratio remains with 43,1 %. Thus, in this calculation a linear extrapolation is further kept as the reference approach.*
Specific solar gain (NEW)	236.40	kWh/(m²a)		*Copied from above*
Solar gain (NEW)	22 219.84	kWh/a		*Evaluated from multiplying the solar gain per m^2 with the NEW solar panel area*
Energy demand in total	43 653.90	kWh/a		*Evaluated figure from summing up the NEW total solar gain and the other energy sources for heating purposes*
Characteristic values of solar plant				
Collector area per gross floor area	0.18	m²/m²		
Puffer storage per collector area	212.78	l/m²		

Appendix 13: Solar Panel Extrapolation (IV)

All calculations and extrapolations below were used to determine, as exact as possible, the required solar panel area as well as required volume of the puffer storage

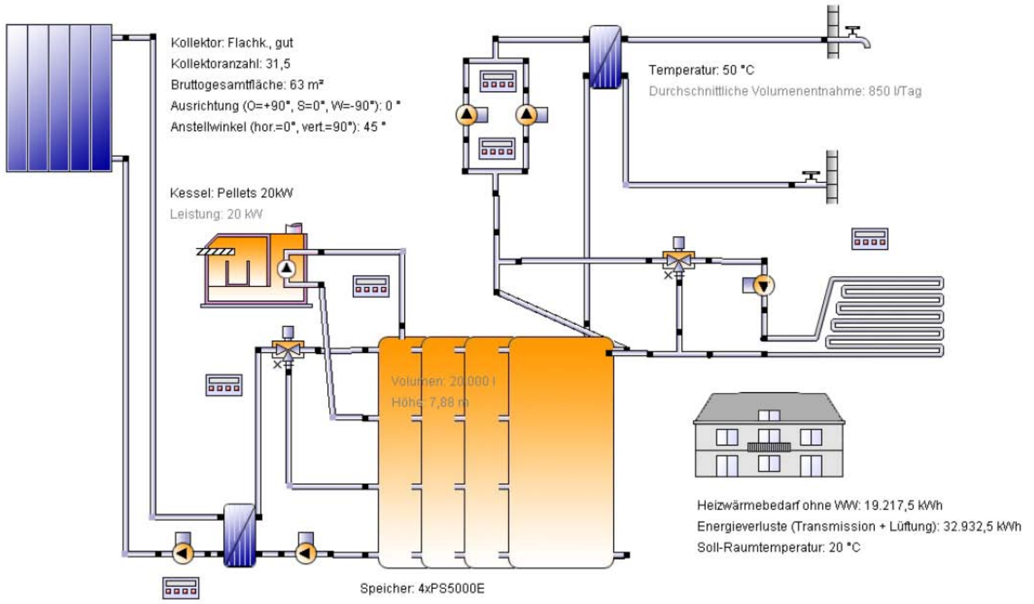
Step 4: Opposing the initial PH with the modelled SH

	Vienna after Freistadt		
Gross floor area	8451.55	m²	_Data from the energy certificate_
Residents	123.70		Calculation similar to step 1 (= 61 * 1.7 + 5 * 4)
Specific heating demand	31.33	kWh/(m²a)	_Data from the energy certificate (site climate)_
Heating demand	264787.06	kWh/a	_Data from the energy certificate and assimilated with the SH characteristics (= 19217.50 / 514.10 * 8451.55)_
Heat loss	452785.88	kWh/a	_Data from the energy certificate_
Facade area South/West	515.70	m²	_Dimensions from the construction plan (=(621*10*7+10*15*54)100)_
Facade area South/East	240.68	m²	_Dimensions from the construction plan (=(190*150-16.2*15.2*18)/100)_
Roof top area*	1 273.60	m²	_Data from construction plan_
Solar panels roof top	560.00	m²	_Solar panals are installed on a maximum extent (= 1273.6 * 0.44)_
Solar panels facade	731.63	m²	_Represents the remaining area to achieve a solar ratio of 50.9% (= (376236.44 - 560 * 363) / 236.4)_
Solar panels total	**1291.63**	m²	_(= 560 + 731.63)_
Puffer storage	**164 395.06**	l	_Proportionally extrapolation according to the cross floor area + reduced by factor 2 because of simultanety effects (= 20000 / 514.1 * 8451.55 / 2)_
Furnance/District heating	328.79	kw	_Proportionally extrapolation according to the cross floor area (= 20 / 514.10 * 8451.55)_
Solar ratio	**50.9**	%	_Taken from above and as the goal value_
Solar gain	376 236.44	kWh/a	_(= 739167.86 * 50.9)_
Energy demand (heating)	739 167.86	kWh/a	_Proportionally extrapolation according to the cross floor area (=44962.9 / 514.1 * 8451.55)_

* The factor for installed solar panels per m² rooftop area is, in accordance to avoid shadding inefficiencies, 0.44

Appendix 14: Polysun calculation results of Sun House in Freistadt (reduced by factor 2)

Projekt **Freistadt (reduziert bei Faktor 2)**



Systemübersicht (Jahreswerte)

Gesamter Brennstoff- und Strom-Verbrauch des Systems [Etot]	28.968,9 kWh
Gesamter Energieverbrauch [Quse]	33.620,6 kWh
Systemeffizienz [(Quse+Einv) / (Eaux+Epar)]	1,16
Komfortanforderungen	Energiebedarf ist gedeckt

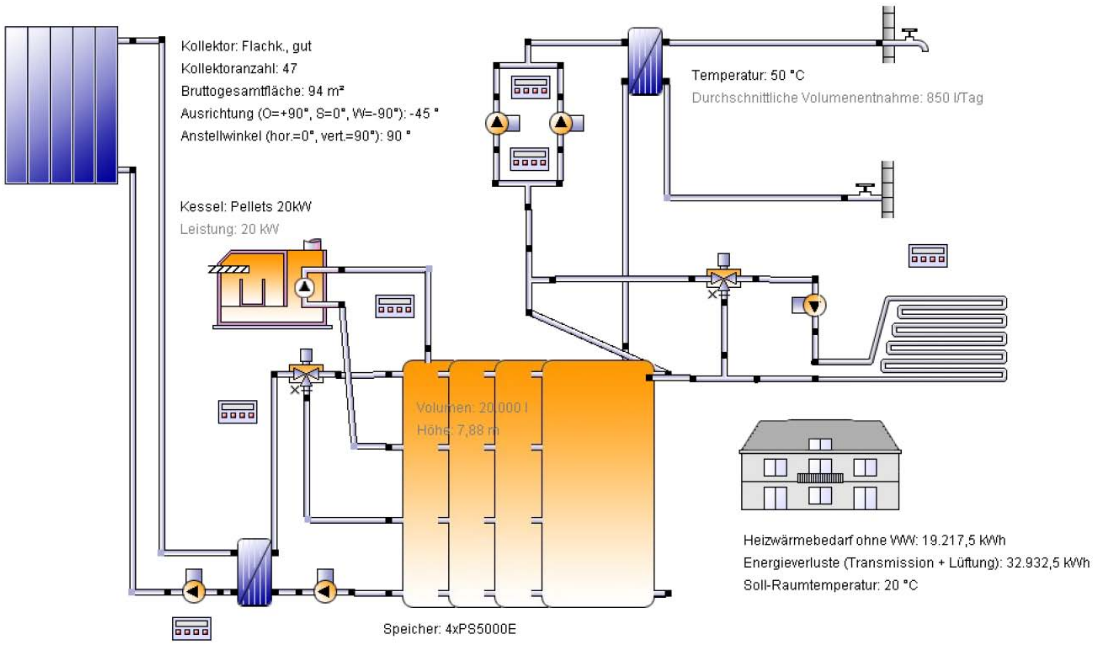
Übersicht Solarthermie (Jahreswerte)

Kollektorfläche	63 m²
Solarer Deckungsgrad gesamt	50,9%
Solarer Deckungsgrad Warmwasser [SFnHw]	59,2 %
Solarer Deckungsgrad Gebäude [SFnBd]	29,4 %
Gesamter Kollektorfeldertrag	22.869,9 kWh
Kollektorfeldertrag bzgl. Bruttofläche	363 kWh/m²/Jahr
Kollektorfeldertrag bzgl. Aperturfläche	403,4 kWh/m²/Jahr
Max. Brennstoffeinsparung (VDI 6002)	5.578 kg: [Pellets]
Max. Energieeinsparung (VDI 6002)	27.890,2 kWh
Max. vermiedene CO2-Emission	1.405,7 kg

	Jahr	Jän	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Solarthermische Energie an das System [Qsol]													
kWh	22870	1150	1449	2322	2499	2665	2288	2497	2448	2118	1647	1046	742
Energie der Wärmeerzeuger an das System (ohne Solarthermie) [Qaux]													
kWh	22093	4235	3647	2892	1387	514	57	127	0	127	981	3473	4653
Brennstoff- und Strom-Verbrauch der Wärmeerzeuger [Eaux]													
kWh	28731	5479	4723	3780	1835	686	77	170	0	169	1301	4511	6002
Solarer Deckungsgrad: Anteil Solarenergie an das System [SFn]													
%	50,9	21,4	28,4	44,5	64,3	83,8	97,6	95,1	100	94,4	62,7	23,1	13,8
Gesamter Brennstoff- und Strom-Verbrauch des Systems [Etot]													
kWh	28969	5502	4745	3809	1860	705	92	186	15	182	1316	4533	6024
Einstrahlung in Kollektorebene [Esol]													
kWh	70091	3230	4088	6293	7169	7941	7738	8496	8272	6755	4835	2918	2355
Stromverbrauch der Pumpen [Epar]													
kWh	237,4	23,3	22,3	29	24,8	19	15	16,6	15	13,1	15,5	21,9	21,9
Gesamter Energieverbrauch [Quse]													
kWh	33621	4617	4231	4247	3020	1875	1364	1279	1248	1252	2167	3819	4501
Wärmeverlust an Innenraum (inklusive Wärmeerzeuger-Verluste) [Qint]													
kWh	17212	2028	1801	1732	1292	1097	976	1079	1113	1000	1191	1781	2121
Wärmeverlust an Umgebung (ohne Kollektorverluste) [Qext]													
kWh	1060	50	53	90	102	118	117	136	138	110	70	39	37

Appendix 15: Polysun calculation results of Sun House in Freistadt (alternative collector orientation + enlargement)

Projekt **Freistadt (Fassadenkollektor vergrößert + reduziert bei Faktor 2)**



Systemübersicht (Jahreswerte)

Gesamter Brennstoff- und Strom-Verbrauch des Systems [Etot]	34.802,1 kWh
Gesamter Energieverbrauch [Quse]	33.618,5 kWh
Systemeffizienz [(Quse+Einv) / (Eaux+Epar)]	0,97
Komfortanforderungen	Energiebedarf ist gedeckt

Übersicht Solarthermie (Jahreswerte)

Kollektorfläche	94 m²
Solarer Deckungsgrad gesamt	39,8%
Solarer Deckungsgrad Warmwasser [SFnHw]	46,7 %
Solarer Deckungsgrad Gebäude [SFnBd]	32,4 %
Gesamter Kollektorfeldertrag	17.531,8 kWh
Kollektorfeldertrag bzgl. Bruttofläche	186,5 kWh/m²/Jahr
Kollektorfeldertrag bzgl. Aperturfläche	207,2 kWh/m²/Jahr
Max. Brennstoffeinsparung (VDI 6002)	4.276,1 kg: [Pellets]
Max. Energieeinsparung (VDI 6002)	21.380,3 kWh
Max. vermiedene CO2-Emission	1.077,6 kg

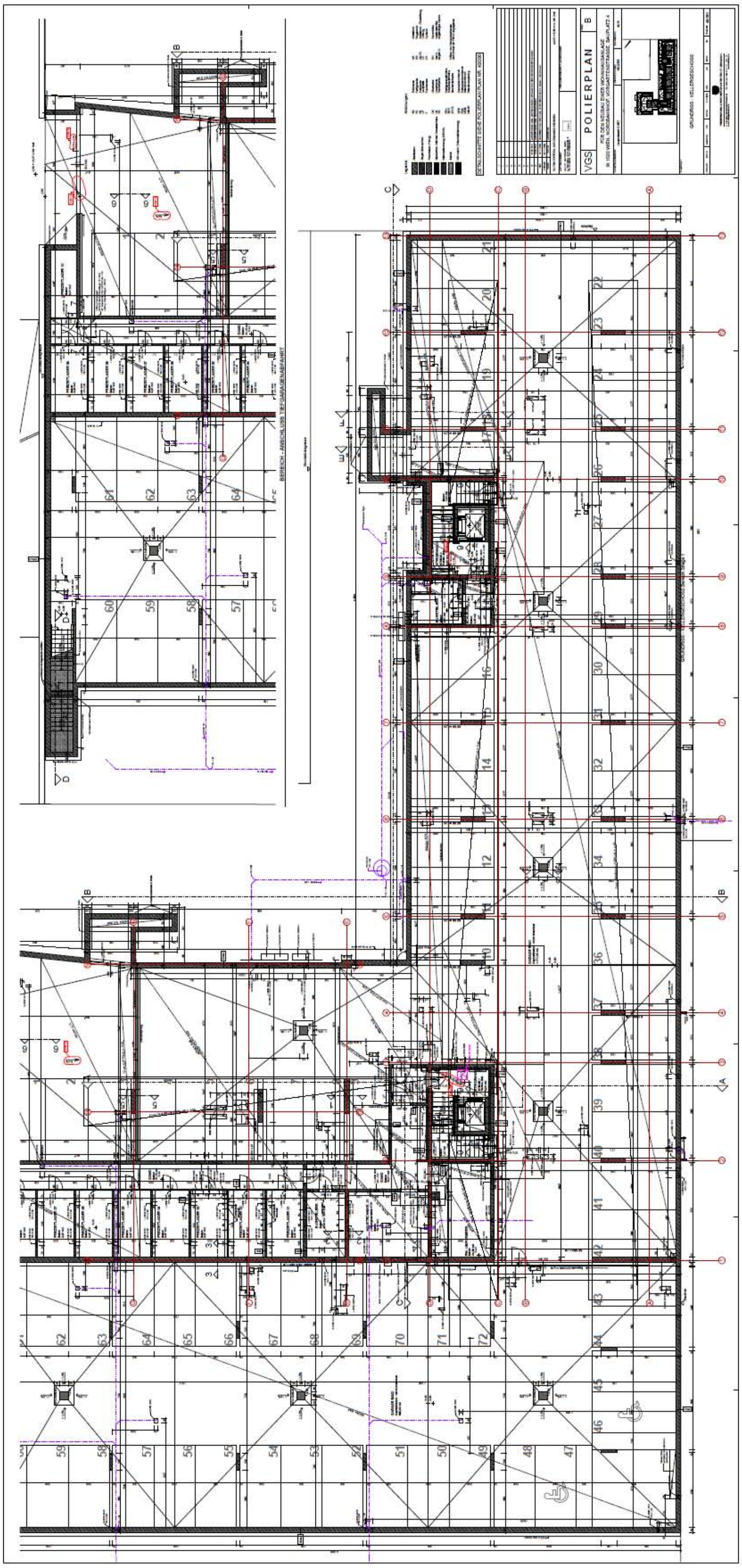
	Jahr	Jän	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Solarthermische Energie an das System [Qsol]													
kWh	17532	1146	1281	1947	1887	1704	1367	1503	1759	1730	1472	986	749
Energie der Wärmeerzeuger an das System (ohne Solarthermie) [Qaux]													
kWh	26515	4251	3805	3210	1888	1302	861	770	477	568	1206	3516	4659
Brennstoff- und Strom-Verbrauch der Wärmeerzeuger [Eaux]													
kWh	34592	5499	4922	4187	2491	1735	1152	1035	638	757	1600	4566	6010
Solarer Deckungsgrad: Anteil Solarenergie an das System [SFn]													
%	39,8	21,2	25,2	37,8	50	56,7	61,3	66,1	78,7	75,3	55	21,9	13,9
Gesamter Brennstoff- und Strom-Verbrauch des Systems [Etot]													
kWh	34802	5520	4943	4213	2512	1751	1164	1048	651	768	1614	4587	6031
Einstrahlung in Kollektorebene [Esol]													
kWh	71786	3992	4585	6902	7394	7546	7211	7713	7884	7030	5209	3394	2925
Stromverbrauch der Pumpen [Epar]													
kWh	209,8	21,9	20,7	25,9	21,7	15,6	12,2	13,1	13	11,1	13,4	20,5	20,7
Gesamter Energieverbrauch [Quse]													
kWh	33619	4619	4230	4248	3014	1871	1368	1280	1253	1254	2166	3815	4501
Wärmeverlust an Innenraum (inklusive Wärmeerzeuger-Verluste) [Qint]													
kWh	17990	2032	1838	1806	1406	1279	1141	1157	1099	1083	1238	1790	2120
Wärmeverlust an Umgebung (ohne Kollektorverluste) [Qext]													
kWh	743	43	44	71	73	76	71	78	89	79	54	33	31

Appendix 16: Energy-Certificate Calculations

	Var. 1 Passivhaus 'young corner'	Var. 2 Sonnenhaus OIB 16er Linie	Var. 3 LowTech '2226'
Heating demand (reference climate)	6.36 kWh/m²a	30.15 kWh/m²a	20.57 kWh/m²a
Heating demand (location climate)	6.82 kWh/m²a	31.33 kWh/m²a	21.50 kWh/m²a
Hot water heat demand	12.78 kWh/m²a	12.78 kWh/m²a	12.78 kWh/m²a
Heating technology energy demand (room heating)	6.84 kWh/m²a	-3.50 kWh/m²a	4.86 kWh/m²a
Heating technology energy demand (hot water heating)	16.57 kWh/m²a	16.57 kWh/m²a	16.57 kWh/m²a
Heating technology energy demand (hot water heating)	23.42 kWh/m²a	13.08 kWh/m²a	21.43 kWh/m²a
Heating energy demand	43.01 kWh/m²a	57.18 kWh/m²a	55.70 kWh/m²a
Final energy demand	43.01 kWh/m²a	57.18 kWh/m²a	55.70 kWh/m²a

		Passivhaus	Sonnenhaus	LowTech B2226	
Variation U-Werte		W/(m².K)	W/(m².K)	W/(m².K)	
	AW1	0.118	0.35	0.140	
	AW2	0.116	0.35	0.140	
	AW5	0.265	unverändert	0.140	
	AW8	0.256	unverändert	0.140	
	AD1	0.087	0.20	unverändert	
	AD2	0.087	0.20	unverändert	
	AD3	0.114	0.20	unverändert	
	DGUo1	0.116	unverändert	unverändert	
	DGUo2	0.191	unverändert	unverändert	
	DGUo6	0.127	0.40	unverändert	
	DGUo7	0.126	unverändert	unverändert	
	DGUo8	0.099	unverändert	unverändert	
	DGUo9	0.123	unverändert	unverändert	
	DGUo13	0.143	0.40	unverändert	
Variation Dämmstärken		Var. 1		Var. 2	
		cm		cm	Material
	AW1	18.0	Hochlochziegel	5.7	Phenol-Hartschaumplatte
	AW2	18.0	Hochlochziegel	5.4	Phenol-Hartschaumplatte
	AD1	36.0		12.8	EPS W 25
	AD2	36.0		12.8	EPS W 25
	AD3	22.0		10.6	EPS W-30 plus
	DGUo6	10.0		0.0	EPS W 25 plus
	DGUo6	9.0		2.2	Isover KDP
	DGUo13	10.0		0.0	EPS W 25 plus
	DGUo13	5.8		1.5	IsoverMultiKomfort-Klemmfilz

Appendix 17: Plans of 'young corner'



Appendix 18: Conversion calculation of operational energy from energy certificate to LCA related figures

The conversion from the energy certificate to the LCA related figures is based on two factors:

- Factor 1: Conversion from the conditioned to the unconditioned gross floor area
- Factor 2: Conversion by primary energy factors

As an example, a retroactive calculation of the PH related operational energy is subsequently conducted:

The operational energy results from multiplying the energy demand per square meter of conditioned gross floor area, which is divided into heat and electricity, with a **primary energy factor**[28] of a particular energy source. As the PE-NR results from district heating and electricity (lightening is not included) the calculation is as follows:

$$\boldsymbol{Operational\ Energy_{PH}} = 26.40\ \left[\frac{kWh}{m^2.a}\right] * 0.96 + 3.90\left[\frac{kWh}{m^2.a}\right] * 0.89 = 28.60\left[\frac{kWh}{m^2.a}\right]$$

The operational energy represents the final result. But before getting to this, the energy demand for heating and electricity per square meter of conditioned gross floor area has to be converted into **unconditioned gross floor area** first. This can be achieved by putting the initial energy demand into relation with the unconditioned floor area of the building:

$$\boldsymbol{Heat\ Energy\ Demand}\ _{\boldsymbol{PH\ cross\ floor\ area}} = 37.5\ \left[\frac{kWh}{m^2.a}\right] * \frac{8452\ [m^2]}{12003[m^2]} = 26.4\ \left[\frac{kWh}{m^2.a}\right]$$

$$\boldsymbol{Electricity\ Energy\ Demand}\ _{\boldsymbol{PH\ conditioned\ floor\ area}} = 5.5\ \left[\frac{kWh}{m^2.a}\right] * \frac{8452\ [m^2]}{12003[m^2]} = 3.9\ \left[\frac{kWh}{m^2.a}\right]$$

For completing the calculation, as a last (respectively a first step) it is necessary to determine the initial energy demand for every concept. This is conducted by taking particular data from the prepared energy certificates. By summarizing the listed figures from Table 6, which are results from the energy certificate of each concept, it comes to the inquired data.

[28] The applied primary energy factor derives from two different sources, ökobau.dat for district heating and ÖGNI for electricity.