What is the impact of a basement on a building LCA and what role does the functional unit play?

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Abstract. The goal of reaching nearly zero emissions in the construction sector by 2045 is important and at the same time ambitious. Therefore, emissions from operation and structural design of a building play an important role. Life cycle assessment is an established method for determining the environmental impact of a building throughout its life cycle. The implementation of an LCA follows in general the standards ISO 14040 / 14044, and on building level the standard EN 15978. It requires, among other things, the definition of the goal, the system boundaries and the functional unit. For buildings with basements, there are certain discrepancies in the definitions of goals, system boundaries, and functional units. When the production, construction and maintenance phases of a building are included in the system boundaries of the LCA, the whole building is considered and is for example related to the functional unit gross external area or others as net external area or heated area. The set goal, system boundaries and selection of the functional unit has a direct influence to the LCA results. In this paper, the effects of a basement on the LCA results of the operational and structural design of a building are presented as a function of different functional units. Therefore, a comparative LCA on residential buildings in two different energy standards (level 40, level 55) and additionally for conventional and future-oriented construction were calculated.

Keywords: LCA, Residential buildings, basement, functional unit, GWP

1 Introduction

The goal of achieving near-zero emissions in the building sector by 2045 is important and ambitious at the same time. Therefore, emissions from the operation and structural design of a building play an important role. These emissions can be revealed through life cycle assessment (LCA), which is an established method for determining the environmental impact of buildings over their entire life cycle. The LCA method is already used in sustainability assessment.

Especially for the building sector, which includes the construction, maintenance and operation of buildings and causes 39% of all greenhouse gas emissions in Germany [1], ambitious reduction targets are defined [2]. Next-generation benchmarks for buildings (currently in Germany by emissions m$^2$ a net floor area) will have to implement that.

The possible reduction potential of greenhouse gas emissions is highest at the beginning of the planning phase, so architects and planners in general need to know the impact of their decisions.
Therefore, in order to still be able to construct as many future-oriented buildings as possible, precise target values and specifications should be set as quickly as possible. The building sector is currently working on these specifications. One topic of great importance that should not be neglected is the basement of buildings. It can be debated whether basements, in this case in residential construction, are still contemporary and necessary. Basements in residential buildings are mainly used for car parking, space for technical equipment or as storage rooms. The question arises, how does my building without a basement compare to a building with a basement and how high are the emissions generated by the changes. This evaluation depends on the functional unit used. In this paper, the influence of these aspects is shown in detail.

In the first chapter this paper presents the approach for a comparative LCA study at the building level according to the current normative standards for residential buildings and, in particular, the influence of a basement on the LCA results of the operational and embodied emissions of a building. Chapter 2 presents the methodology and framework for the LCA study and the buildings studied. In addition, Chapter 3 presents the LCA results for the indicator global warming potential (GWP) in relation to the functional unit gross floor area (GEA) and net floor area (NEA). Chapter 4 evaluates the results and gives an outlook on future necessities regarding the basement consideration.

1.1 Life Cycle Assessment of Buildings

A life cycle assessment presents quantified values for the potential environmental impacts of services or products. This involves a holistic evaluation of input and output flows over the entire life cycle. The general assessment rules for LCA are defined in EN ISO 14040:2020 [8] and EN ISO 14044:2020 [6], with additional requirements for buildings found in EN 15978:2012 [5]. The central theme of LCA is to cover the entire life cycle. Starting with production and construction (Module A), through the use phase (Module B), and ending with disposal (Module C), all life cycle phases are considered according to EN 15804:2019 [7]. Module D shows potential of recycling or reuse and is mapped outside the system boundary. Figure 1 shows these life cycle phases and further subdivisions for building LCAs.

![Figure 1. Life cycle stages for buildings [3]](image)

1.2 Functional Unit

According to EN 14044:2006 [4] the functional unit describes the quantified performance of a product system for use as a reference unit. In this study the functional units are the provision of 1 m² gross floor area (GEA) and 1 m² net floor area (NEA) of the product system “building” over a life cycle of 50 years. The definition of different areas is defined by the Germany standard DIN 277. The buildings to be compared are functionally equivalent.
2 Methodology for Life cycle assessment of residential buildings

2.1 Methodological Approach

By performing life cycle assessments of buildings, this study determines comparative values for the environmental indicator GWP in kg CO\textsubscript{2} eq, which can be used to compare and evaluate different buildings. The LCA comparison of buildings was carried to the standard DIN EN 15978:2012 \cite{5}, which defines the calculation method for LCA for buildings. The methodology is carried out in the following order. The technical terms are explained in the following chapters.

(1) The first step is to define a functional equivalent. There is a comparison of buildings in timber construction with mineral construction.
(2) In a further step all buildings are evaluated according to G\textsubscript{EA} and NEA. Thereupon a comparison of the results on different functional units is possible.
(3) In a third step the indicators GWP of residential buildings without basement and residential buildings with basement are shown in order to determine the influencing variables of the basement on the building level.

2.2 Functional equivalent

According to EN 15978: 2012 \cite{5}, equivalent functionality describes the qualitative and technical requirements of buildings or composite components that form the basis of comparative lifecycle assessment studies. Being functionally equivalent, the building meets the minimum technical and functional requirements. As a basic functional quality, all the buildings investigated meet the minimum legal requirements and the latest technology. Therefore, all buildings in this study meet the same requirements for structural stability and load-bearing capacity, as well as fire protection according to the Building Standards Act and fire protection according to DIN 4109:1 \cite{6}. All buildings comply with the Energy Saving Ordinance EnEV 2014 (2016) and above, thus meeting the physical requirements of winter and summer buildings. Functional equivalence is limited to the essential requirements of the component and represents the minimum standard for the entire life cycle of the building.

In this study, the functional equivalent as reference unit refers to the building construction for multi-family dwellings. A distinction is made between buildings with and without basements.

The results produced in wooden construction are compared to those in functionally equivalent mineral construction. In addition, the same building without basement is compared with structurally identical buildings with basement.

2.3 Construction method

In this study, the differentiation of construction methods from König (2017) \cite{7}, Hafner and Schäfer (2017) \cite{8} and Hafner et al. (2017) \cite{9} is used to compare MFH over the entire life cycle. Additional baselines are taken from Heeren et al. (2015) \cite{10} and Takano et al. (2014) \cite{11}. Buildings that are predominantly made of wood and other resource-conserving raw materials (bio-based materials / recycled products / low-carbon products in the future), and thus can be assigned to future-oriented construction, are subsequently called "timber construction". For the buildings, which are produced in mineral construction, the designation is "mineral construction".

Therefore, all buildings in this study are modeled in two construction methods.

The label of the construction methods is:
- (A): mineral construction
- (B): timber construction
2.4 Energy standards
The German building energy law (GEG 2020) also introduced new energy standards that are intended to reduce energy consumption without drastically increasing construction costs. In addition to the legal binding requirements of GEG standard, there are other accepted sub-standards for better the energy performance of buildings in Germany in place in relation to funding programs. These more ambitious sub-standards are considered in this study. The “energy performance level 55” (45% below legal requirements) and “energy performance level 40” (60% below legal requirements) for buildings. The maximum annual primary energy requirement of a building in energy performance level 55 is 55 kWh/m². This means that an energy performance level 55 building requires only 55% of the primary energy of the GEG reference building and is 45% below the legal requirement. A building with the energy performance level 40 has a maximum annual primary energy requirement of 40 kWh/m², requires only 40% of the primary energy of the GEG reference building and is 60% below the legal requirement.

Therefore, all buildings in this study are modeled in two energy standards. The label of the energy standards is:
- 55: level 55
- 40: level 40

2.5 Selection of the analysed buildings
A medium-sized, realized multi-family house was used as the data basis for this study. The original building was realised in sustainable construction, predominantly in timber construction, and according to level 55. The database was expanded to include the same building but with level 40. Based on these buildings, functional equivalents were created in conventional construction. Creating an equivalent building guarantees the functional equivalence of the building used for the comparative LCA survey.

The counterparts have mineral building materials and are compatible with current state-of-the-art technology and construction. They have the same floor plans and living standards as "original" wooden buildings (e.g. building services, number of bathrooms, etc.). The building elements of the "original" wooden building (outer walls, inner walls, ceilings, roofs) have been replaced with mineral building materials with the same energetic and technical functions.

The data basis was extended by the above-mentioned buildings with the addition of a basement. The following table 1 shows the constructions and the area values of the buildings.
### Table 1: Analysed Buildings and construction

| Code | Construction | GEA [m²] | NEA [m²] | Basement | Fundament | Exterior wall | Interior wall | Ceiling | Roof | Balcony |
|------|--------------|----------|----------|----------|-----------|--------------|--------------|---------|------|---------|
| 2-A-55 | Sand-lime brick, reduced building services | 560 | 457 | | | Sand-lime brick | Lime sandstone, plasterboard | Reinforced concrete | Wood, mineral wool insulation | Steel, wood |
| 2-A-55-K | | 744 | 597 | x | | External thermal insulation composite system | | | | |
| 2-B-55 | Wooden frame, reduced building services | 560 | 457 | | | Wooden frame, cellulose, Wooden formwork | wooden frame, plasterboard | Cross laminated timber, concrete | Wood, cellulose insulation | Steel, board stack wood |
| 2-B-55-K | | 744 | 597 | x | | | | | | |
| 2-A-40 | Sand-lime brick, reduced building services | 572 | 464 | | | Sand-lime brick | Lime sandstone, plasterboard | Reinforced concrete | Wood, mineral wool insulation | Steel, wood |
| 2-A-40-K | | 756 | 605 | x | | External thermal insulation composite system | | | | |
| 2-B-40 | Solid wood construction (10 cm), reduced building services | 572 | 464 | | | Solid wood, cellulose, Wooden formwork | wooden frame, plasterboard | Cross laminated timber, concrete | Wood, cellulose insulation | Steel, board stack wood |
| 2-B-40-K | | 756 | 605 | x | | | | | | |
2.6 Modelling operating values
The operational energy use (module B6) is calculated according to the specifications of the GEG. The energy demand, together with the selected heating system and energy source, forms the basis for the balancing of greenhouse gas emissions for module B6.1 "Operational energy use". The values for final energy demand are used in the life cycle assessment calculations.

2.7 System boundaries
- Considered module
The LCA calculations were performed in accordance with the EN 15978:2012 [5, 6] and EN 15804:2020 [3] standards using the "cradle to gate with options" principle, see Figure 1, Chapter 1.1. The figure presents the module information for the different phases of the building assessment. The framed modules you can see in figure 1 are part of the LCA.

The calculation method and considered modules are based on the German assessment system for sustainable Building (BNB) [12]. According to BNB, the life cycle is set to 50.
Within the system boundaries there are the modules A1-A3 (product stage), module B2 (maintenance), module B4 (replacement) and the modules C3-C4 (waste processing and disposal). Module D (benefits and loads beyond the system boundary) is listed as supplemental information beyond the building life cycle, but is shown separately as required by the standard. Module D is not considered in this study.

- Considered product system
The four buildings, which differ in the type of construction (see chapter 2.3) and energy efficiency class (see chapter 2.4) are described in chapter 2.5 and listed in table 1 were each calculated with and without a basement. For the variants without basement, the foundations were nevertheless taken into account in order to be able to realistically represent the influence of the basement on the building components really required in addition to the basement. Exterior installations on the building site and furniture are not taken into account. This means that the building construction and technical equipment are within the system boundary. Table 1 gives an overview of the balanced building types.

- Database oekobau.dat
The life cycle inventory analysis is based on the German open-source database oekobau.dat 2020-II [13]. The oekobau.dat 2020-II complies with the new standard EN 15804 and predominantly fulfils the requirements on LCA performance.

- Modeling Software LEGEP
LCA calculations were done with the LCA-tool LEGEP. The tool is standards compliant and linked to the valid oekobau.dat version.

2.8 Environmental indicators
The goal of achieving a net zero greenhouse gas (GHG) emissions building stock in Germany by 2045 has consequences for the design of new construction and refurbishment measures. The traditional requirements for limiting the demand of primary energy, non-renewable (PENRT) in the use phase must be expanded, on the one hand, in the direction of including the entire life cycle (embodied emissions) and, on the other hand, supplemented by requirements for limiting greenhouse gas emissions. The PENRT input in the life cycle represents the use of primary raw materials (in this case energy sources), the global warming potential (GWP) shows the impact on the global environment and climate protection. PENRT and GWP become the target-, calculation-, and verification-variables.

In this paper the LCA results of the buildings are presented for the indicator GWP per functional unit of one m² GEA and NEA. The findings from the GWP are used as a proxy for findings that would have resulted from other environmental indicators such as the PENRT. Furthermore, the indicator
GWP is divided into modules A, B2-4, C and B6. The definition and contents of the modules are presented in Chapter 1.1.

3 Results

3.1 Global Warming Potential (GWP)

In the following figures 2 and 3, the results for the indicator GWP in kg CO2-eq./GEAm²a and kg CO2-eq./NEAm²a are presented in modules A, B2-4, C and B6 for the buildings listed in Table 1. The results are interpreted in sections 3.2, 3.3 and 3.4.

![Figure 2](image2.png)

**Figure 2**: Result GWP [kg CO2-eq./GEAm²a], variant A (conventional construction) and variant B (timber construction)

![Figure 3](image3.png)

**Figure 3**: Result GWP [kg CO2-eq./NEAm²a], variant A (conventional construction) and variant B (timber construction)

3.2 Comparison of results future-oriented/conventional

Comparing the functionally equivalent buildings in Figure 2 and 3 with each other, it is noticeable that the GWP in modules A1-A3 over 50 years is greatest for the conventional construction method. In the timber construction method, the GWP in module A is very low or even negative. This is due to the biogenic carbon stored in wooden building products.
This advantage is fully compensated at the end of the life cycle by higher values in module C (approach "-1 / +1"). Nevertheless, GWP emissions are lower for all timber buildings when considered over the entire life cycle. This is due to the use of less energy intensive building material in timber buildings.

The emissions from module B6 are the same for both building variants conventional and timber as both use the same technical equipment for heating and achieve the same energetic standard. The differences result only from the changed material choice and construction. This finding can be shown in the results related to GEA as well as to NEA.

3.3 Comparison of results GEA/NEA

Both non-basement conventional and timber buildings generally perform better in all modules with respect to GEA. This result is logical since the overall result is divided by a larger reference area. However, it is generally the case that for buildings without basements, the relationship between GEA and NEA is consistent with the GWP values determined on this reference area.

For buildings with basements there is a significant difference between the GWP values determined on the reference area GEA and NEA. This is due to the mostly very low NEA in the basement which is divided by the total building mass according to DIN277. This results in a deterioration of the overall assessment of the building in relation to NEA for buildings without basements. However, this overall evaluation depends on the sizes of modules A-C and B6 and the associated reference areas, which often differ.

It would make sense to consider the building mass (embodied emissions, module A-C) and the operation (module B6) separately for buildings with basements. Operational use generally occurs in NEA areas. Thus, the results of B6 related to NEA are realistic, related to GEA they would be calculated too positively.

For the building mass, module A-C, it is the other way around. This mass includes the whole building. Thus, the consideration of these modules on NEA would be too negatively evaluated, on GEA it is realistic.

3.4 Comparison with/without basement

When comparing the emissions of a building without and with a basement, the reference area, in this case GEA and NEA, must also be considered, as the results depend on this.

In the overall consideration of building and operation, the LCA results are often divided equally by the larger area, the GEA. When comparing buildings over the entire life cycle of the same type with and without basements, it can be seen that the buildings with basements perform better in the GEA calculation, i.e. they have a lower GWP. This can be explained by the fact that taking the basement into account leads to an increase in the reference value. If the basement is not heated, as it usually is in the case of residential buildings, the energy demand remains the same even if a basement is added. If it is nevertheless related to the GEA, this value will improve. Due to the high proportion of energetic operation (operational emissions, module B6), this has an enormous impact on the overall result. Buildings with basements benefit in this case in contrast to buildings without basements and target values can be reached more easily.

Comparing the overall results in relation to the entire life cycle and the NEA of the buildings without basements with the buildings with basements, it can be seen that the buildings with basements perform worse, i.e. with a higher GWP value. This can be explained by the fact that the entire building parts of the basement are included, but only divided by the area NEA, which often includes only a small part of the area in the basement. For modules A-C, this results in worse values because the NEA area is not relative to the building mass. Thus, the overall calculation of a building with a basement, relative to the NEA, has a negative effect.
Overall, it can be stated that the results for buildings without basements are relative and realistic with respect to both reference areas. The overall evaluation of buildings with basements is shown improved in relation to the GEA, and shown worse in relation to the NEA. This is generally independent of the construction method.

In addition, the difference between conventional and wooden buildings and the differences in module A should be pointed out. For the conventional buildings in relation to the GEA, the module A remains relatively the same from without basement to with basement. This is due to the fact that the material previously found in the upper floors, mostly mineral building materials, is increased by the basement in relation to the larger GFA.

In the case of the wooden buildings, on the other hand, it is striking that module A in this comparison deteriorates relatively strongly in the building with a basement, in relation to the gross floor area. This is due to the high addition of mineral mass of reinforced concrete in the basement. This material has very poor GWP values and thus makes the building perform much worse. This example illustrates the large negative influence of basement floors.

4 Conclusion
Taking the basement into account usually leads to an increase in the reference value by adding the basement area to the GEA. On the one hand, the material masses used and the embodied emissions increase, and on the other hand, the characteristic values decrease due to the increased reference area by which the values are divided. The overall characteristic value-related result is reduced. If the basement is not heated, the energy demand remains the same. However, in the overall evaluation of building and operation, the LCA results are divided by the larger area GEA. This significantly reduces the operating portion. Buildings with basements have advantages over buildings without basements because they can easily reach their targets.

Regarding the structure of the building, it can be seen that the characteristic values of the building with basement and the building without basement are slightly different in the conventional mineral building. For buildings made mainly in timber construction, the characteristic values deteriorate more significantly, since the basement in reinforced concrete construction means a relatively higher load. The reason for this is that these buildings are usually much lighter [14], so adding a basement in reinforced concrete construction. Alternatively, since the basement must be made of concrete, the results are inevitably much worse if a basement is built.

These differences are reflected in all the comparisons presented here between the building without a basement and the building with a basement, for both timber and conventional construction.

5 Outlook
The results of the study show that no overall assessment for the life cycle of residential buildings can be made using the GEA or NEA reference value. For the correct evaluation for embodied emissions, the calculation of the building emission (module A-C) has to be in relation to GEA, emissions generated by the operation (module B6) must take place in relation to the NEA.

Nor can a blanket value, for example a percentage of GEA, be assumed for determining operational emissions. There are many reasons for this:

In some cases, single-family houses have basements, but do not contain any living space. On the other hand, especially in the area of single-family houses, there are developed basements with heated functional areas. A small apartment building often has a basement that is used as a storage room, mechanical room, or washing and drying room. Large apartment buildings have basements, but only half of them are used for storage and social rooms, the other half is often used as underground parking. The accommodation of stationary traffic is a mobility issue that has nothing to do with the building and its residential use.

In order to be able to implement the aspirations of the climate-neutral building stock by 2045, an agreement on all issues concerning the basement must be formulated in the short term.
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