Environmental quality of buildings

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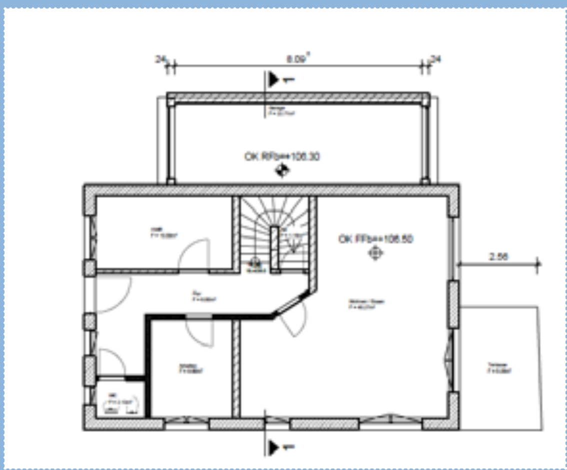
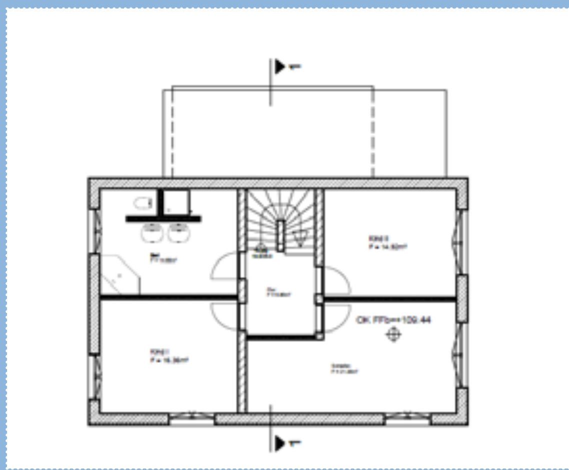
The climate policy targets meanwhile set by the EU and many member states to reduce or at least contain global warming have a direct impact on the future assessment of buildings and construction methods. While in the past decades the focus was mainly on measures that reduce the heating energy and final energy demand of buildings, in the coming years greater attention will be paid to a building's CO_2 footprint over its life cycle. Since this footprint is an extremely complex issue that is influenced by many factors, its assessment is always the result of precise or in fact less precise input data. In addition, there are political influences that use striking, but per se incomplete results to influence a development which is or is assumed to be in line with a self-imposed political credo.

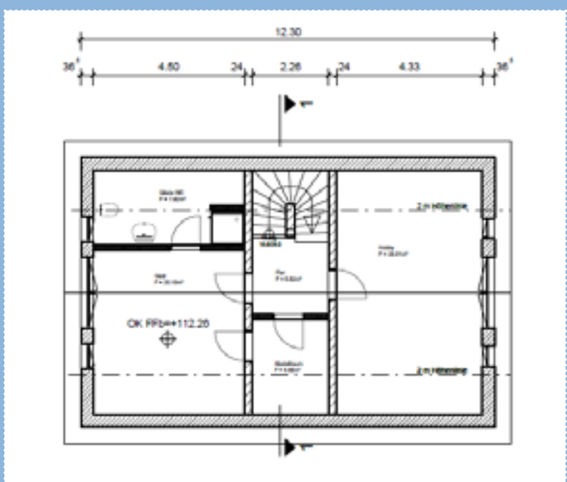
Fig. 1: Floor plans of the building and view of the construction site



First floor



Second floor



Attic

View of the construction site

It is often claimed that switching from the construction method using mineral building materials predominating in Europe to a timber construction method can make a key contribution to successfully completing the path to a decarbonized society. This assumption is based on the simple thought that one cubic meter of wood can store about one ton of CO_2 during its growth. That is all you need to know. Given that the widely used mineral building materials, e.g. concrete, bricks and autoclaved aerated concrete, are made of raw materials that have a very high CO_2 impact, it is suggested that these building materials can no longer meet the future requirements. The associated debate of how to reconcile the use of wood, reforestation and the future demand for conifers that procure most of the construction timber with the protection of forests is, of course, another side of this challenge.

In a study [1] by the German Association for Masonry Construction (Deutsche Gesellschaft für Mauerwerksbau - DGfM) in cooperation with LCEE Darmstadt, many of the supposedly clear climate-relevant advantages of timber construction have already been reduced to absurdity in the context of a life cycle assessment (LCA). As the study was conceived as a kind of cross-sectional approach for all main types of masonry used in Germany, the concrete performance of individual masonry types cannot be directly derived from it. Together with LCEE Darmstadt, Xella Technologie- und Forschungsgesellschaft mbH therefore repeated this assessment for a typical single-family home made of autoclaved aerated concrete and compared it with an imaginary identical timber building taking current changes in energy-saving legislation in Germany (Gebäudeenergiegesetz (Buildings Energy Act) - GEG) into account and using the new Ökobaudat_2021 database.

The building

The building selected was a single-family home already under construction with two full stories and an attic, see Fig. 1. A building without a basement was selected based on the consideration that a basement cannot be constructed of timber and that there may consequently be difficulties to analyze individual influencing variables in the presentation of the results for a comparison of the two construction methods. In contrast to earlier studies, no reinforced concrete ceiling structure has been included for the timber building.

The building components can be found in Table 1.

Table 1: Building structures (only components and building materials relevant for the assessment)

Component	AAC building	Timber building
Exterior walls	36.5 cm AAC PP2, = 0.08 W/(mK); interior plaster: gypsum plaster, exterior render: lightweight render **U = 0.21 W/(m²K)**	Gypsum boards, OSB boards, timber/ mineral wool 160 mm, wood fiber insulation 40 mm, lightweight render **U = 0.21 W/(m²K)**
Foundation slab	Cement screed, EPS 60 mm, concrete 300 mm, XPS 120 mm **U = 0.18 W/(m²K)**	Cement screed, EPS 60 mm, concrete 300 mm, XPS 120 mm **U = 0.18 W/(m²K)**
Roof	Solid roof: lime-cement plaster, AAC roof panel 200 mm, mineral wool/rafters 180 mm **U = 0.19 W/(m²K)**	Wooden roof: gypsum plaster boards, mineral wool/rafters 220 mm **U = 0.19 W/(m²K)**
Ceilings	Reinforced concrete ceiling 200 mm, floating screed	Solid wood beams, without ceiling weights, with dry screed, single planked
Interior walls	115 and 240 mm AAC, bulk density class 550 kg/m³, load-bearing and non-load-bearing	Interior wall, single planked, room enclosing, load-bearing and non-load-bearing
Windows	U_w = 0.8 W/(m²K) g = 0.5 Sun protection roller shutters	U_w = 0.8 W/(m²K) g = 0.5 Sun protection roller shutters

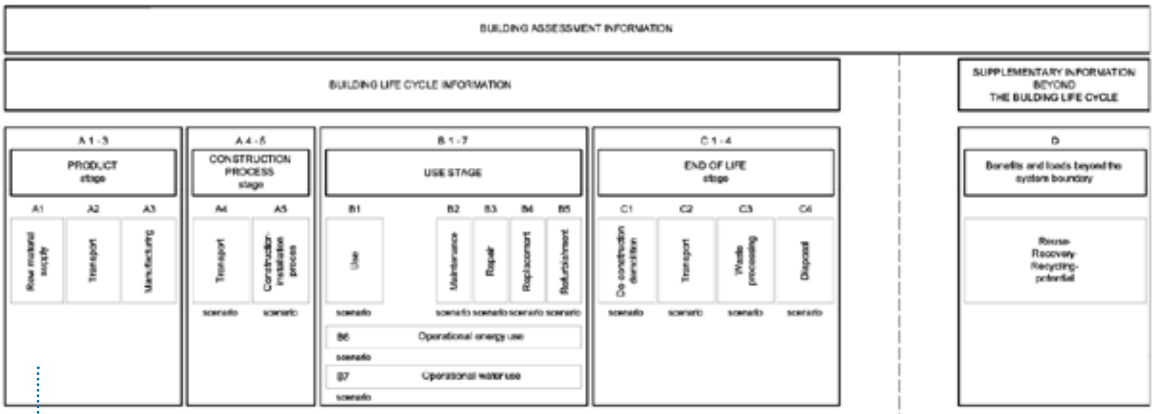


Fig. 2: Modular information required for the different life cycle stages acc. EN 15978

With the selected configuration, both buildings meet the requirements of the German Buildings Energy Act of 2020. For space and water heating, a condensing boiler with solar thermal support for domestic water heating and solar storage tank was used as state-of-the-art technology. The useful energy demand for space and water heating was calculated with both the Helena program and simulation calculation in the TRNSYS 18 program using the boundary conditions of use defined in [2]. Only the reference location Potsdam was included as a climatic boundary condition. Proof of the summer thermal protection was provided for a room on the first floor with north-east-south orientation and for a room in the attic with west orientation using the simulation boundary conditions defined in [3].

The assessment

General information

The building was assessed on the basis of EN 15978:2011. Fig. 2 shows the modular information required for an assessment of the different life cycle stages.

The already mentioned complexity of a life cycle assessment requires as uniform an understanding as possible about the data basis for the assessment steps. Moreover, assumptions about the level of detail required for individual steps of the assessment have to be made. Helpful are, for example, the criteria included in [4], which, however, do not represent normative specifications and sometimes there are also differentiated national specifications. Since the assessment was made for a building in Germany, the specifications from the catalog of the German Sustainable Building Council (Deutsche Gesellschaft für nachhaltiges Bauen - DGNB) have largely been implemented.

In this article, only the results of the assessment of the global warming potential (GWP) are presented in the form of the calculated tons of CO_2 in the individual modules and the total result for the building. All other variables relevant for the assessment such as ODP, POCP, AP or PE have, however, also been calculated for the building and are available as an assessment basis.

Building materials data

Every calculation model, no matter how good it is, stands and falls with the quality of the input data. This also applies to life cycle assessments. It is therefore essential to create a high level of transparency for the data used. For Type III, EN ISO 14025:2011 regulates how environmental declarations must be structured, while EN 15804:2020 specifies the product category rules (PCRs) that are important for the assessment. There are also separate standards with additional PCRs for some products, e.g. EN 16767 for concrete and concrete elements. Environment product declarations (EPDs) can be downloaded from the website of the Institute for Construction and Environment (Institut für Bauen und Umwelt e.V., www.ibu-epd.com).

For those making the assessment, it would be very time-consuming to collect and, if necessary, evaluate the data of the individual building materials. They must therefore be able to rely on valid data in independent databases. Such a database is, for example, Ökobaudat_2021-1 from the ÖKOBAUDAT platform, which is made available by the Federal Ministry of the Interior, Building and Community (Bundesministerium des Innern, für Bau und Heimat - BMI) for the life cycle assessment of buildings. This database includes the ecological impact of both building materials and construction and transport processes of the so-called data categories A and B, i.e. EPDs verified and/or certified according to the PCRs of EN 15804 in accordance with EN ISO 14025.

The ecological data for the analyses presented in this article have been taken exclusively from Ökobaudat_2021-1.

The stages or modules of an entire life cycle shown in Fig. 3 are also found in EN 15804. After the revision of this standard, it will no longer be possible to make life cycle assessments only for module A (product stage), as was predominantly the case in the past. Fig. 3 contains the mandatory modules required for life cycle assessments depending on the selected declaration. In the macrosocial context of environmental building assessments, it would be desirable that modules A to D, or at least A to C, could be used for the calculations to ensure reasonable comparability. Currently, not all materials are included in the database with all modules. As a result, the stages A4 to A5 (transport and construction – installation process) could not be included in this study.

The product stage of the building

In the product stage according to EN 15978, i.e. modules A1 to A3, a life cycle assessment of the building materials of a building is made (Fig. 4 and 5). The difference in the information in the EPD according to EN 15804 and EN 15978 is that reference values change.

While, for example, the CO_2 equivalents according to EN 15804 refer to volume and weight units, the GWP in the life cycle assessment of buildings is converted to the usable areas and volumes and assessed for a so-called reference useful life. Publications such as [5] permit a direct comparison of the life cycle assessments of individual structures of a building.

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After holding positions in project development and construction engineering at Ytong AG, in 2006 he as appointed CEO of the Xella Technologie- und Forschungsgesellschaft mbH in Kloster Lehnin. He is also involved in various national and European standardization committees, e.g. heat transfer, energy performance of buildings and structural thermal insulation in high-rise buildings, to name a few.
He is chairman of the Verband Bauen in Weiß, a manufacturer's association which provides architects and civil engineers with information about white building materials (AAC and calcium silicate blocks). He is Board member of the European AAC Association (EAACA) and chairman of the EAACA Technical Committee, chairman of the engineering and standardization committee of the German Association of Mineral Building Materials and he is a board member of the German committee for Masonry (DAfM). In 2017, he joined the board of the German Institute for Standardization (DIN) and since 2019 he is Curator of the Fraunhofer Institute for Building Physics.
Torsten Schoch is the author of various specialist articles and books about masonry construction and building physics. In addition, he has produced several guides to the German Energy Saving Ordinance (EnEV) for old buildings, residential and non-residential buildings published by Beuth Verlag. He has also written a practical guide to masonry construction.

For the building to be assessed with a useful life of 50 years, the following results are obtained for module A. A useful life of 50 years was selected because it is regarded as an accepted basis of comparison between the construction methods analyzed here and because it dispels arguments that consider the longer useful life consistently expected for solid buildings an artificially induced assessment intervention. The effects of different useful lives can among others be found in [1].

Fig. 3: Types of environment product declarations (EPDs) by included life cycle stages acc. EN 15804

	CONSTRUCTION WORKS ASSESMENT INFORMATION																	
	CONSTRUCTION WORKS LIFE CYCLE INFORMATION																	SUPPLEMENTARY INFORMATION BEYOND CONSTRUCTION WORKS LIFE CYCLE
	A1 - A3 PRODUCT STAGE			A4 - A5 CONSTRUCTION PROCESS STAGE		B1 - B7 USE STAGE							C1 - C4 END OF LIFE STAGE				D BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
	Raw material supply	Transport	Manufacturing	Transport	Construction - Installation process	Use	Maintenance	Repair	Replacement[1]	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse, recovery, recycling, potential
				scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario
Cradle to gate with modules C1-C4 and module D	Mand.	Mand.	Mand.										Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to gate with options,modules C1-C4 and module D	Mand.	Mand.	Mand.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to grave and module D	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to gate[2]	Mand.	Mand.	Mand.														
Cradle to gate with options[3]	Mand.	Mand.	Mand.	Opt.	Opt.												

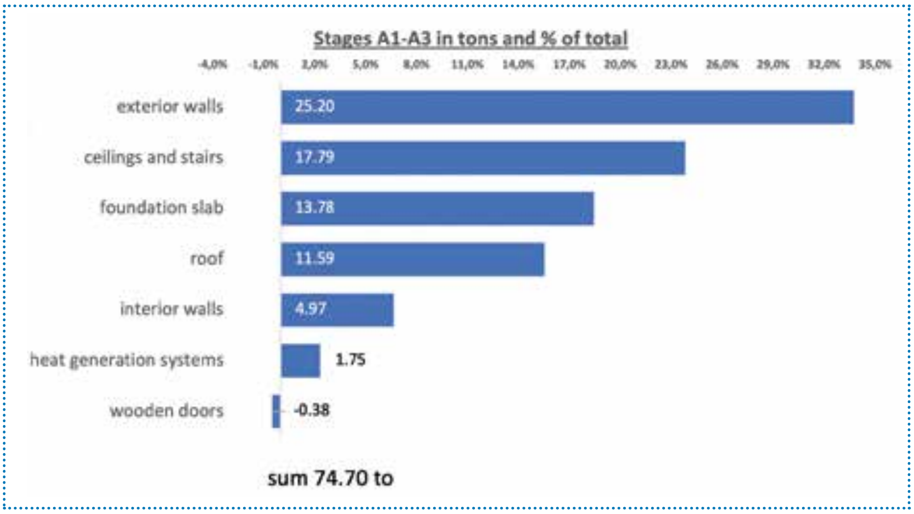

Fig. 4:
Results of modules A1 to A3 for AAC in tons and percentages

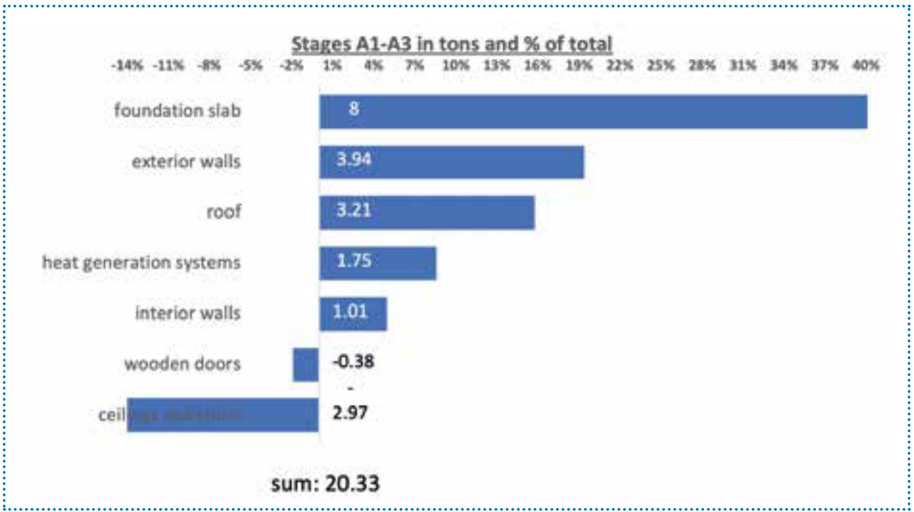

Fig. 5:
Results of modules A1 to A3 for timber in tons and percentages

Due to the expected differences in the initial CO_2 "burden" between the timber and autoclaved aerated concrete structures, the advantages of an eco-based building material mentioned above seem to be confirmed. A burden of approx. 50 tons more to the disadvantage of the AAC building could lead to the conclusion that this already clearly shows the ecological superiority of the timber construction method. However, it already becomes apparent here that even in modules A1 to A3 the timber construction method does not have a negative sum total. This is among other things due to the fact that timber construction in Germany is predominantly timber frame construction with numerous components and only 10 %-15 % wood content and that this construction method also reaches its usability limits when it comes to components such as foundation slabs. It must nevertheless be admitted that, if the assessment were to end here, the AAC construction method would have an extremely unfavorable basis of comparison.

The use stage of the building

In the use stage of the building, there are already first signs that the advantages from the product stage are diminishing, as shown in Fig. 6 and 7.

Modules B1 to B5 mainly represent the effort required to maintain the technical quality of the building and its technical equipment. In total tons and percentages, timber frame walls with insulation and cladding are less favorable in GWP terms. The reason for this is not the shorter life of the structure, but rather the more frequent painting of the surfaces and the expected life of the individual components. Compared to still approx. 21 tons per exterior timber wall in the product stage, 7.6 tons more are accounted for by the exterior timber walls alone in stages B1 to B5. Module B6, which describes the building's energy consumption in operation, leads to the results as shown in Fig. 8.

The difference of a further five tons over a useful life of 50 years in favor of autoclaved aerated concrete increases the total advantage in tons of this construction method in the use module to 12.6 tons, which does not yet fully compensate for the gap from product stage A, but already reduces it considerably. The question is why there is any difference at all given that the U-values of the two buildings are the same and whether this difference, which will no longer be important in a future decarbonized world anyway, is relevant at all. In addition to low conductivity, the difference is due to the greater thermal

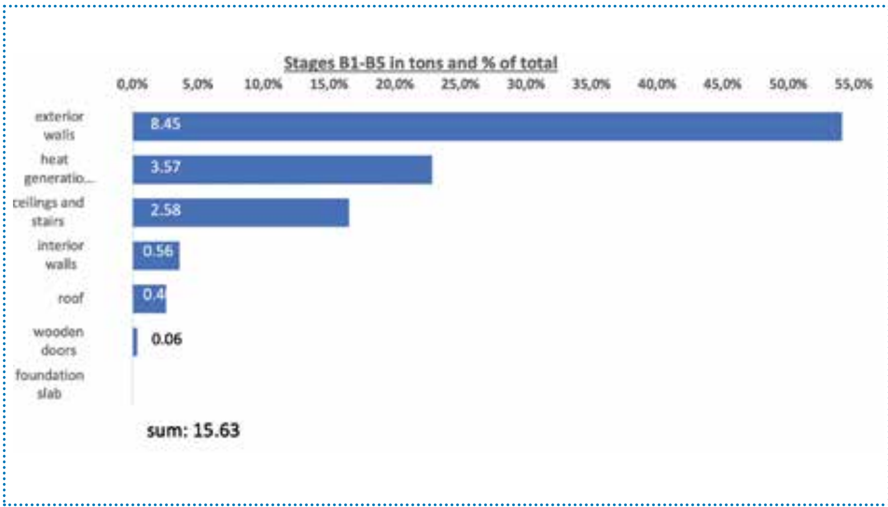

Fig. 6:
Results of modules B1 to B5 for AAC in tons and percentages

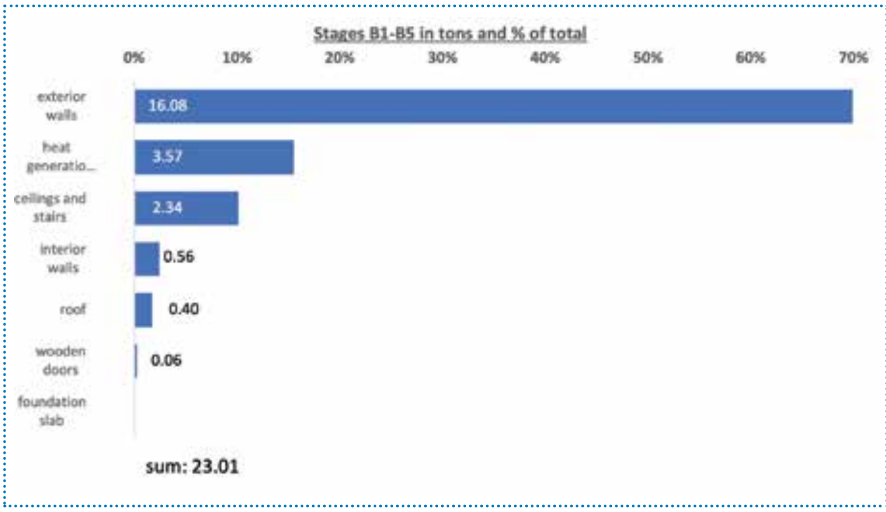

Fig. 7:
Results of modules B1 to B5 for timber in tons and percentages

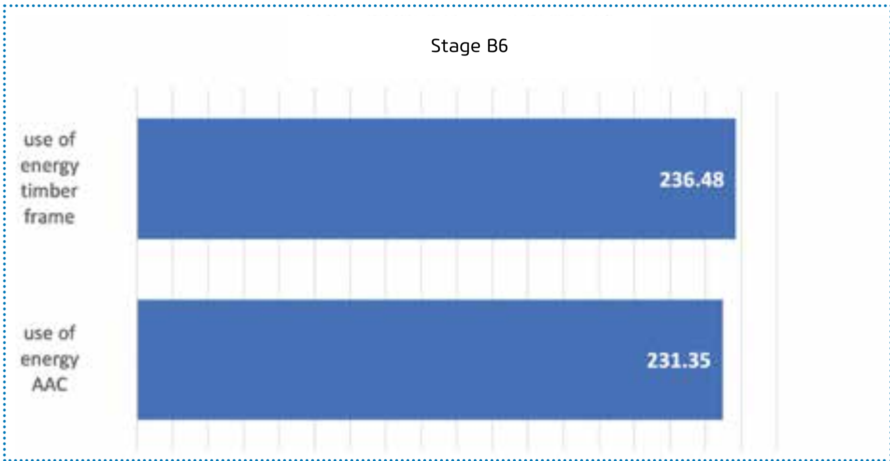

Fig. 8:
Results of modules B6 for AAC and timber

inertia of solid buildings compared to timber frame buildings. Depending on the climatic conditions and the accuracy of the calculation method, this advantage reduces the final energy demand in the order of 3 %-5 %.

One of the key questions is then, of course, which fuel with which CO_2 equivalent is used to cover the final energy demand. In this study, a confirmed and accepted set of values in a not yet decarbonized world has been used for all stages. Whether and in what form or speed the specifications for the change steps in CO_2 emissions represent a state of the art for the first time in practice cannot be answered with scientific precision. Moreover, even the use of heat pumps with the currently customary COPs for space and water heating would, for example, only really improve the result if as little electricity as possible were taken from today's electricity mix – which, as we know, is not easy, in particular when it comes to space heating.

The end of life stage

One of the main and frequently put forward arguments in favor of mineral construction is the almost complete reusability of the building material – its so-called second life or "from cradle to cradle". Today, the majority of mineral construction waste is recycled or reused – although not yet sufficiently in the circularity that is desirable and increasingly demanded politically – but to a much greater extent than in the past decades, which is a hopeful sign.

It can be assumed that the recycling of construction waste, if it takes place, can significantly improve the CO_2 footprint, even if some effort has to be put into processing and transporting these secondary raw materials. For the compared buildings, the differences based on the current ecological data are as shown in Fig. 9 and 10.

The results of the calculations for the end of life stage show a much better footprint for the solid construction method compared to the timber frame construction method based on the available EPDs. The reason for this is the still predominant thermal utilization of wood components, i.e. their burning after use. While the involved business sectors' interest in a secondary use is increasing, this is not yet reflected in measurable LCA results. The end of life stage of buildings made of wood tends to be excluded with reference to their ecological superiority and in particular politically because the timber construction method can lead to a short-term improvement of the CO_2 construction result of new buildings (see product stage). But this approach negates the obvious postponement of the problem to another generation, which will then have to think about how to deal with these CO_2 emissions in a then already decarbonized world.

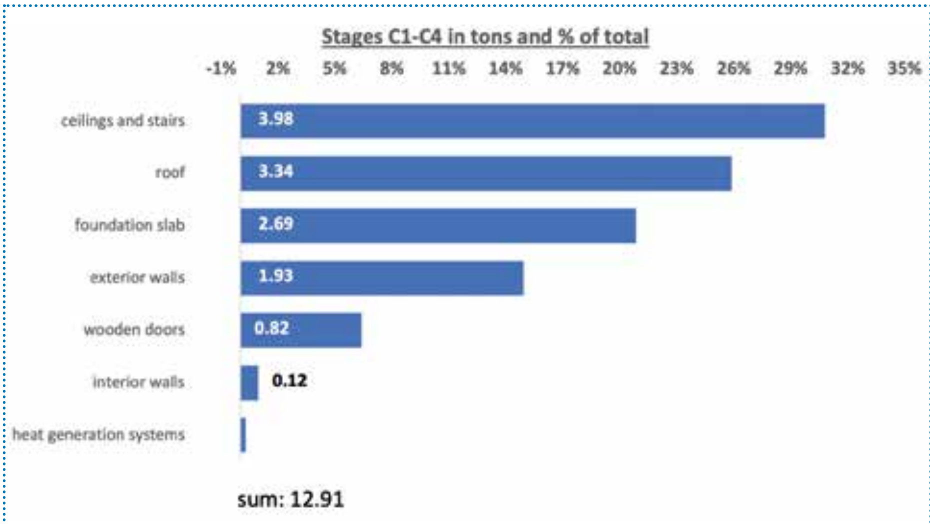

Fig. 9: Results of modules C1 to C4 for AAC in tons and percentages

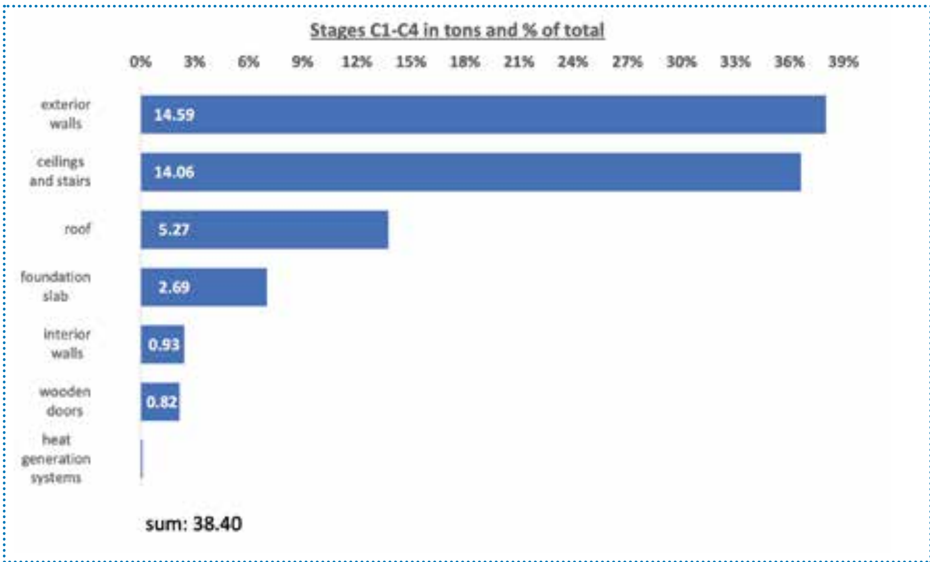

Fig. 10: Results of modules C1 to C4 for timber in tons and percentages

Additional information outside of the building cycle

EN 15978 includes the option to consider an additional module D outside of modules A to C, which may not benefit the life cycle of the building, but directly or indirectly other life cycle assessments. The burning of wood or foils or the recycling for other materials is, for example, seen as a potential that can be included in the assessment.

With respect to the two building types, this would result in the following potentials. In this module, the advantages for timber construction mainly result from the replacement potential of burning wood instead of oil or gas. From a logical point of view this figure would also have to be questioned in a decarbonized environment.

Overall result

The overall result for the two buildings in tons over a useful life of 50 years is as follows.

Based on a life cycle assessment, both construction methods can be considered to be equivalent in terms of their potential to contribute to global warming. The slight difference of 16 tons over 50 years can be considered minor and within the expected limit of construction methods of the same quality with respect to their GWP if one takes a realistic look at the current representativeness of the ecological data available for the building materials. In any case, the data do not permit to derive any preference, however phrased, for the replacement of any of the two construction methods based on a life cycle assessment. Both construction methods analyzed offer ample room for improvement.

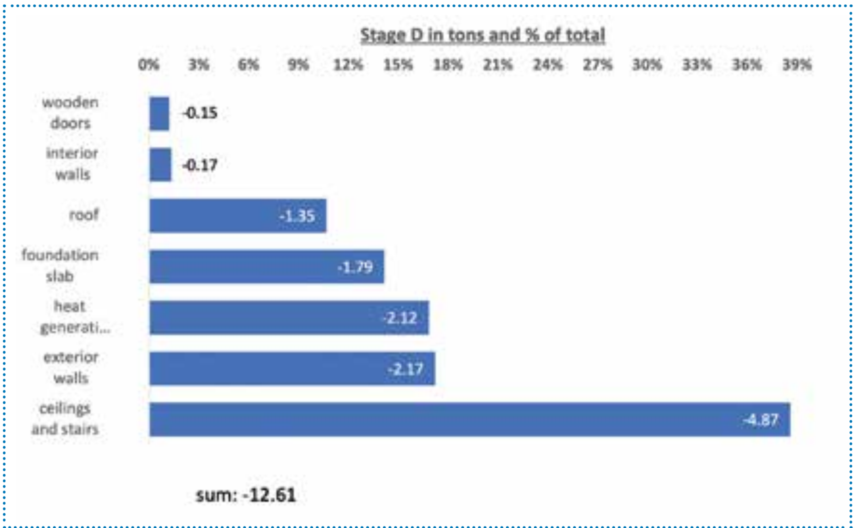

Fig. 11: Results of module D for AAC in tons and percentages

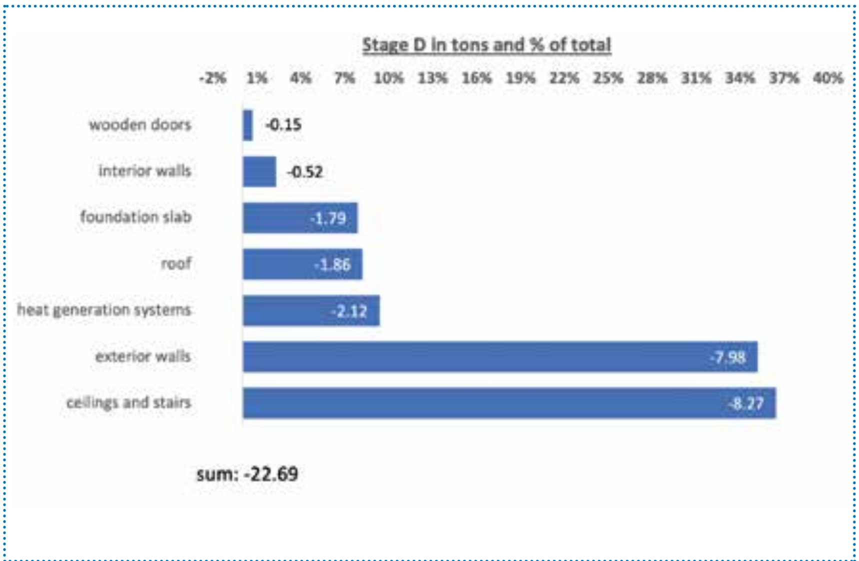

Fig. 12: Results of module D for timber in tons and percentages

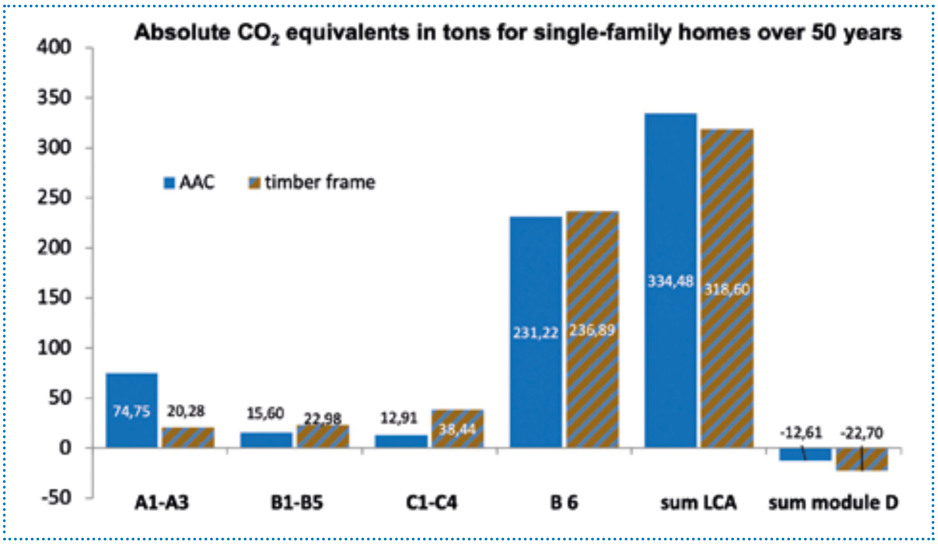

Fig. 13: Comparison of the overall result of the two construction methods

For autoclaved aerated concrete, it is certainly the reduction of the GWP in module A, while timber construction has some homework to do in module C, in particular.

However, a good life cycle assessment in the sense of a low global warming potential is not in itself proof of sustainable construction. Many other factors play a role here, especially technical and economic processes as well as important socio-cultural and functional qualities of the buildings. Even if, for example, the fire resistance of today's timber structures of 30 to 60 min is considered sufficient in the building codes for many types of buildings, the 90 to 180 min of a solid house may be decisive in the not desirable, but still sometimes occurring event of a fire. Other factors such as summer thermal protection and noise protection often make the difference between a sustainable and less sustainable building in the eyes of the user.

Literature

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