Comparative evaluation of the ecological properties of timber construction components of the dataholz.eu platform

S. Ott & S. Ebert
Chair of Timber Structures and Building Construction
Technical University Munich, Germany

ABSTRACT: The comparison between different materials are quiet popular amongst construction products suppliers to promote the own product, if it succeeds in performance assessment against concurrent materials. Beyond this pure marketing related material comparison, in planning processes decision makers search trustful, transparent and independent assets of the ecologic impact of construction components. As surplus, they also request a bunch of facts to know about the components performance, from structural load-bearing to heat and sound protection. The dataholz.eu web-platform supplies a multitude of such data for timber components either timber-framed as well as for mass timber. Based on a coherent calculation method according to EN standards LCA-results for components are calculated, followed by an in-depth comparative analysis between variations of the same component composition. Overall results from traditional, frequent used indicators like Global Warming Potential are presented and discussed in the light of various compositions of the floor-slab components. As components are the basis for entire building-LCA we use our results from component level and try to relate it to full building LCA. In practice full building LCA are made ex post what makes them useless for decision making because building owners need information earlier on a reliable basis and not only on expert guess.

1 INTRODUCTION

1.1 *Background*

Comparison between different materials are quiet popular amongst construction products suppliers to promote the own product, if it succeeds in performance assessment against concurrent materials. Beyond this pure marketing related material comparison, in planning processes decision makers are looking for trustful, transparent and independent facts about the components performance, from structural load-bearing to heat, moisture, fire and sound protection. As surplus, from a responsibility point of view, building owners nowadays already tend to request also a bunch of information of the ecologic impact of construction components although this asset is not mandatory from a legal point of view. Now, there are only the requirements that the ecological quality of products in a building must be proven within sustainability certification systems. In addition, the European Construction Products Regulation (CPR) requires manufacturers to provide information on the protection of the environment and resources, defined there as safety goals (EU 2011). This is ensured by the creation of environmental product declarations in a standardized and comparable quality of data collection and calculation. The intention of the EPDs is to support the management of the environmental performance. In consequence a comprehensive dataset on products and components needs i) transparent assessment method, ii) strict data consistence, and iii) broad range of best-practice constructions to derive iv) key figures and empirical standard deviation of all datasets and categorized groups of them. This paper presents an overview on the ecologic properties of a large amount of timber-based components for floor and for comparison reason of selected exterior wall constructions, which are widely used in the DACH region (Germany, Austria, Switzerland). The evaluated component data is not only characterized by ecological comparability. Rather, the collected examples also contain verified information on quality-related performance data e.g. sound protection or fire safety and so on. The inspection of the components by independent institutions gives the building owner the guarantee that the data and also the construction itself is trust-worthy and that it can also be used by construction companies in a practical way in the current legal context. This desire or this request is currently relatively difficult to implement for components in timber construction, since these are constructed by composition of several functional layers. In contrast, masonry or concrete constructions are usually monolithic and sometimes two-layered. The ecological characteristics of these structures are quickly determined and key figures for the most important environmental indicators are easy to estimate. This is much more difficult for timber construction components, so this data collection makes a significant contribution to better assessing the effects of typical design or variants thereof.

2 BACKGROUND CONTENT AND CALCULATION METHOD

2.1 *Methodical Basics*

Ecological properties are measured using the LCA method, which is regulated for all different types of products and services in the international standard CEN 2009, CEN 2006. This ensures that the calculation results are collected transparently and, above all, calculated comparably. Ecological studies and assessments can vary in many different assumptions, indicators and methods according to the intended goal and scope. Therefore, the result of a study can consider and present different indicators, as well as present different results for identical indicators (Albrecht et al. , Kuittinen et al. 2013, Sölkner et al.). EN ISO 14040 series standards define the structure to perform a life cycle assessment and divide the process in the following framework:

1. Goal and Scope Definition
2. Life Cycle Inventory Analysis
3. Life Cycle Impact Assessment
4. Interpretation

The goal and scope phase of a LCA-calculation defines important decisions on how to proceed with the functional unit, impact categories, dataset quality and system borders (CEN 2009, CEN 2006). Here, besides above-mentioned goals, empirical and robust figures are sought as input for design level whole building LCA estimates. The achievement of the goal and scope definition in consideration of the interpretation can only be met with various iteration processes, which reveal the interdependencies and relations (ILCD 2010). The life cycle inventory is based on quantity take-off and linkage of the pre-configured impact datasets of compositions specific materials. In a regular LCA calculation for buildings and building components, based on (CEN 2013, CEN 2011), the life cycle of a building is divided in three modules A, B and C:

A: Product and Construction stage
B: Use stage
C: End of Life stage

In addition, all potential benefits and burdens outside the product systems life can be accumulated in the Module D, which is defined as beyond a products or buildings system border. The standards subdivide impact categories and category indicators deliberately in different input and output categories:

- Use of Resources
- Environmental Impacts

Within the latest developments, indicators were distinguished especially for primary energy in addition to renewable / non-renewable, between energy use and material use of primary energy and equivalent is planned for the carbon content and the greenhouse gas emissions, today still unified in the Global Warming Potential (GWP) indicator.
The development of appropriate decisions regarding the method and assessment of timber construction components is based on a LCA study in the context of an online database for timber structure. The following sections gives all relevant details regarding background, goal, scope, impact categories and results of the study.

2.2 *Dataholz.eu Platform Database*

The *dataholz.eu* database is an online-catalogue for building materials, components and details particularly for wood, engineered wood products and timber structures. The platform already existed for 14 years and received a major update in December 2017 (HFA Austria, 2018) with additional timber construction components for the German market as part of a cooperative project between the *Technical University of Munich* and *Holzforschung Austria* (HFA, Austrian Forest Products Research Society) funded by the *Deutsche Bundesstiftung Umwelt* (DBU, German Federal Environmental Foundation).

2.3 *Timber Construction Components*

Within in the scope of the dataholz.eu-platforms renewal over 350 new and additional timber construction components especially for an application in the German market were added cp. (HFA Austria 2018). The implementation included a life cycle assessment for all these components as well as an ideal solution for a clear and helpful presentation of their ecologic properties for all users of this catalogue. The calculated components include 59 floor slabs consisting of the categories massive timber components with 7 and timber frame components with 52 instances. The mass of the slabs can be categorized in compositions with (11) and without (48) an additional mass layer. The mass timber is assumed to be CrossLaminated Timber (CLT) panels. The insulation material that appears only in the timber frame slabs, varies between mineral wool (24 components), woodfiber (18 components) and cellulose (11 components). The thickness of the insulation is either 100 mm or 200 mm for very few cases. On top of the floor slab there is a screet layer with an impact sound-damping layer from variable insulation material. The covering on the lower side consists of one and often two layers gypsum boards, due to fire safety reasons. Visible wood surfaces result in lower fire resistance. An increase thickness of wood would have been needed to ensure structural safety by considering the charring rate of softwood 0.7 mm/min in conjunction with the required fire resistance class, this is not the case for the examined slabs. The timber beams or the mass timber panels are all assumed with a constant structural height. The exterior walls are divided between mass timber and timber framed structures. Furthermore they have additional assets like installation layers on the interior oriented side preferably for electrical wiring and partly for the routing of small ducts, pipes. These installation layers consist of a substructure, variable fill material and a covering that is mostly chosen as gypsum boards. Either the exterior oriented façade layers consists of ventilated claddings or render covered external thermal insulation compound systems (ETICS). Various materials for the ventilated facades are being studied so that the impact of a wider choice of materials can be shown. New timber buildings in urban areas often have alternative cladding materials ranging from glass, steel cassette, aluminum wave, or sometimes plastic, that is expected for urban multi-storey buildings. An exemplary floor slab construction component is shown in with following layers for a):

A - 50.0 mm cement screed
B - separation layer (PE membrane)
C - variable insulation material
D - gravel, loose (optional)
E - separation layer (paper)
F - cross laminated timber
G - 70.0 mm timber battens, steel damping bracket
H - variable insulation material
I - 12.5 mm gypsum fiberboard

for c):

A - 50.0 mm cement screed
B - separation layer (PE membrane)
C - variable insulation material
D - gravel, loose (optional)
E - separation layer (paper)
F - OSB
G - construction wood (80/*; e=*)
H - variable insulation material
I - 24.0 mm wood as gap planking
J - steel spring rail between gap planking
K - 12.5 mm gypsum fiberboard

2.4 *Goal and Scope Definition*

The calculation method is based on the ISO standards 14040 and 14044 and performed according to EN ISO 15804. The goal in the project is a purely accounting LCA, describing and documenting the ecological indicators for a variety of timber construction components without unification of different performance levels. On the contrary, the difference of fire safety, thermal comfort and mass or acoustic qualities is an essential part of the databases content. The goal of the comparison shown is not to compare functional identical components, but to deduce basic principles between different parameters of these components. Therefore, the functional unit is per definition as one square meter [m^2] of construction area of the component. The presented impact categories are conform to EN ISO 15804 standards. Environmental Impacts:

GWP [kgCO2e] global warming potential
AP [kgSO2e] acidification potential
EP [kgPO4e] eutrophication potential
ODP [kgR11e] ozone depletion potential
POCP [kgEthen-e] photochemical ozone creation potential

Use of Resources:

PENRE [MJ] non-renewable primary (PE) energy for energy use
PENRM [MJ] non-renewable primary (PE) energy for material use
PERE [MJ] renewable PE for energy use
PERM [MJ] renewable PE for material use

The database used is the kobaudat version 2017-I from 27.11.2017, based on the background data of the GaBi database and others (Thinkstep 2017). All data in kobaudat database are conform with the EN ISO standard 15804 (BMUB 2017). The data sets are used for separate construction layers as they are shown in 2.3.

For calculation purposes, no material flows of fasteners, screws, bolts, and tapes with less than five percent of the total material flow of the wall structure were considered. Also no additional input for formation of connections like additional joints, milling, cutoff, or waste from this special parts are taken into account. The original cradle to gate with options data seldom covers the production of the entire components, sometimes there are EPDs with optional figures for life cycle phases A4 to A5, that is the buildings erection phase. Hence the datasets cut-off these phases due to the lack of sufficient data. The calculated results cover the life cycle according to a cradle-to-gate with options approach (CEN 2013). The Use Phase with replacement (B3/B4) of different elements is not part of the calculation, because the focus of the study is on mere construction components while the context of the building and its use is not defined. Furthermore, the module D is excluded from the presentation of results, because the focus was on the comparative accounting and evaluation on product and component level and not on consequential LCA with specific scenarios to be defined individually. Due to the calculation of renewable materials cp. 2.5, the results consider the End-of-life-phase (EoL-C) explicitly. If the available datasets did not consider the EoL-phase, additional datasets for construction waste treatment and disposal were used, if the contribution of this aspect was more than five percent.

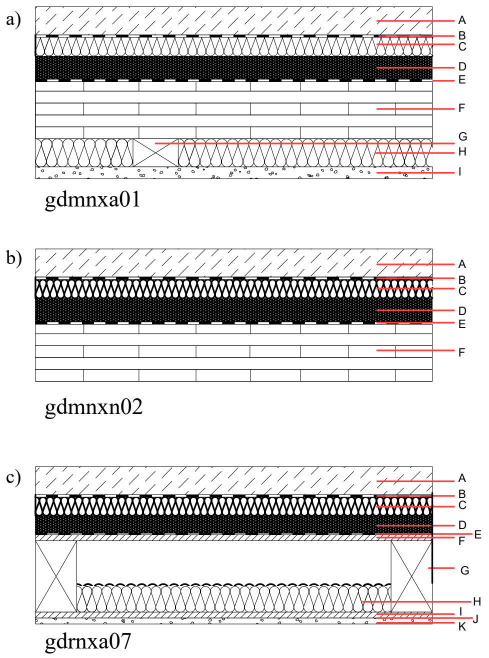

Figure 1: Cross section of floor slabs.

2.5 *Renewable resources, biogenic carbon and carbon storage*

The dataholz.eu database covers many construction components, which are primarily based on renewable materials. Due to the capacity of timber and other renewable materials to embed carbon during its growth, this aspect has to be considered in particular. For furher information please refer to the paper of Ebert and Ott (2018). The indicators of the EN 15804 standard were extended by the amount of regrowing resources (in German nachwachsende Rohstoffe nawaro) and the embedded carbon in them. The biogenic carbon was calculated according to EN 16449 (CEN 2014). Also the embedded primary energy can be distinct between the material use (M) and energy use (E) in addition to the distinction between renewable (R) and non-renewable (NR). The ratios are calculated and presented in this paper. For a detailed explanation on the definition and calculation process see the paper of Ebert and Ott (2018).

3 RESULTS FOR FULL RANGE AND EXEMPLARY COMPONENTS

3.1 *Single Floor Slab Component Result*

Here is given the detailed view on single component results for the composition of a mass timber slab with acoustic insulation and gypsum lining (cp. table 1). According to the goal and scope definition and the selected impact categories the results for one square meter of exemplary timber floor slab construction component gdmnxa01a-01 are shown below:

The illustration of the results for the GWP in figure2 demonstrates the importance of the consideration of the End of Life stage for a holistic interpretation of the results. A solemnly consideration of the construction phase only shows a negative impact of the GWP (see first column). Only with the implication of the end of Life Phase C (see fourth column) the results in total gives all GWP emissions over the whole life cycle, e.g. 27.5 $kgCO2e$.

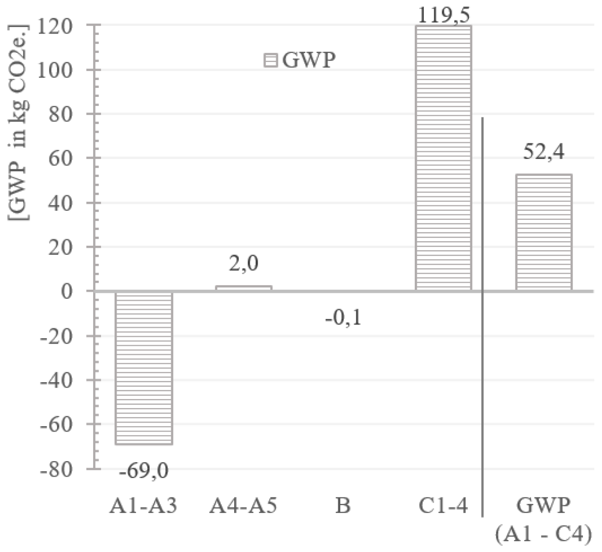

Figure 2: GWP results for 'gdmnxa01a-00', showing each LC phase.

Table 1: Results for the floor slab component gdmnxa01a-00 over the whole life cycle.

	A1-A3	C	A-C
GWP [kg CO2e]	-69.018	119.549	52.434
AP [kg SO2e]	0.161	0.019	0.184
EP [kg PO4e]	0.028	0.004	0.033
ODP [kg R11e]	3.80E-06	1.97E-07	4.00E-06
POCP [kg Eth.e]	0.022	0.002	0.024
PERE [MJ]	312.07	3.19	315.64
PERM [MJ]	1214.99	-1208.83	6.42
PENRE [MJ]	642.55	39.59	687.85
PENRM [MJ]	54.08	0	54.13
Embedded biogenic carbon [kgCO2e]			65.17
Regrowing resources nawaro [kg]			44.62
Primary energy energy use [MJ]			640.19
Percentage of renewable PE energy use [%]			29.28

Figure 2 illustrates the flow of biogenic embedded carbon with the benefit (negative accounting) in stage A1 and the load (positive accounting) in stage C3 (cp. 2.4). Similar to the results for the GWP the illustration of the results for the renewable primary energy considering both the material and the energy use (PERM and PERE) show the flow of the embedded primary energy.

Table 2: Overall life cycle impact results for 59 floor slab components.

	M	SD
GWP [kg CO2e]	44.80	7.14
AP [kg SO2e]	0.16	0.02
EP [kg PO4e]	0.03	0.004
ODP [kg R11e]	1.28E-6	1.03E-6
POCP [kg Eth.e]	0.027	0.006
EBC* [kgCO2e]	54.91	18.57
RR** [kg]	37.25	13.22

*Embedded Biogenic Carbon, **Regrowing Resources

Table 3: Overall resource input results for 59 floor slab components.

	M	SD
PERE [MJ]	211.939	76.97
PERM [MJ]	22.214	28.48
PENRE [MJ]	620.177	120.82
PENRM [MJ]	25.823	14.70
PEET* [MJ]	827.00	191.18
pPERE** [%]	35.0	4.70

*PE as Energy Use Total, **percentage of PERE

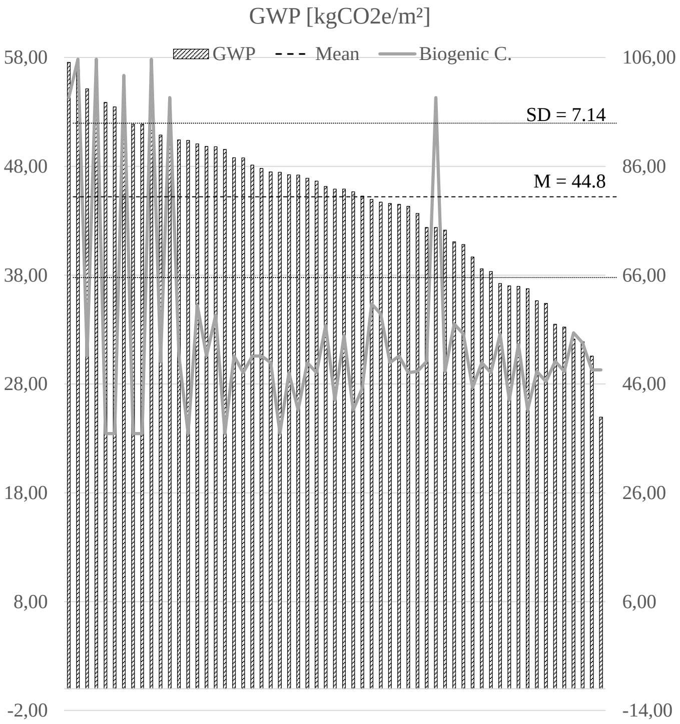

Figure 3: Overall GWP impact on all 59 floor slabs.

3.2 *Overall results - environmental impact*

The environmental impact is represented by various impact categories with its category indicators as shown in the section above. The results for all different wall types are shown in figure 2. For further interpretation the overall GWP results for all 59 different floor slab components is illustrated with a mean average of 44.80 and a standard deviation of 7.14 $kgCO2e/m^2$ over the whole life cycle (A-C) in table 2. Table 2 also shows the results for the embedded biogenic carbon for all the different construction components from timber frame to massive timber constructions with a mean average of 54.91 and a standard deviation of 18.57 $kgCO2e/m^2$. The illustration in addition with the relatively high standard deviations for the indicators show the variation between timber framed and mass timber floor slabs in the results. Therefore, different parameters of the construction components (e.g. characteristic composition or insulation) are analyzed separately for a better understanding of the results (cp. 4).

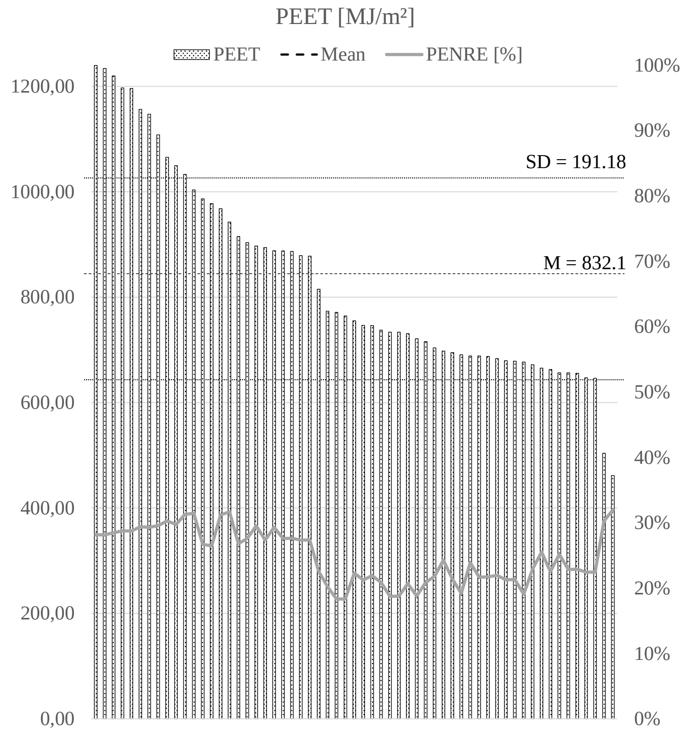

Figure 4: Overall PEET impact on all 59 floor slabs.

3.3 *Overall results - use of resources*

The results for all different types of primary energy representing the use of resources is listed in table 3, calculated for all timber construction components. Figure 6 illustrates the results and the distribution of the total sum of primary energy used in all processes (PERE + PENRE) over the whole life cycle with a mean average of 827 MJ/m^2 and a standard deviation of 191.18 MJ/m^2. In addition, the percentage of the renewable share is illustrated as well with 35 % as a mean percentage.

4 INTERDEPENDENCIES OF FUNCTIONAL LAYERS

4.1 *Distinction between mass timber and timber frame constructions*

For better analysis and interpretation, all results were clustered between timber frame components and mass timber components. The results reflect the improvement regarding the standard deviation of all cumulated results (cp. 3.2 & 2.5). The results show a reduction of the standard deviation for almost all indicators. Furthermore, the distinction between timber frame and massive timber components is more effective considering the change (65 to 81 %) in the standard deviation for regrowing resources and therefore the embedded biogenic carbon, then the change in the standard deviation for primary energy and its renewable share. Figure 5 and figure 6 show the interdependencies between timber frame and massive timber construction. With the benefit of approx. +52 % more embedded carbon regarding the mean averages

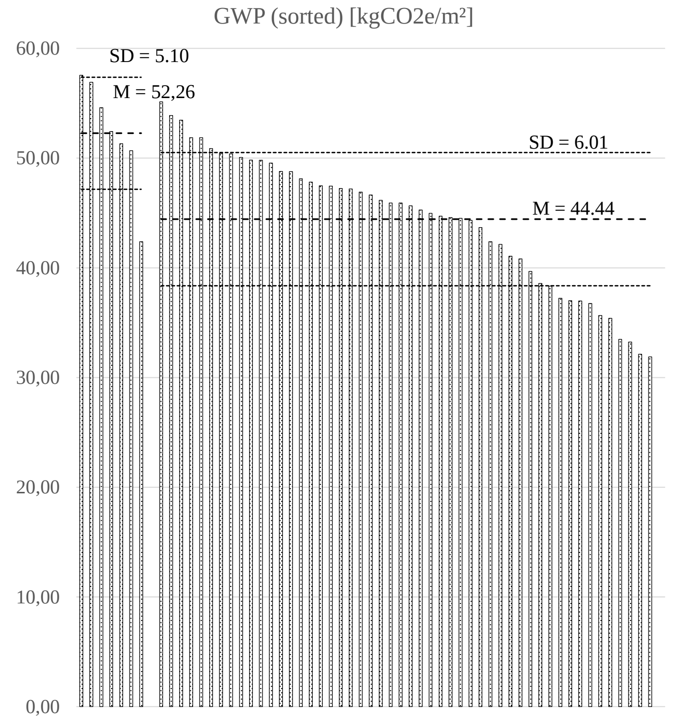

Figure 5: Distinction between structural material on GWP indicator.

Table 4: Distinction between frame and mass timber floors.

	M	SD	SD change
Timber Frame Floors			
EBC [kgCO2e]	48.53	6.59	-65%
RR [kg]	32.68	4.60	-65%
PEET[MJ]	819.18	180.04	-37%
pPERE [%]	23.85	3.56	-24%
Mass Timber Floors			
EBC [kgCO2e]	102.33	3.53	-81%
RR [kg]	71.01	2.45	-81%
PEET[MJ]	1024.31	57.28	-80%
pPERE [%]	30.73	0.87	-81%

for the results, the increase of primary energy use of approx. +20 % regarding the mean averages are connected. Despite single deviations, the results demonstrate clearly the interconnection between embedded biogenic carbon and the primary energy for the energy use over the whole life cycle in general. Mass timber constructions bear the benefit of a higher amount of embedded biogenic carbon, but with the costs of a higher need for primary energy as energy use which has to be invested in the production phase. However the increase in in energy use is significantly lower than the increase in material use.

4.2 *Distinction between insulation material*

Now the goals is to distinct other, less relevant materials. The results should be clustered according to the main insulation material for acoustic purpose in order to better understand the deviation of for primary energy use and its renewable share. The clustering of results show an improvement for the standard deviation regarding the primary energy use for up from 48 % to 87 % and regarding the renewable share from 78 % up to 83 %. The results of the direct comparison of the construction components with different insulation materials show a relativly low increase of a few percentages more embedded biogenic carbon for wood fiber and cellulose components compared to mineral wool components (cp. table 5). This difference is obviously linked to the mineral-based substance of mineral wool. But the amount is lower than in highly-insulated exterior walls due to thinner layers and lower raw density of the acoustic insulation in ceilings.

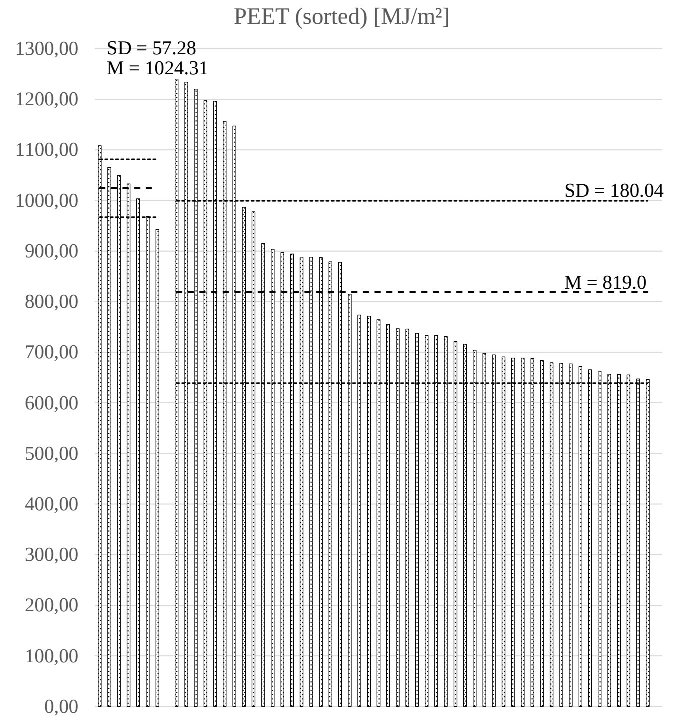

Figure 6: Distinction between structural material on PEET indicator.

Table 5: Distinction between insulation materials.

	M	SD	SD change
wood fibre insulation			
GWP [kgCO2e]	46.18	5.14	-28%
EBC [kgCO2e]	52.30	3.58	-81%
RR [kg]	35.16	2.29	-83%
PEET[MJ]	1021.34	149.97	-48%
mineral wool			
GWP [kgCO2e]	46.71	6.10	-15%
EBC [kgCO2e]	50.56	21.44	15%
RR [kg]	34.07	15.26	15%
PEET[MJ]	762.76	120.67	-58%
cellulose			
GWP [kgCO2e]	39.14	5.29	-26%
EBC [kgCO2e]	53.28	4.50	-76%
RR [kg]	36.49	2.88	-78%
PEET[MJ]	676.90	37.98	-87%

4.3 *Distinction between coverage of floor slab on top and bottom side*

Ceiling structures must be considered differentiated according to further criteria. These include the lining of the undersides and the floor covering on the top. In wood construction, mineral materials are often implemented due to fire protection considerations, here

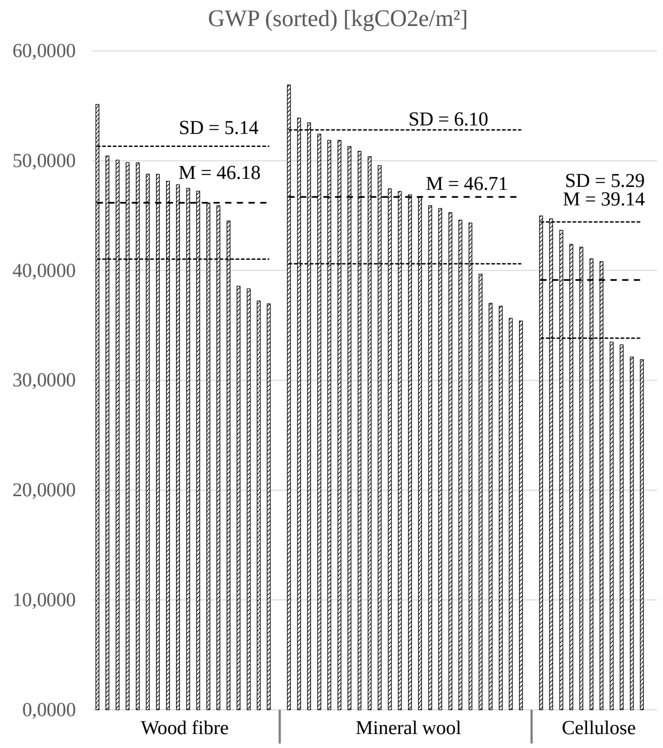

Figure 7: Distinction between different insulation material on GWP indicator.

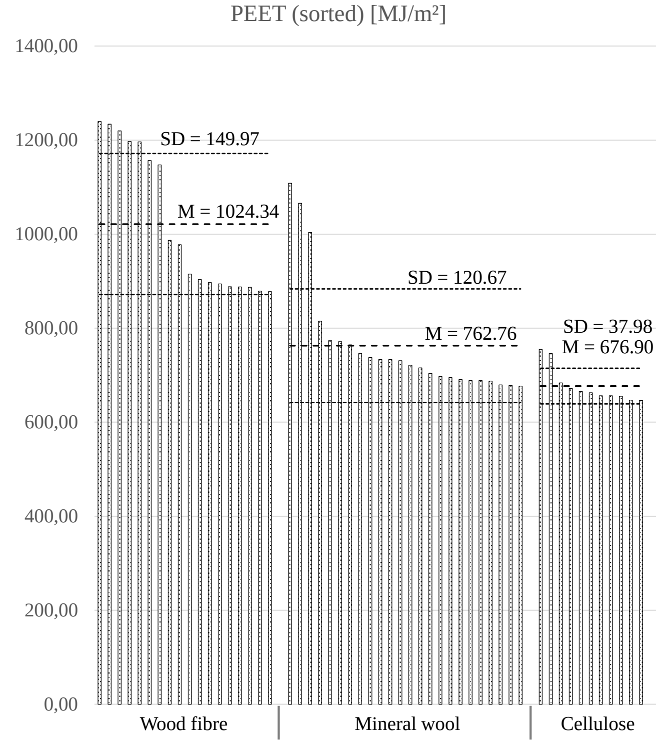

Figure 8: Distinction between different insulation material on PEET indicator.

Table 6: Distinction between covering of lower side (ceiling).

	M	SD	SD change
1-layer gypsum board			
GWP [kgCO2e]	43.71	6.28	-12%
EBC [kgCO2e]	54.09	16.42	-12%
RR [kg]	36.68	11.68	-12%
PEET[MJ]	788.19	148.60	-48%
2-layer gypsum board			
GWP [kgCO2e]	46.28	6.31	-12%
EBC [kgCO2e]	51.61	16.22	-13%
RR [kg]	34.84	11.51	-13%
PEET[MJ]	875.08	202.35	-30%
without gypsum (visible wood)			
GWP [kgCO2e]	41.23	13.56	90%
EBC [kgCO2e]	78.61	27.41	48%
RR [kg]	54.42	19.31	46%
PEET[MJ]	785.15	279.30	-3%

the linings of the bottom by non-combustible construction products. The linings of the undersides are mostly made of gypsum building materials and thus their contribution to primary energy consumption and global warming potential is considered more closely. It is also differentiated according to the number of gypsum board layers, because to achieve higher fire resistance periods must be covered with thicker or multi-layered sheets. The result is again a clear pattern, comparable to the distinction of insulating materials. There is only little difference of a few percentage between the two gypsum covered classes but a larger difference for the uncovered ceilings between 46 % and 90 %, (cp. 6). In addition to differentiation of the undersides, another pattern can be seen in the same criteria classes. The top surfaces in the examined 59 floor compositions are either wet-processed cement-based screed or, alternatively, gypsum-based dry screeds. The two subgroups are clearly visible in the data in figures 9 and 10. The dry screed group has a lower average GWP and PEET value than the cement-based screeds. Major changes can be observed for the GWP. For the dry-screed there is a decrease of the mean average of GWP of 19 % and an increase of PEET of 3 %. The wet-screed is in line with 6 % increase for GWP and 1 % decrease for PEET, (cp. table 7). Within these very differentiated evaluations of the different constructions, the efficient use of resources of design constructions can be described and evaluated on the basis of a reference value, here the overall average (cp. (Ott et al. 2015, Ott and Hausmann 2015, VDI 2016)). For the different gypsum cladding, the needed primary energy efficiency of 0.95 for 1-layered, 1.06 for two-layered and 0.95 can be determined without linings. For biogenic raw materials, resource efficiency is in the range of 0.94 for single-layer paneled framed slabs to 1.46 for solid wood slabs, the latter without lining.

5 CONCLUSIONS

Compared to another evalution of exterior walls the floor slabs show similar patterns (Ebert and Ott

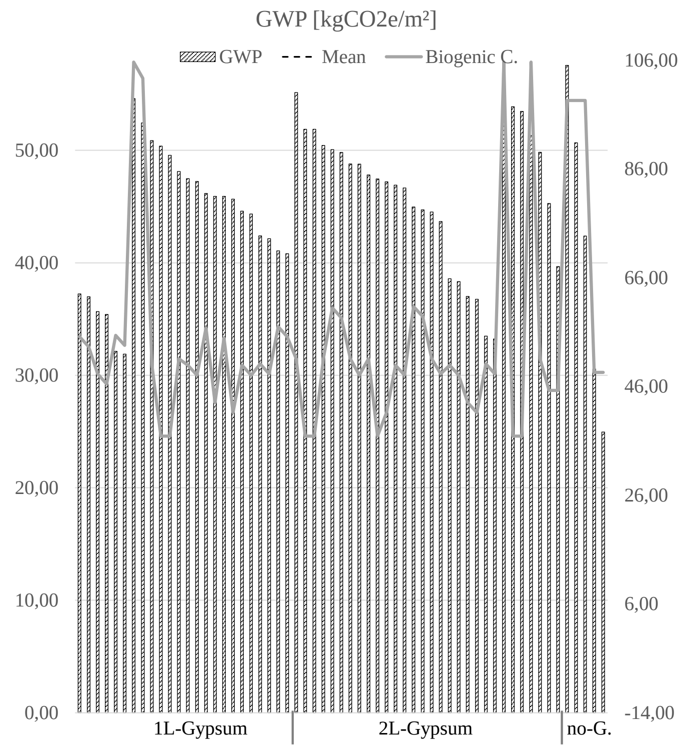

Figure 9: Distinction between different covering of ceiling side on GWP indicator.

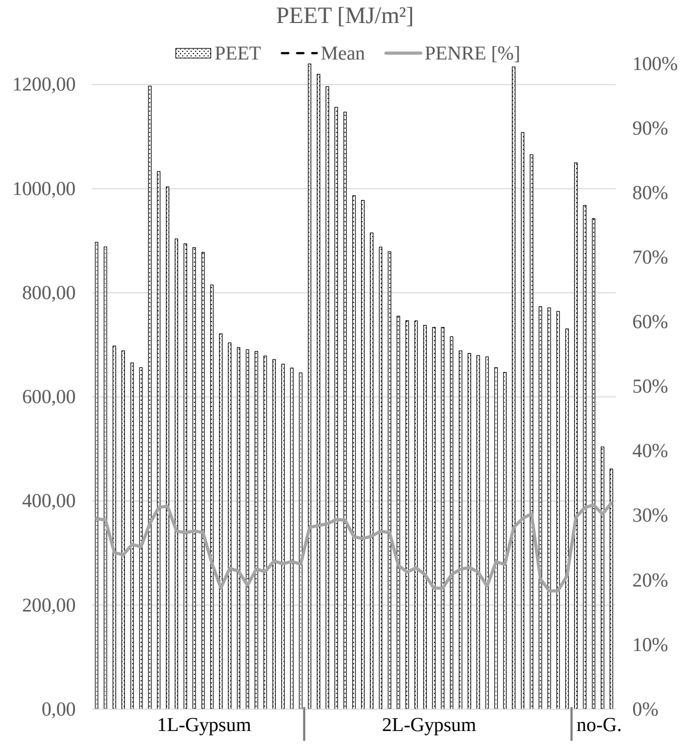

Figure 10: Distinction between different covering of ceiling side on PEET indicator.

Table 7: Distinction between screed type for the class of 1-layer gypsum board covered ceilings.

	M	SD	SD change
dry-screed			
GWP [kgCO2e]	36.77	5.44	-13%
PEET[MJ]	812.88	198.03	33%
wet-screed			
GWP [kgCO2e]	46.56	3.98	-37%
PEET[MJ]	875.08	202.35	-30%

2018)). The exterior walls have an overall mean value for GWP of 30.1 $kgCO2e/m^2$ or 827 MJ/m^2 for PEET. In the further course, the distinction between timber frame construction and solid wood construction leads to more differentiated results for the mean values and standard deviations within the respective group, especially to a decreased standard deviation for regrowing resources and therefore the embedded biogenic carbon. The next essential distinction has dealt with the different insulation materials. Again, more accurate characteristics can be determined and in the same move is also clearly identifiable for the biogenic insulation materials. The gypsum lining of the lower side is also responsible for differentiating the GWP and the PEET. Within the defined lining classes, the construction of the top covering floor structure is also shown at the same time. The authors expected a higher difference between dry and wet screed variants. This can partly be confirmed on the basis of the GWP data. The required primary energy for production differs only slightly in both variants. In comparison with the study of (Hafner et al. 2017), which is based on comparable LCA data and the same calculation methodology, the value for the ceiling floor slab compositions is quiet similar. It shows for multi-storey wooden buildings a value of 67 $kgCO2e/m^2$, which differs only slightly from dataholz.eu average value. Although, knowing the given data are only a first estimate for full building LCA, we have shown that it is close to a state-of-the-art full LCA of buildings, qed.

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