REPORT
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D.4.3 Manufacturing and heating energy: method, examples, tool

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1 INTRODUCTION

This report intends to contribute to the discussion on the relevant topic of life cycle assessments for buildings. It should not be understood as a complete scheme ready for implementation proposed as a final solution by the Passive House Institute. The Passive House Institute is beginning to work on the topic of life cycle assessments as part of the EU-funded project outPHit and this report describes the general approach and first steps taken.

The topic of life cycle assessment is approached from the perspective of operating and manufacturing energy. The issue of CO_2 in the life cycle is also addressed briefly.

The main question is how a life cycle assessment can be conceptualized to deliver meaningful results. Concerning economic considerations, the answers are largely given; the net present value method is the method of choice, cf. e.g. [AkkP 42]. Regarding the energy demand in the life cycle, [EN 15978], Sustainability of buildings - Assessment of the environmental performance of buildings, provides a framework. Within this framework, a proposal is developed according to which different constructions are compared with each other as well as with a reference construction (sand-lime brick with EPS ETICS). The question is: Which of the examined constructions has the lowest energy demand over the life cycle and at which insulation thickness?

2 ENERGY

Various publications of the Passive House Institute (PHI) have shown that the economic optimum of the insulation thickness is, in some cases, far above the level required by building codes when appropriate insulation materials are chosen. The question to be answered here is whether it also makes sense, regarding the energy demand over the life cycle, to insulate as thickly as economically feasible. Which insulation materials are advantageous in this regard (especially important for the outPHit-topic of deep retrofitting) and are timber constructions better than the reference system of sand-lime bricks with EPS insulation (timber constructions are also important, for fast and serial retrofits they may rely on prefabricated timber structures, mounted to existing walls)?

As early as 1986, Wolfgang Feist published an article contemplating the question of the "energetic optimum" of polystyrene insulation [Feist 1986]. With an assumed usage period of 25 years, Feist came up with a PE optimum of approx. 33 cm with a thermal conductivity of 0.04 W/(mK). Here, the term PE optimum means the minimum of the sum of PE requirements for the manufacturing process of the insulating material (including the energy chemically stored in the material (PENRM, see below for further explanation) non-energy use) and the transmission heat losses of the walls over only 25 years. It is now known that the service life of correctly installed thermal ETICS systems is generally much longer.

In 2006, the first international standard, ISO 14025, was published, on which the aforementioned EN 15978 is also based. This standard divides the life cycle of the building into four stages A-C (and a total of 16 sub-stages A1-C4): A 1-5: Production and construction stage. B 1-7 Use stage. C 1-4 Disposal stage. These phases are supplemented by module D, the potential for reuse, recovery and recycling.

The series of standards thus offers the possibility of evaluating the building over its entire life cycle.

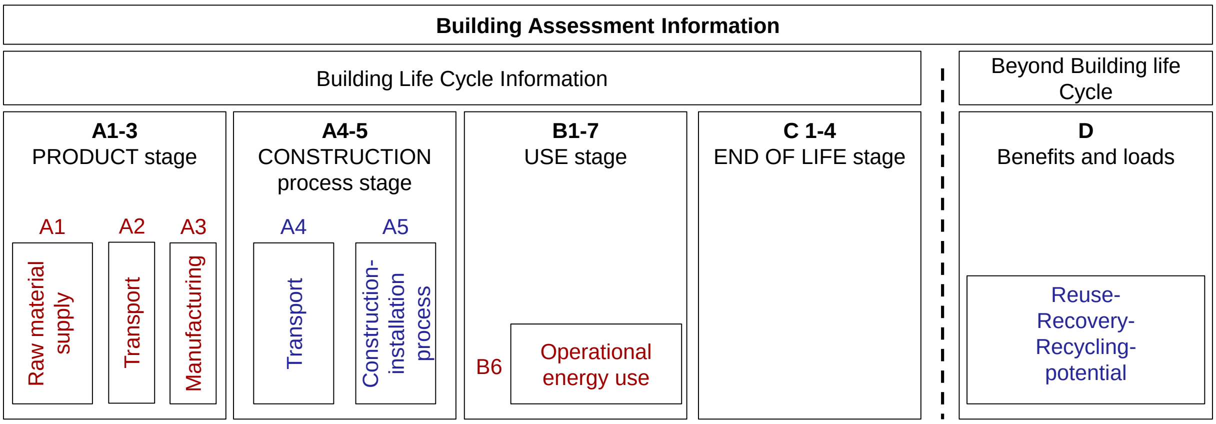

Figure 1: Scheme of EN 15978, sustainability of buildings

2.1 ENERGY REQUIREMENTS IN THE USAGE STAGE (MODULE B6)

For the study carried out, the heat generator of the future and reference system is the heat pump. Therefore, electricity is the energy used. To calculate the primary energy demand from the heat pump's electricity requirement, it is multiplied by a specified primary energy factor. The conventional primary energy factor, like the primary energy content of the building materials, often refers solely to the non-renewable part of electricity (PE_{NE}), which means that the shares of solar and wind power, for example, are weighted with the PE factor zero and are therefore not included in the evaluation. This is the main reason why the PE_{NE} factor dropped from 2.6 in the German Energy Saving Ordinance (EnEV 2002) to 1.8 in the German Building Energy Act (GEG 2020) With an increasing share of renewable energy sources in the grid, this PE_{NE}-factor will tend towards zero, which will be achieved, when the grid is operated completely with renewable energy (in the following, this is assumed to be the case in the year 2060). This means that no matter how much electricity is required for heating (or for a production process), and no matter whether a heat pump is used or not, the PE_{NE} requirement will be zero. It is evident that this approach is not expedient because heating and production continue. Renewable energy is not available in unlimited quantities, requires a significant amount of space and cannot be transported indefinitely via the existing power grid. These limiting factors remain unaddressed by the suggestion of zero primary energy, as do the high energy costs due to the continued energy demand.

Following this principle, it would appear that very little energy is needed in the operating phase (because of the declining primary energy factors in the period of consideration), but a lot of energy is needed in the construction phase, since "historical" PE factors (from a time, where the PE-factors were high and the production was less efficient) are used to produce the building materials. This could result in poorer thermal insulation being chosen, which would counteract the efforts to achieve the energy transition (and thus the prerequisites for achieving the low PE_{NE} factors for electricity).

The sole reference to non-renewable primary energy is therefore insufficient.

To solve this problem, the Passive House Institute developed the PER methodology, which evaluates the efficiency of the supply chain for electricity and other energy sources in a fully renewable system. Here, for example, a PER factor of 1.8 was determined for electricity for heating purposes in heating dominated climates, cf. e.g. [Feist 2014], [Grove-Smith 2021]: To produce one kWh of electricity for heating purposes, 1.8 kWh of renewable primary electricity must be generated. See also the outPHit Deliverable D.6.8 (Adequate net-zero rating approach chosen for case study projects).

Another possibility is the addition of renewable and non-renewable shares to make up the total PE factor. [GEMIS] shows KEV factors (German: “kumulierter Energie Verbrauch”, cumulative energy consumption) that roughly correspond to such total PE factors. Including grid and transformation losses of 10%, the KEV factor "power plant mix 2020" renewable + non-renewable is 2.44 (the non-renewable factor is 1.7 in 2020, 2.05 in 2015). With a fully renewable power grid, as in the PER system, a factor of around 1.8 will also occur here. The average factor for 2020-2050 could then be 2.0, depending on the electricity mix. However, the addition of renewable and non-renewable energy mixes two different kinds of energy: Non-renewable energy, which is massively harmful to the environment. As well as renewable energy with its fundamentally far less drastic effects.

To illustrate this, Figure 2 shows the effects of different methods.

Since it represents a future scenario, and a fixed factor is easier to handle when evaluating different time periods, the PER method is used in the further analysis. It estimates the influence of the use stage use phase rather cautiously, compared to using method of addition renewable and non-renewable primary energy.

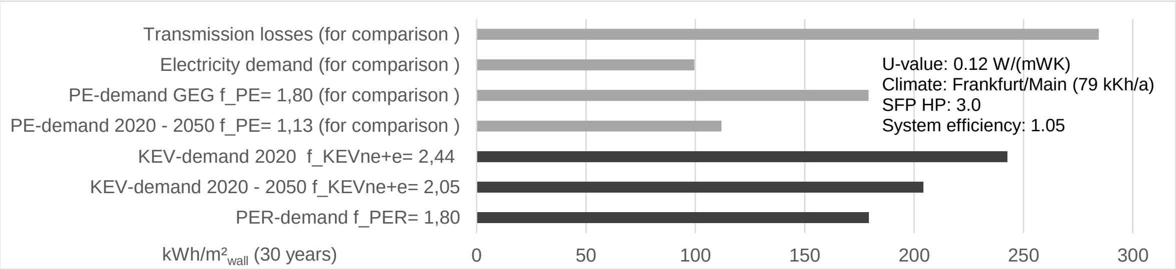

Figure 2: Transmission losses of a wall, U=0.12 W/(m²K). Resulting final energy demand (electricity) with heat pump and primary energy demand determined according to the methods discussed.

2.2 EMBODIED ENERGY

2.2.1 Renewable and non-renewable energy share

According to the classic definition [Kohler/Klingele 1995] for embodied energy, the primary energy content (PEC) "refers to all preliminary and manufacturing processes up to the product ready for delivery. The criterion only considers energy from non-renewable sources. Energy contents from wood, water, sun etc. are therefore not included." The system boundary *Cradle to Gate* is chosen here. This corresponds to modules A 1-3 from EN 15978. According to the literature, cf. e.g. [Borsch-Laaks 2019], these three modules comprise the essential parts of the grey energy, while modules A 4-5 (transport to the construction site and installation) as well as module C (disposal), play a subordinate role. This is certainly true for conventional building products. For building materials with a high level of embodied energy, such as straw bales, phases A 4 and A 5 can account for a significant share, but this is almost negligible in absolute terms.

As already shown for the operating energy demand, the limitation to non-renewable primary energy is incorrect since the primary energy demand in our changing energy system is close to zero, although energy is being used.

It is evident that the entire energy demand for production processes must be included in order to achieve usable results. Here, too, a "PER system", as presented for energy required in the use-stage, would be conceivable. However, the building materials used today are produced in today's energy system and not in a future one. For this reason, the sum of renewable and non-renewable primary energy is calculated below but differentiated by colour in the diagrams.

This means that the primary energy contents of renewable building materials increase significantly compared to those of fossil origin, as the following examples show. All data used are taken from [Ökobaudat].

Figure 3 shows the energy demand from the use-stage (B6, red) over 40 years and the manufacturing phase (A1-3) depending on the U-value for EPS with graphite additive. While the energy demand for production increases with decreasing U-value, the operational energy demand decreases. The aim is to identify the optimum of both aspects combined.

With regard to embodied energy, a distinction is made between:

- PENRE (black) is the non-renewable primary energy required for the manufacturing process and the transport of materials. This energy demand refers to the point in time when the data was collected. Due to the ongoing degression of the primary energy factors, e.g. for electricity, the manufacturing primary energy demand is reduced correspondingly and is already reduced, when the components to be used are produced.
- PENRM is the primary energy chemically bound in the material (caloric energy related to the calorific value). This energy is stored energy. It can be released during combustion.
- Accordingly, PERE and PERM are the renewable energy required for production and stored within the material. In the case of EPS-g they are negligible.

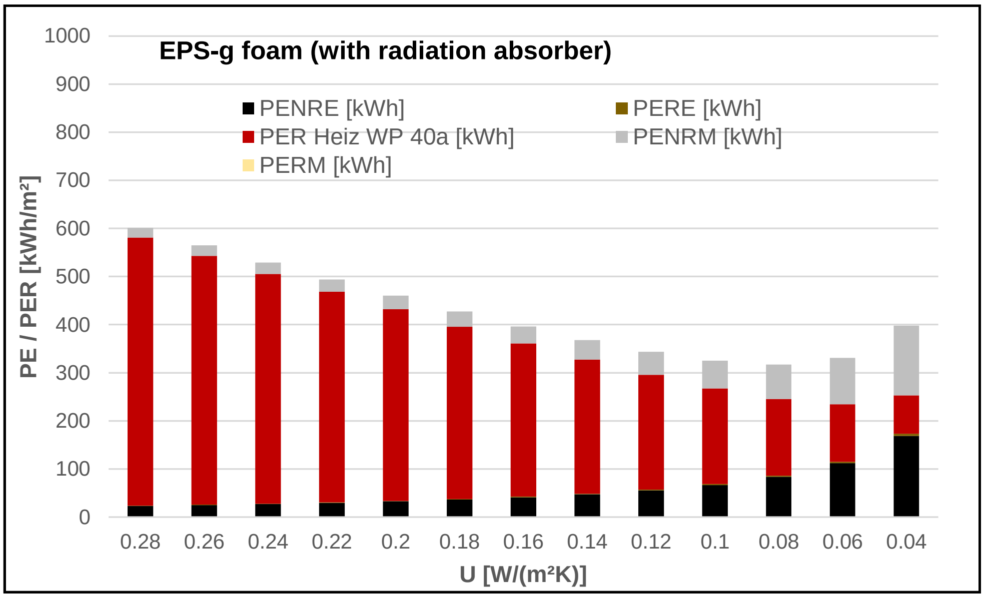

Figure 3: The energy demand over 40 years of EPS-g insulation (16.6 kg/m², 0.032 W/(m²K)). Climate: Frankfurt am Main (79 kKh/a), Seasonal performance factor of the heat pump (SFP): 3.0, system expenditure factor: 1.05, PER factor: 1.8.

When completely taking into account the embodied energy, the optimum is 0.08 W/(m²K) (corresponding to an insulation thickness of approx. 50 cm). If the caloric, i.e. stored, energy content (which is not "consumed" during use, i.e. is not physically converted, i.e. is retained) is not taken into account, this optimum is 0.06 W/(m²K) (corresponding to an insulation thickness of approx. 80 cm). In both cases, the insulation thicknesses are clearly above the usual range for exterior walls today as well as the recommended values.

In cool temperate climates, wall U-values significantly below approx. 0.15 W/(m²K), corresponding to insulation thicknesses of up to approx. 24 cm, however, are not typically recommended. There are several reasons for this:

- Thermal comfort is no longer noticeably improved by even higher insulation thicknesses.
- The economic optimum typically lies in the range of these insulation thicknesses.
- We can significantly simplify the building services engineering at this thermal insulation level.
- For practical construction reasons, even higher insulation thicknesses are costly.
- Overall, it saves more energy to equip a surface with 24 cm EPS, for example, than to equip half of this surface with 48 cm.

If a gas boiler (with a PE_{NE} factor of 1.1 for natural gas) is assumed for the use stage instead of the electric heat pump, the energy demand increases over the utilisation phase. This shifts the overall energy optimum further in the direction of even higher insulation thicknesses, cf. Figure 4. The same applies to a heat pump with a lower SPF or a direct electric heating system.

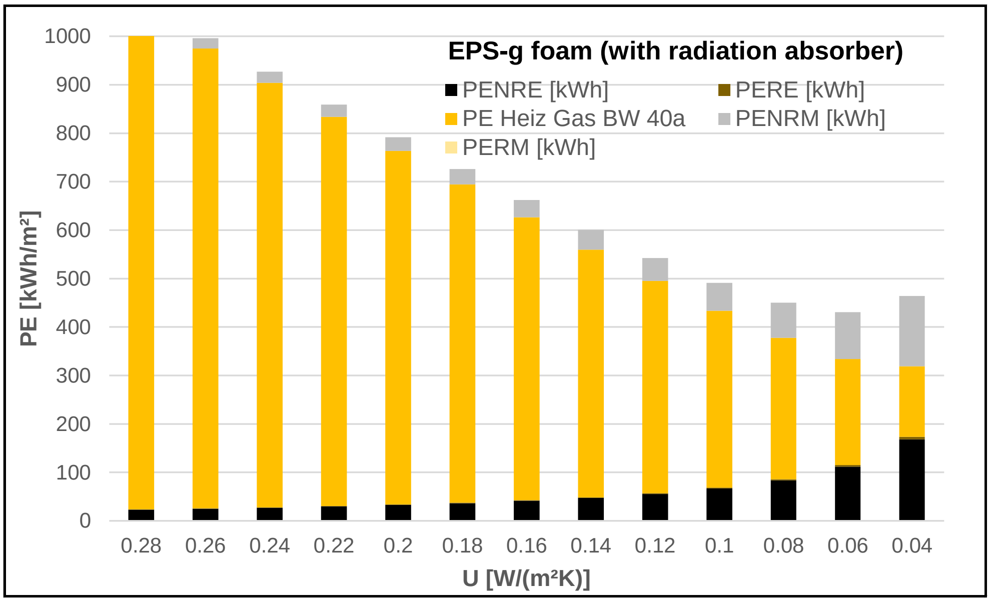

Figure 4: The energy demand over 40 years of EPS-g insulation (16.6 kg/m², 0.032 W/(m²K) with graphite as radiation absorber to reduce the radiative heat transport). Climate: Frankfurt am Main (79 kKh/a), caloric gas boiler, system expenditure factor: 1.05, PE factor: 1.1.

Figure 5 shows the evaluation for the insulation material cellulose, which consists of recycled waste paper material. The main energy content of the insulation material is now PERM, i.e. the caloric renewable fraction, which is not included in the definition according to [Köhler/Klingele 1995]. However, the total energy demand is also lower than for EPS. Including PERM results at an optimal U-value of 0.06 W/(m²K), excluding PERM below 0.04 W/(m²K). For the insulation of exterior walls, additional construction materials are still required, which are then filled with cellulose insulation. However, cellulose is also suitable on its own for insulating upper storey ceilings. In such cases, when enough space is available, insulation thicknesses above the 24 cm mentioned can also be useful for the cellulose as a material cheap as well as quick and easy applied.

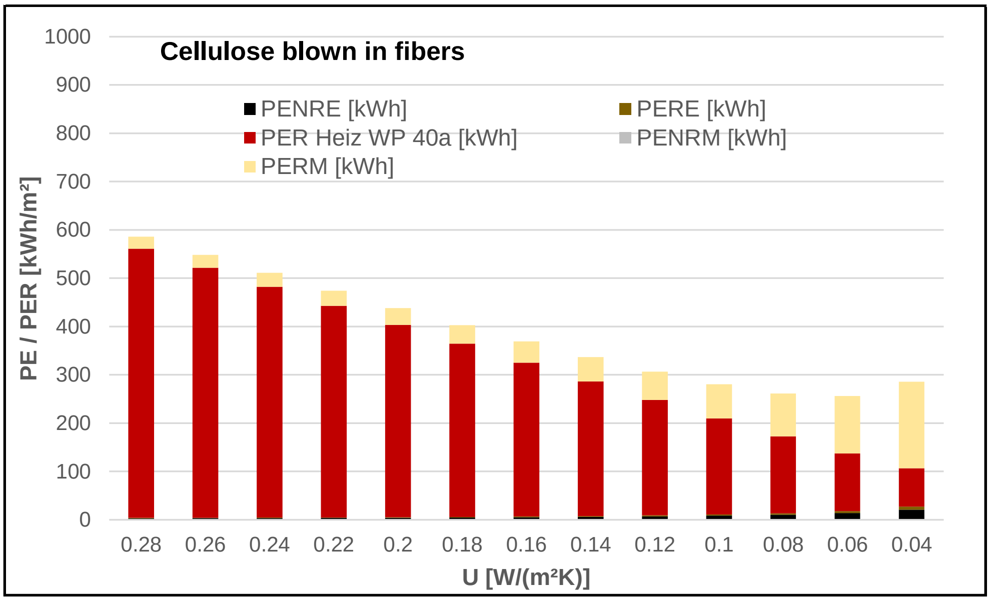

Figure 5: The energy demand over 40 years of cellulose insulation (45 kg/m², 0.04 W/(m²K)). Climate: Frankfurt am Main (79 kKh/a), SPF heat pump: 3.0, system expenditure factor: 1.05, PER factor: 1.8.

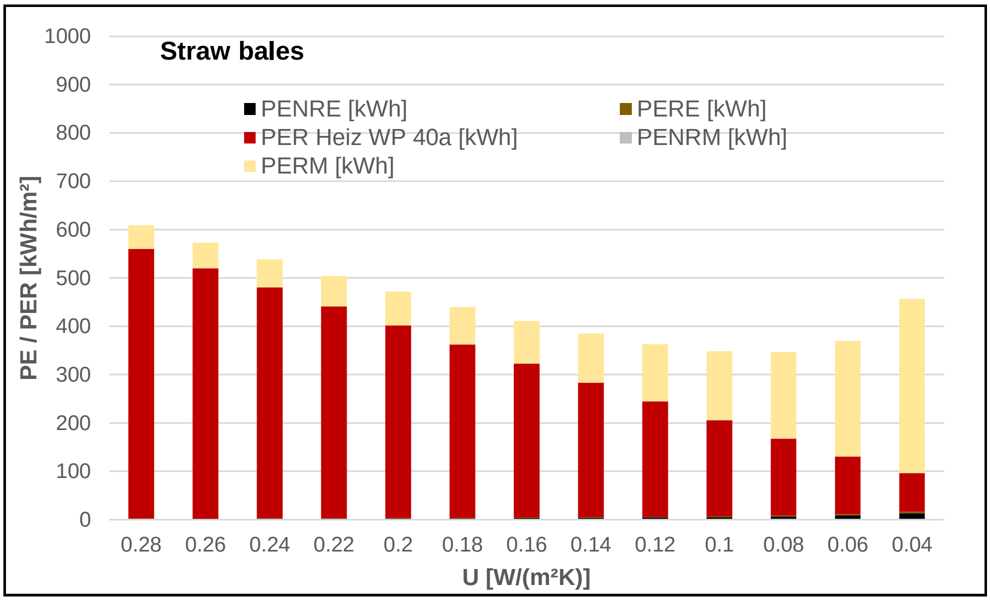

Figure 6: The energy demand over 40 years of straw bales (100 kg/m², 0.49 W/(m²K)). Climate: Frankfurt am Main (79 kKh/a), SPF of the heat pump: 3.0, system expenditure factor: 1.05, PER factor: 1.8.

The same applies to straw bales as an insulation material, cf. Figure 6. However, due to the higher density and the higher thermal conductivity of the insulation material, more material is required, so that the optimal U-value incl. PERM is 0.08 W/(m²K). The manufacturing energy requirement (PENRE, PERE) is equivalent to that of cellulose.

This example illustrates that it is physically incorrect to include the energy stored in the material (PENRM, PERM), since this energy is stored and is not converted, i.e. it remains available after the use stage.

It should be noted that straw bales, due to their production, have a thickness of either 28 or 36 cm (U-value then 0.15 W/(m²K)).

However, thermal insulation is not the only building component required, although thermal insulation plays a crucial role, especially in the context of outPHit, because the load-bearing structure of the building already exists. Figure 7 shows the energy demand of other building materials in the same way. Here, too, the relevance of the stored energy (PERM in this case) is evident, which is particularly clear in the example of the solid wall made of cross-laminated timber.

Combining the building materials to form the wall, Figure 8 shows that a sand-lime brick wall with EPS has the highest non-renewable manufacturing energy demand, while a timber stud wall with straw insulation has the highest total primary energy (renewable + non-renewable) content.

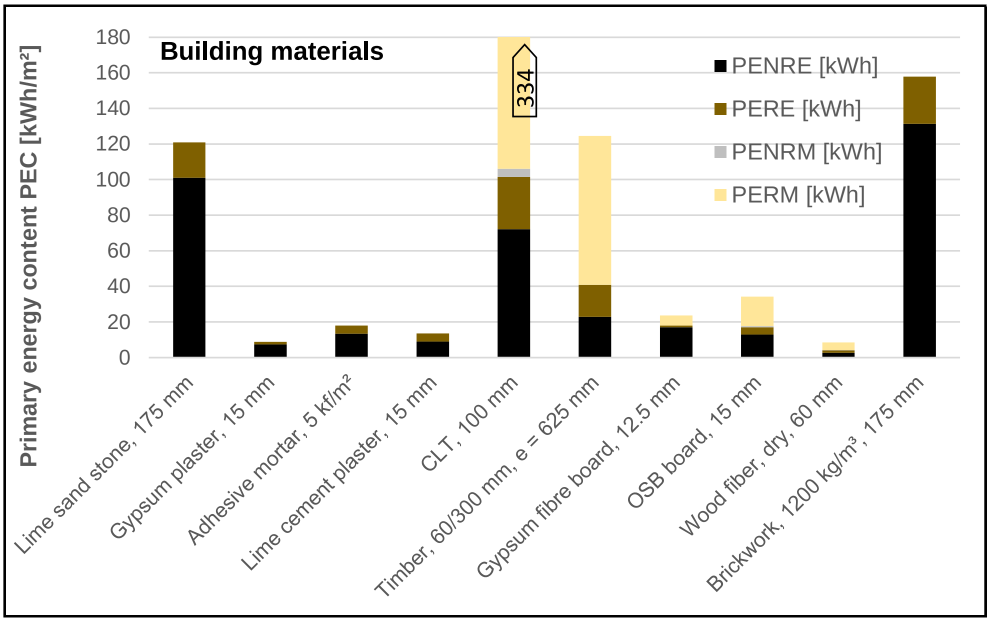

Figure 7: Manufacturing energy demand of other building materials. CLT = cross-laminated timber

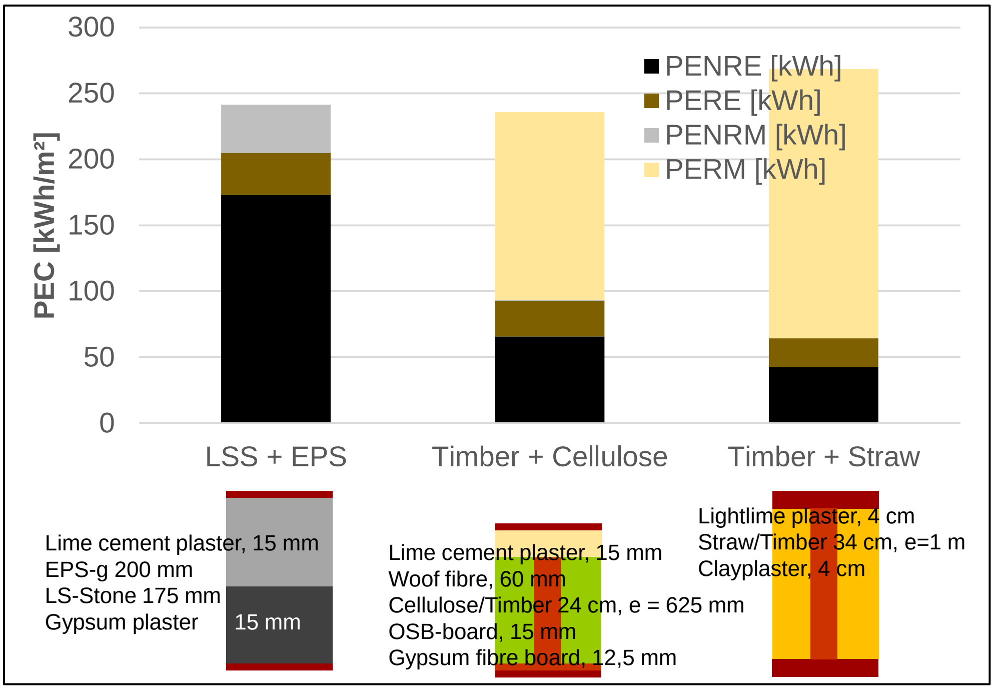

Figure 8: Energy content of exemplary wall constructions with a U-value of 0.15 W/(m²K)

It has already been pointed out that the primary energy used to produce a material changes with the change in the energy supply system. A building material produced today, therefore, has a different primary energy demand than the same building material produced in the future. If it is assumed that building materials with different service lives are used in a building, some building materials will have to be replaced during the life cycle. This leads to the question of which PEC is assigned to the replacement building material. This problem can be solved by differentiating between the period of use and the period of consideration, as in the economic consideration, and selecting the periods of consideration according to the shortest useful life of the materials used, see also section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

2.2.2 Reuse, recovery and recycling

The continued use of the building material after it has served in a building (Module D in EN 15978) is becoming increasingly important and should therefore be included in the assessment. According to EN 15804, credits for subsequent use should not be offset against the expenses at the beginning of the life cycle but shown separately for information purposes. This makes sense for reasons of transparency.

Regardless, a subsequent use can be assumed because our economic system should develop from a linear one (cradle-to-grave) to a circular economy, in which as many materials as possible are reused after their initial use. This approach is known as *Cradle to Cradle*. This is not just an idea but is laid out, for example, in the German Closed Substance Cycle Waste Management Act [KrWG 2020], which places reuse above other types of recycling or disposal. Since it is difficult to estimate the processes and possibilities of recycling or reusing building materials used today or in 30 to 100 or more years, the need for a pragmatic approach to Module D arises.

Building materials can be divided into the two groups organic and inorganic.

Organic materials are all renewable raw materials as well as products from fossil energy sources. They have in common that a high proportion of the embodied energy (renewable and non-renewable energy taken together) is of a calorific nature, i.e. it has a calorific value and can (theoretically) be burnt. Combustion would be the worst case of subsequent use in a circular economy.

If data on module D is available throughout, it can be shown additionally. In [Reinhard et.al. 2019], such processes are proposed for insulation materials, for example, for glass wool the material recycling in the cement plant or for foam glass panels the processing into foam glass gravel. What they all have in common is that, at least in terms of energy, they always result in gains rather than loads.

Therefore, the non-consideration of Module D is always the worst case.

2.3 PERIOD OF USE

Calculating the life cycle energy demand, an important factor is the considered period of use. According to the criteria of the German Sustainable Building Council [DGNB 2018], the standard period of use for residential buildings is 50 years, and modules C and, if possible, D are included. In [Schöndube et.al. 2020], 30 years of useful life is suggested without taking modules C and D into account, as one cannot foresee the effects of the use phase in the rapidly changing energy supply system beyond this period.

According to [Destatis 2020], the stock of residential buildings was approximately 19 million as of 31.12.2019. In 2019, just under 6,000 residential buildings left, corresponding to about 0.03% of the stock. From that of cause, no service life of 3,000 years can be concluded. However, it becomes clear that the above-mentioned periods are too short, at least for the load-bearing building structure.

It also makes sense to differentiate between materials and components. A sound basis for the approach of utilisation periods is provided by [BTE 2008]. Here, a table with a statistical evaluation of expert surveys provides minimum, maximum and average values. From this table, one can derive recommendations. These recommendations seem debatable in some places if a product, because it has not been on the market for very long, is assigned a low service life due to a lack of experience. In some places, the recommendations are also difficult to understand, which becomes clear in the example of the insulation material group cellulose/cork/wool etc. Here, the recommended service life is 30 years, but the statistical evaluation shows a minimum of 40 years, a maximum of 65 years and an average of 45 years. Also, no differentiation is made between mineral and organic exterior plaster, although experience shows that the former is more durable.

The question now arises as to how building products with different service lives can be assessed together. For example, a masonry wall (90 years of service life) can be taken as a reference together with the energy content of an associated external thermal insulation composite system (50 years of service life) multiplied by 90 years / 50 years = 1.8, and thus standardised to the service life of the masonry wall. However, this raises the question of whether the production of the ETICS, the basic materials and thus its energy content still correspond to todays, and whether different insulation will then be used.

Therefore, it is more appropriate to take the opposite approach, as in the economic analysis: The energy demand is standardised to a consideration period by multiplying it by the quotient value from the consideration period and the service life.

Example: Consideration period: 30 years. In this case, a factor of 30 years / 90 years = 0.33 would be applied to the masonry wall, and 30 years / 50 years = 0.6 to the ETICS.

This approach was implemented in Figure 9. For these special cases, there is only a slight relative deviation compared to Figure 8. Figure 10 shows the demand including the use-stage (Module B6).

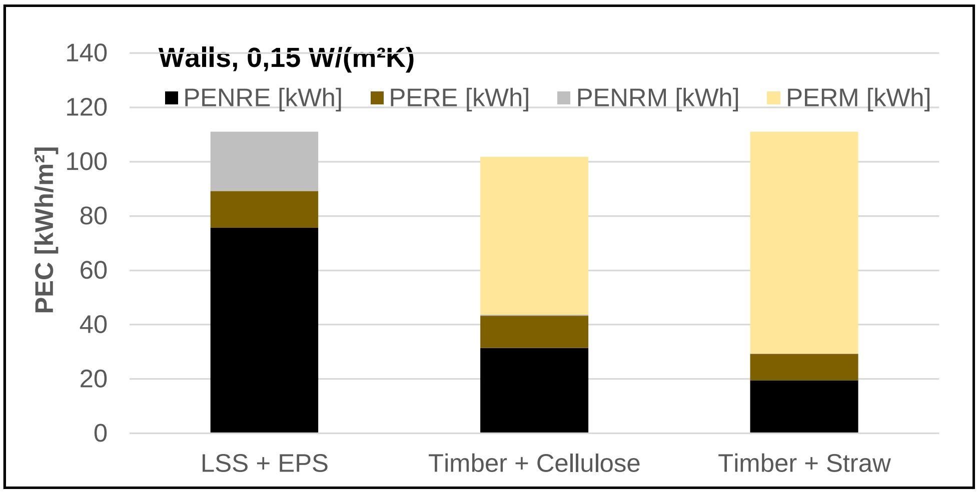

Figure 9: The primary energy content of wall constructions, standardised to an observation period of 30 years. Wall constructions as in Figure 8. Useful life cycles: masonry: 90 years, interior plaster: 70 years, exterior plaster: 50 years (in connection with the ETICS), timber wall: 75 years (roof) (in fate with cellulose, straw) gypsum fibre board: 50 years.

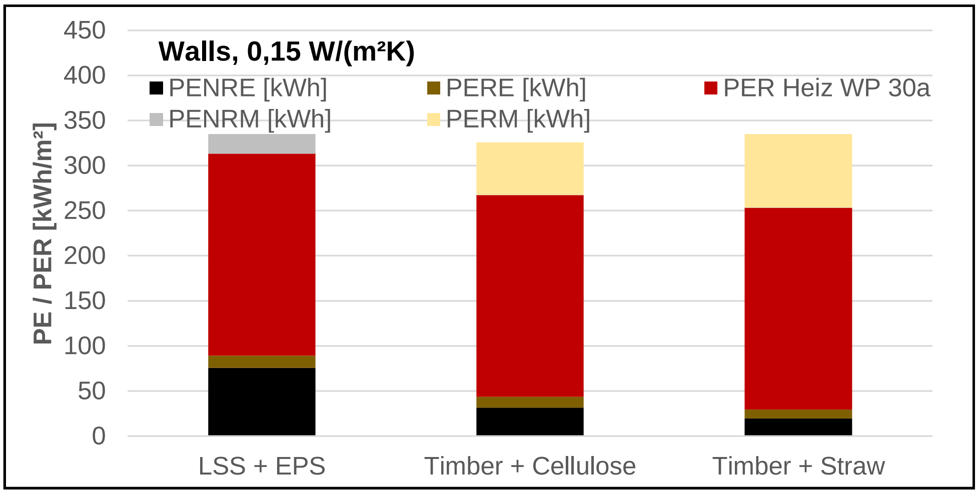

Figure 10: The primary energy content of the wall constructions and PER requirement to compensate for transmission heat loss.

2.4 EMBODIED ENERGY OR MANUFACTURING ENERGY?

At this point, we can draw the first conclusion: Even with typical wall constructions at a Passive House level (here sand-lime bricks + EPS), the demand for embodied energy is far below the demand for renewable primary energy to compensate for the transmission heat loss. If renewable materials, preferably recycled or waste materials are used, substantial savings of the non-renewable primary energy content can be achieved. Regarding the total primary energy content, all the variants presented here are about the same - if the energy stored in the material is included in the balance.

So far, embodied energy has been defined as the sum of all primary energy from renewable and non-renewable sources contained in the building material or used for its production. Thus, embodied energy includes both the energy required to produce the building material (PERE, PENRE) and the energy chemically bound in the material (PERM, PENRM, calorific energy). As previously explained, the energy chemically bound in the material is stored energy. It is not converted and is available for subsequent use.

The energy used for the production of the building material (PEER, PENRE) is the relevant part of the embodied energy since this is the part converted to produce the material and is not available for subsequent use.

It makes sense to limit the assessment to the production energy and to take the stored energy into account only during the conversion, for example, if construction timber is thermally utilised after the use phase and the stored chemical energy is released through combustion converted into thermal energy.

Thus, the principle of "counting upon conversion" applies. The assessment includes the manufacturing energy of the building materials (PERE, PENER) in modules A1-A3 and the operating energy in module B6 of EN 15978.

2.5 AS A FIRST APPROXIMATION, THERMAL PROTECTION IS DECISIVE.

So far, the manufacturing and heating energy demands have been discussed based on the different insulation materials. After that, different construction methods were compared at the Passive House level. The analysis shows large differences in the total energy demand, including material production and operational heating energy. However, the differences resulting from different levels of thermal insulation are decisive, as Figure 11 shows.

This applies particularly to the modernisation of existing buildings which happens in far greater numbers than the construction of new builds in Europe. Starting with an old building wall, improving the thermal insulation to 0.15 W/(m²K) and taking into account the production of a composite thermal insulation system with EPS for the improvement of thermal insulation in the climate of Frankfurt am Main, can save 91 % energy. From this example, the significance of the heating energy demand for the ecological assessment becomes clear. Calculated from this level, the energy demand increases by 66 % if the wall is retrofitted only to 0.24 W/(m²K) instead of 0.15 W/(m²K).
The additional insulation, therefore, saves further energy in total. As a rule of thumb, regardless of whether the building is in a heating or cooling dominated climate, the following can be applied:

If an insulation measure is economical, it is also worthwhile to use the manufacturing energy, because the costs of this energy are included in the price of the insulation material.

The insulation material or insulation system used plays a subordinate role. The ETICS with wood fibre insulation leads to the lowest savings due to the high density and thus the high manufacturing energy required. However, these are still savings of remarkable 87 %.

Between the wood fibre insulation and the EPS is a wooden construction insulated with cellulose, which is mounted in front of the old façade. The necessary wood increases the energy demand of "construction and plaster" compared to the EPS-ETICS. Although the manufacturing energy demand of cellulose is considerably lower than that of EPS, a 6 cm thick softwood fibreboard is used here for the room closure to the outside, which increases the manufacturing energy demand of the thermal insulation to about the level of the EPS insulation material. However, there is still considerable potential for optimisation here, for example, by reducing the proportion of wood or by replacing the softwood fibreboard. In order to support the spread of constructions with low manufacturing energy requirements, monetary subsidies for such constructions could be established. It is crucial that such subsidies are only granted for highly efficient building components.

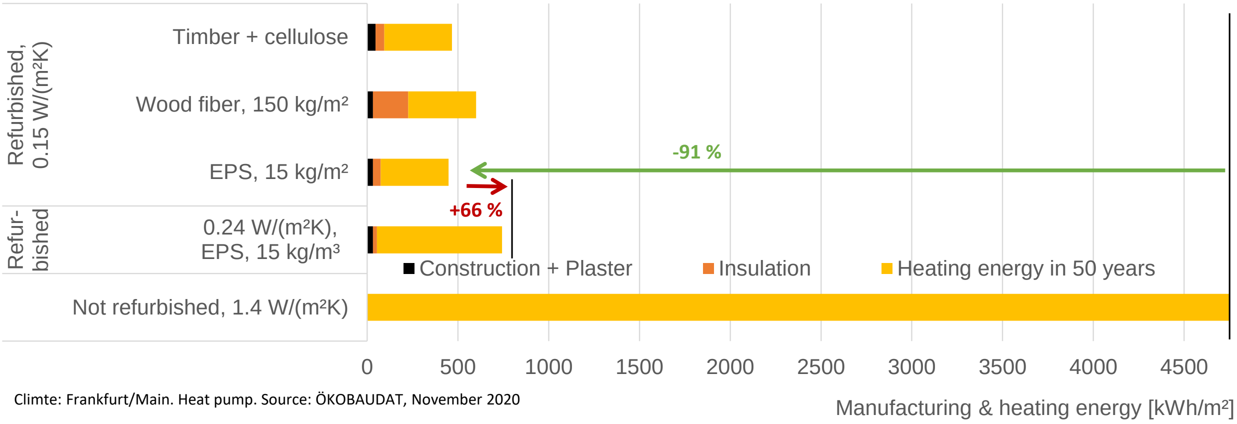

Figure 11: The energy demand from production and heating energy over 50 years of different insulation standards and insulation systems before and after modernisation.

3 CO_2

Carbon sequestered in fossil-based materials was removed from the atmosphere a long time ago and contributes to global warming as soon as it is released, e.g. through the combustion of these materials. Carbon from fossil sources is, therefore, sooner or later (if it is not permanently deposited after material use), a source of CO_2.

In contrast, the carbon bound in renewable materials has only recently been removed from the atmosphere. If, for example, the wood were to remain in the forest instead of being processed into a building material, it would be released by the rotting of the wood and bound again in other trees, the CO_2 cycle is closed. The growth and rotting processes are (although not related to the individual tree and its successor, but possibly to the forest as a whole) CO_2-neutral. By using the wood as a building component, the carbon it contains is removed from this cycle and stored in the structure. A carbon sink is created as long as the carbon is not oxidised to CO_2 through decay, combustion or other processes, and released back into the atmosphere, cf. also Figure 12.

Such CO_2 sinks are essential for mitigating climate change. This sink can be accounted for with a negative CO_2 emission. If the sequestered carbon is released after use, i.e. the carbon reservoir is discharged, the sink becomes a source, and the resulting CO_2 must also be accounted for as such in order to restore the CO_2 neutrality of the natural process. Consequently, this means that e.g. waste wood (which was previously assessed as a CO_2 sink) is now to be treated like fossil fuel during combustion.

These assessments are complex and can be misleading if not done correctly. It is certainly easier not to include renewable carbon as a sink. There seems, however, to be a general interest and popularity for this type of accounting. It is important that such calculations must be done correctly, as described above, if this method is chosen for an assessment. However, the chosen database ÖKOBAUDAT does not give the possibility for such kind of differentiated assessment.

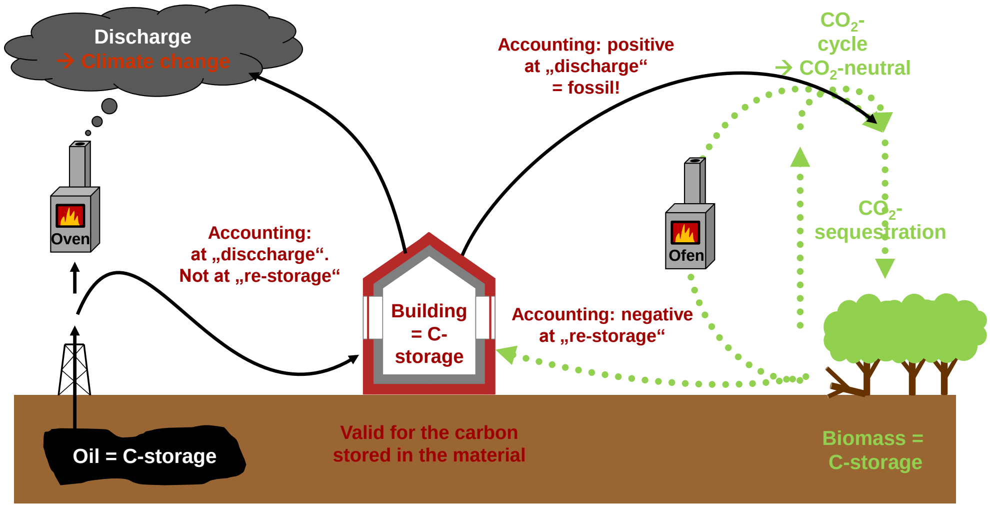

Figure 12: CO_2-paths

Figure 13 shows the global warming potential of the discussed renovation variants, including the CO_2 emission of heating with heat pump. For this purpose, it was assumed that the CO_2 factor of electricity decreases linearly to zero by 2050, which results in an average factor of 126 $kgCO_2eq/kWh_{End}$. Compared to the not refurbished variant, 85 % of the emissions can be saved by improving the thermal insulation with EPS. The ETICS with wood fibre insulation and the timber construction with cellulose insulation both achieve 97 % savings, as the carbon stored in the construction is used as a sink. In contrast, the stored fossil carbon in EPS insulation is accounted for directly at the point of extraction, not at the point of release.

The PER methodology introduces a biomass budget that reflects the limited availability of biomass. This finite nature of biomass also applies to the building construction sector. It is not the goal of building construction to store as much CO_2 as possible in individual buildings but to use this limited resource as efficiently as possible so that it can replace fossil and possibly also mineral materials with high manufacturing energy demands in as many buildings as possible. Thus, as with our energy supply, it is a matter of finding a holistic optimum.

The primary purpose of a building is to provide a comfortable and healthy environment for the users who spend most of their lives indoors.

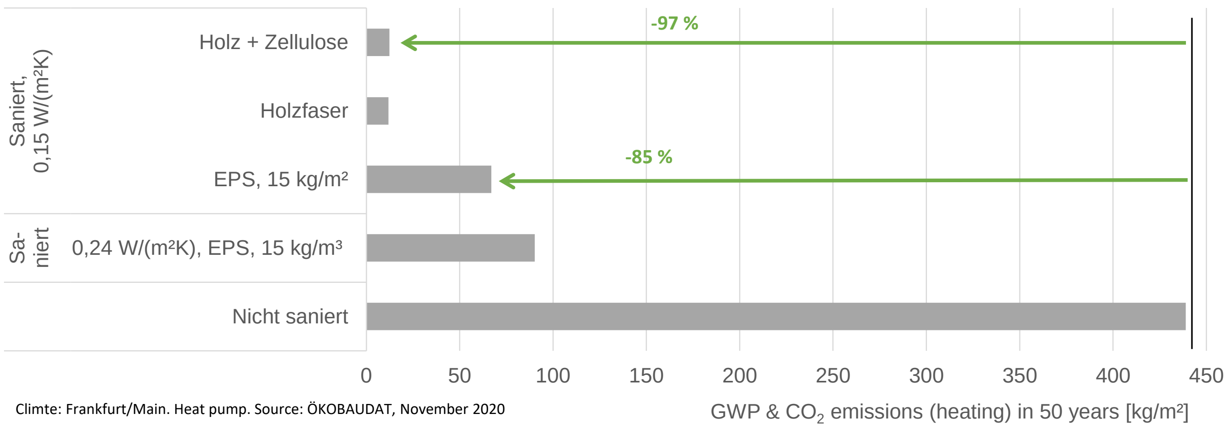

Figure 13: The GWP and CO_2-emissions of the previously discussed retrofitting approaches.

4 QUELLEN

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5 THE TOOL

Following, we present some screen-shots of the related MS Excel-Tool

5.1 SHEET 1, ABOUT THE TOOL

About the tool

outPHit

outPHit Manufacturing-Energy-Tool v. 1.0

Use the tool to

- Assess and compare single materials regarding manufacturing energy and CO_2
- Assess and compare opaque assemblies regarding manufacturing and operational energy and CO_2
- Assess and compare glazing and window frame regarding manufacturing and operational energy and CO_2
- Assess whole buildings regarding manufacturing and operational energy as well as CO_2

How to use the tool

- Copy data from ÖKOBAUDAT into the sheet “ÖKOBAUDAT” (download the latest ÖKOBAUDAT CSV-file from https://www.oekobaudat.de/en/service/downloads.html) or
- Put data from EPDs manually in the sheet “ÖKOBAUDAT”
- Select materials in column “Material” in the sheet “Material editor”
  - Add service life and thermal conductivity.
  - Adjust thickness and density if needed. Beware of correct conversion, for automatically conversion does not work in all cases.
- Put your wall, roof etc. together in the sheet “Opaque assemblies”.
  - Use the reduction factor of 1, if the assembly is to ambient air, 0.6, if to ground and 0 if it is an interior construction, which only counts to manufacturing energy, but not to operational energy.
  - Use “Count” to define with “1”;”0”, if a material should count to embodied energy (e.g. “0” for the existing building structure in retrofits).

- Set up the energy balance including manufacturing energy and CO2 of a building in the sheet “Balance”.
  - Choose your climate. You can define own climates in the “Date”-sheet. Simply copy the figures from PHPP.
  - Set your utilisation pattern.
  - If you define “yes” for including stored energy, the calorific energy bound chemically in the materials will be included in the manufacturing energy. For this energy will not transformed during the service life thus will be available afterwards, PHI recommends to choose “no”.

  - Consideration period and the start of the period. You can define the CO2 factors and their degression in the “Data”-sheet.
  - Choose your heating system, the SPF of the heat pump (if applicable) and the distribution energy.
  - Write down the treated floor area, e.g. from PHPPs Area-sheet.
  - Define your ventilation by putting in the effective heat recovery efficiency as well as the average airflow rate. Use figures from PHPP e.g.

  - Select now the opaque assemblies and type in their respective areas, e.g. from PHPPs Area-sheet.
  - Select your glazing, respective orientation and glazing areas, e.g. from PHPPs Window-sheet.
  - Select a window frame and the respective profile length. If you want to use the length from PHPP, calculate sum them up from the installation length in the Window-sheet or divide the frame area by an average frame width. In PHPP 10, you can sum up the length directly.

Example	Meaning
78.8	Input field: Please enter the required value here
015-Cement screed	Data entry field with drop down list
6619	Calculation field; please do not change
78.8	Field with reference to another worksheet
126.0	**Important result**

outphit – Deep retrofits made faster, cheaper and more reliable

outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards.

outphit.eu

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Energy balance

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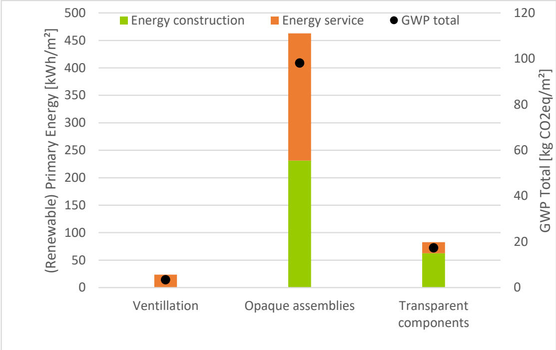
General settings

Climate	1-Frankfurt/Main (DE)	
	Degreehours [kKh/a]	79
	Heating period (days)	214
Utilisation pattern	5-Other	
	Internal gains [W/m²]	1.5
Include stored energy (PERM, PENRM)		no
Period under consideration [years]		20
	Start year of period	2022
Heating	Heat pump	
SPF heat pump		3.00
Heat generator efficiency		100%
Distribution efficiency		90%

Energy carrier	Average CO2-factor in period	PER-factor
Electricity	263	1.80
Natural / EE gas	249	1.75
Biomass	19	1.10

Treated floor area	m^2_{TFA}	160.00



	Energy construction	Energy service	GWP total	Heating energy
	kWh/m²	kWh/m²	CO_{2eq}/m^2	kWh/(m²a)
Internal gains		-99	-15	-7.4
Ventillation		24	3	1.8
Opaque assemblies	231	232	98	17.4
Transparent components	63	20	17	1.5
Sum	**294**	**275**	**119**	**13.2**

Ventillation

Effective heat recovery efficiency	Average air-flow rate
$\eta_{HR,eff}$	m³/h
89%	99

	Energy construction	Energy service	GWP total	Ventillation loses
	kWh	kWh	CO_{2eq}	kWh/a
Sum		**3785**	**553**	**284**
Sum [m^2_{TFA}]		**23.66**	**3.45**	**1.77**

Areas and assemblies

Opaque assemblies

	Opaque assemblies	Area	U-value	Reduction factor	Energy construction	Energy service	GWP total	Transmis-sion losses
		m²	W/(m²K)	ft [-]	kWh	kWh	CO_{2eq}	kWh/a
01	01 Flor slab, Concrete, XPS	83.0	0.118	0.6	6041	6181	3015	464
02	02 Exterior wall, Lime-Sand stone, EPS	196.2	0.127	1.0	13278	26165	8499.77	1962
03	03 Roof, Cellulose	95.8	0.089	1.0	5130	8974	-247.04	673
04	04 Wall to neighbour	44.5	1.077	0.0	1590	0	686.47	0
05	05 Interior ceiling	166.0	0.273	0.0	9370	0	3750.48	0
06	06 Interior wall	59.00	2.936	0.0	1586	0	618.08	0
12								
	Delta-U thermal bridges	292.0	-0.014	1.0		-4306	-628.82	-323
	Delta-U thermal bridges	83.0	0.001	0.6		52	7.66	4
	Delta-U thermal bridges (installation)	45.8	0.024	1.0		1157	168.92	87
				Sum	**36995**	**37066**	**15702**	**2780**
				Sum [m^2_{TFA}]	**231.22**	**231.67**	**98.14**	**17.37**

Glazing

	Glazing	Orientation	Area	U-value	g-value	Energy construction	Energy service	GWP total	Transmis-sion losses
			m²	W/(m²K)	[-]	kWh	kWh	CO_{2eq}	kWh/a
01	06 Triple low-e	North	3.22	0.53	0.5	636	719	278	54
02	06 Triple low-e	West	12.54	0.53	0.5	2476	200	701	15
03	06 Triple low-e	South	17.50	0.53	0.5	3455	-5379	152	-403
04	06 Triple low-e	East	5.53	0.53	0.5	1092	152	318	11
12									
			38.8		**Sum**	**7658**	**-4307**	**1449**	**-323**
					Sum [m^2_{TFA}]	**47.86**	**-26.92**	**9.06**	**-2.02**

Window frames

	Window frames	Profile length	U-value	b_f	Energy construction	Energy service	GWP total	Transmis-sion losses
		m	W/(m²K)	ft [-]	kWh	kWh	CO_{2eq}	kWh/a
01	05 PH Ti-Alu integral with PU insulation	81.00	0.700	0.086	2357	7525	1328	564
12								
		81.0		**Sum**	**2357**	**7525**	**1328**	**564**
				Sum [m^2_{TFA}]	**14.73**	**47.03**	**8.30**	**3.53**

5.3 SHEET 3, OPAQUE ASSEMBLIES

Opaque Assemblies

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		U-value	Energy construction	Energy service	GWP total	Reduction factor
		W/(m²K)	kWh/m²	kWh/m²	CO_{2eq}/m²]	f_t [-]
01	01 Flor slab, Concrete, XPS	0.118	73	74	36.3	0.6
02	02 Exterior wall, Lime-Sand stone, EPS	0.127	68	133	43.3	1.0
03	03 Roof, Cellulose	0.089	54	94	-2.6	1.0
04	04 Wall to neighbour	1.077	36	0	15.4	0.0
05	05 Interior ceiling	0.273	56	0	22.6	0.0
06	06 Interior wall	2.936	27	0	10.5	0.0
07	07 EIFS Wood faser	0.148	142	156	18.7	1.0
08	08 Leightweight timber wall Cellulose	0.148	59	156	8.5	1.0
09	09 Monolithic Aerated concrete	0.148	46	156	44.1	1.0
10	10 Monolithic Brickwork	0.148	72	156	43.9	1.0
11	11 Retrofit (EPS g)	0.148	31	156	31.3	1.0
12	12 Retrofit (Holzweichfaser)	0.103	105	109	-1.2	1.0
13	13 Leightweight timber wall Mineral wool	0.148	73	156	21.3	1.0
14	14 Leightweight timber wall Straw	0.147	59	155	-0.7	1.0
15	15 EIFS Phenol	0.148	74	156	47.1	1.0
16	16 EIFS Mineral faser	0.148	117	187	63.8	1.0
17	17 0		0	#WERT!	#WERT!	1.0

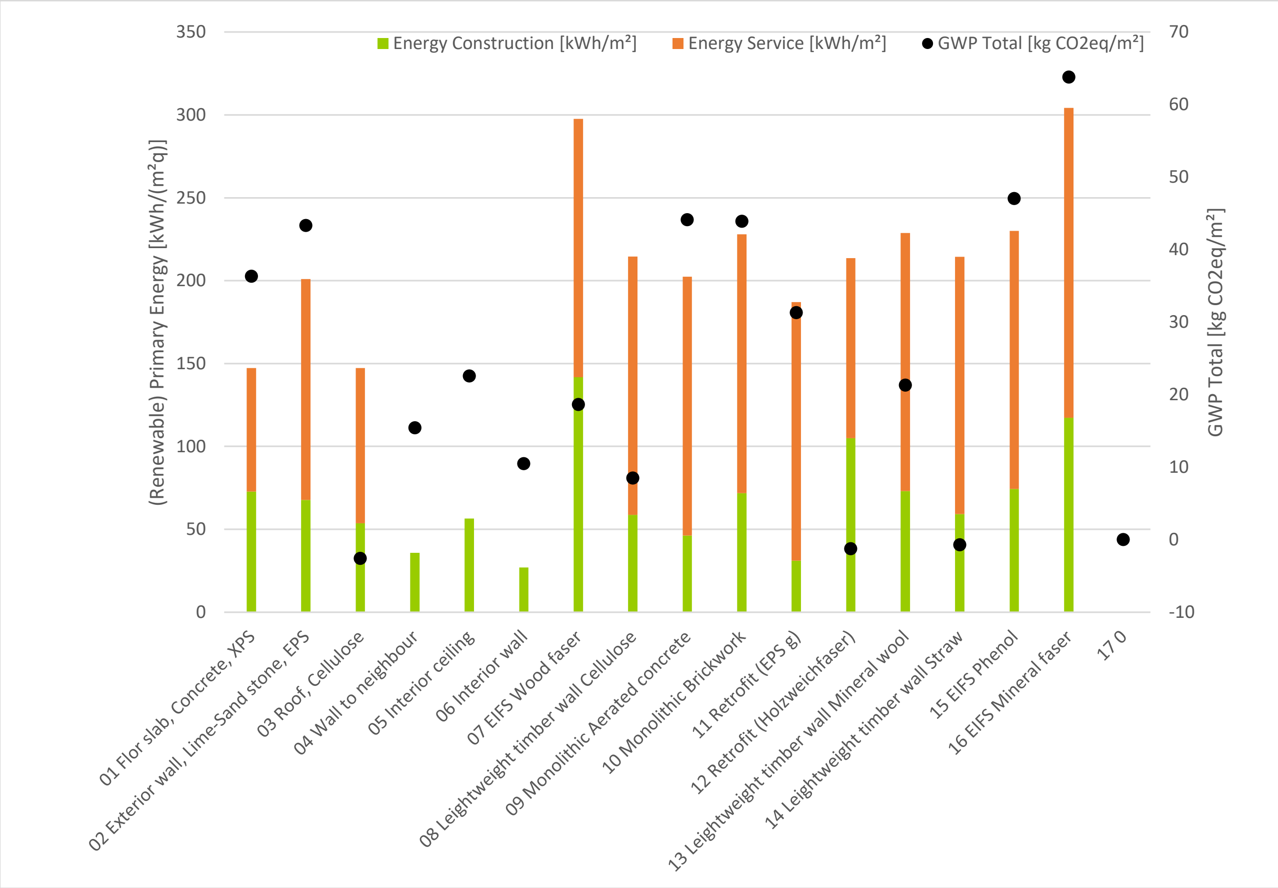
Assembly no.	Building assembly description
1	Flor slab, Concrete, XPS

Heat transmission resistance [m²K/W]

0.17	interior Rsi	0.6	Recuction factor f_t [-] 1,0 to ambient air; 0,6 to ground; 0 interior construction
0.00	exterior Rse		

Area section 1	Count?	Area section 2 (optional)	Count?	Area section 3 (optional)	Count?	Thickness
	1 / 0					[mm]
015-Cement screed; 2400 kg/m³; 1.6 W/(mK); 60 years	1					50
324-EPS-foam (grey) with radiation absorber; 16.6 kg/m³; 0.035 W/(mK); 60 years	1					35
013-UD_Steel reinforced concrete 100 kg steel; 2469.42675159236 kg/m³; 0.07 W/(mK);	1					160
322-Extruded polystyrene (XPS); 39 kg/m³; 0.036 W/(mK); 80 years	1					180
100% Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3		Total
U-value supplement [W/(m²K)]						42.5 cm

	(Renewable) Primary energy		Carbon dioxide emissions	
			U-value	0.118 W/(m²K)
Construction phase	73	kWh_{PE}/m^2	25	kg CO_2eq/m² (embodied + manufacturing)
Service period	74	kWh_{PER}/m^2	11	kg CO_2eq/m²
Total	**147**	kWh/m²	**36**	kg CO_2eq/m²



5.4 SHEET 4, TRANSPARENT COMPONENTS

Transparent components

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Settings

		Degreehrs Gt [kKh/a]	Radiation [kWh/(m²a)] by Orientation North	East	South	West	Horizontal
Climate	1-Frankfurt/Main (DE)	79	144	228	372	233	352

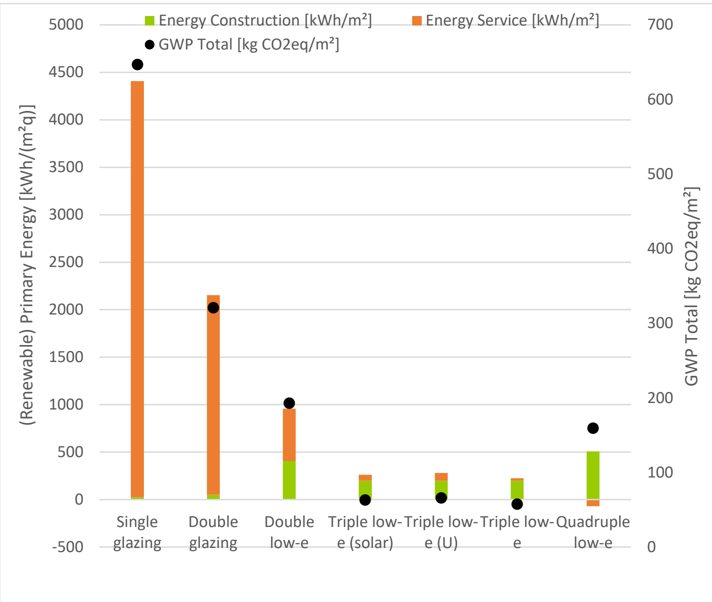
		Shading	Dirt	Non-vertical
Solar irradiation reduction factor	0.32	0.40	0.95	0.85

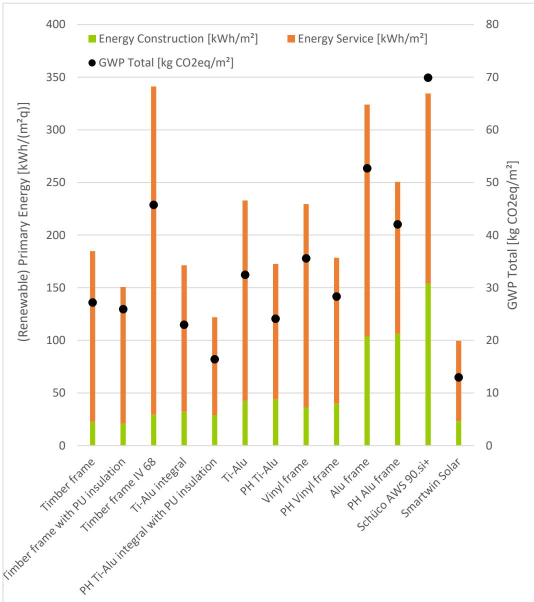
Glazing

No.	Name	Type	Ug [W/(m²K)]	g [-]	Sum glass [mm]	Add. glass [mm]	Filling	Sum Gas [mm]	Edge bond	Manufacturing Energy [kWh/m²]	Manufacturing GWP [kg CO2eq/m²]	Service Orientation	Service Energy [kWh/m²]	Service GWP [kg CO2eq/m²]	Total Energy [kWh/m²]	Total GWP [kg CO2eq/m²]
01	Single glazing	Single glazing	5.00	0.90	4		None	0	None	25.1	6.7	East	4382.1	639.9	**4407.2**	**646.7**
02	Double glazing	Double (no coating)	2.80	0.86	8		None	16	Warm edge	50.2	13.5	East	2104.1	307.3	**2154.3**	**320.7**
03	Double low-e	Double low-e (1 coating)	1.12	0.64	8		Argon	16	Warm edge	406.7	112.4	East	550.7	80.4	**957.5**	**192.8**
04	Triple low-e (solar)	Triple low-e (2 coatings)	0.64	0.62	12		Argon	32	Warm edge	197.4	53.6	East	64.8	9.5	**262.2**	**63.0**
05	Triple low-e (U)	Triple low-e (2 coatings)	0.48	0.43	12		Argon	32	Warm edge	197.4	53.6	East	83.0	12.1	**280.4**	**65.7**
06	Triple low-e	Triple low-e (2 coatings)	0.53	0.54	12		Argon	32	Warm edge	197.4	53.6	East	27.5	4.0	**225.0**	**57.6**
07	Quadruple low-e	Quadruple low-e (3 coatings)	0.40	0.50	16		Argon	48	Warm edge	508.2	159.2	East	-70.1	0.0	**438.1**	**159.2**

Frames

No.	Name	Description	Uf [W/(m²K)] Original	Uf Alternative	Uf Used	Ψg [W/(mK)] Original	Ψg Alternative	Ψg Used	bf [m] Original	bf Alternative	bf Used	Manufacturing Energy [kWh/m]	Manufacturing GWP [kg CO2eq/m]	Service Energy [kWh/m]	Service GWP [kg CO2eq/m]	Total Energy [kWh/m]	Total GWP [kg CO2eq/m²]
01	Timber frame	Soft timber frame form PHI spacer certification, warm climate	0.99		0.99	0.035		0.035	0.120		0.120	22.8	3.5	162.0	23.7	**184.8**	**27.2**
02	PH Timber frame with PU insulation	Soft timber frame form PHI spacer certification, cool, temperate climate	0.78		0.78	0.030		0.030	0.120		0.120	21.0	7.0	129.7	18.9	**150.7**	**25.9**
03	Timber frame IV 68	ÖKOBAUDAT generic Datasets	1.60		1.60	0.040		0.040	0.160		0.160	29.3	0.2	311.8	45.5	**341.1**	**45.7**
04	Ti-Alu integral	Soft timber-Alu integral frame form PHI spacer certification, warm climate	1.03		1.03	0.035		0.035	0.094		0.094	32.1	2.6	139.2	20.3	**171.3**	**23.0**
05	PH Ti-Alu integral with PU insulation	Soft timber-Alu integral frame with PU-insulation form PHI spacer certification, cool, temperate climate	0.73	0.70	0.70	0.031	0.028	0.028	0.094	0.086	0.086	29.1	2.8	92.9	13.6	**122.0**	**16.4**
06	Ti-Alu	Soft timber-Alu frame form PHI spacer certification, warm climate	1.19		1.19	0.038		0.038	0.120		0.120	42.5	4.7	190.4	27.8	**232.9**	**32.5**
07	PH Ti-Alu	Soft timber-Alu frame with XPS-insulation form PHI spacer certification, warm climate	0.75		0.75	0.032		0.032	0.120		0.120	44.1	5.3	128.5	18.8	**172.6**	**24.1**
08	Vinyl frame	Vinyl frame form PHI spacer certification, warm climate with GRP reinvorcement	1.16		1.16	0.040		0.040	0.124		0.124	36.2	7.4	193.3	28.2	**229.5**	**35.6**
09	PH Vinyl frame	Vinyl frame form PHI spacer certification, warm climate with GRP reinforcement	0.82		0.82	0.034		0.034	0.119		0.119	39.7	8.1	138.7	20.3	**178.4**	**28.3**
10	Alu frame	Alu frame seperated by high rigid PU-foam form PHI spacer certification, warm climate	1.17		1.17	0.043		0.043	0.142		0.142	103.7	20.5	220.3	32.2	**324.0**	**52.7**
11	PH Alu frame	Alu frame seperated by high rigid PU-foam form PHI spacer certification, cool, temperate climate	0.71		0.71	0.036		0.036	0.142		0.142	106.2	20.9	144.4	21.1	**250.7**	**42.0**
12	Schüco AWS 90.si+	According to Ökobaudat, thermal values and frame hight according to PHI certification	0.79		0.79	0.023		0.023	0.188		0.188	153.9	43.5	180.7	26.4	**334.6**	**69.9**
13	Smartwin Solar	Spruce/fir frame, special corner conection works as glass carrier (side/top profile)	0.75		0.75	0.026		0.026	0.062		0.062	23.3	1.8	76.3	11.1	**99.6**	**13.0**





5.5 SHEET 5, TRANSPARENT COMPONENTS

Materialeditor

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Name	Thermal conductivity λ [W/(mK)]	Manfacturing energy [kWh/m³]	GWP [kg CO2eq/m³]	Service life [a]	User defined name	Material
001-EPS-foam (grey) with radiation absorber; 16.6 kg/m³; 0.032 W/(mK); 40 years	0.032	218	50	40		EPS-foam (grey) with radiation absorber
002-Mineral wool (flat roof insulation); 145 kg/m³; 0.035 W/(mK); 40 years	0.035	680	208	40		Mineral wool (flat roof insulation)
003-Mineral wool (pitched roof insulation); 30 kg/m³; 0.035 W/(mK); 40 years	0.035	193	46	40		Mineral wool (pitched roof insulation)
004-Wood fiber insulation - dry process (German average); 150.76 kg/m³; 0.045 W/(r	0.045	700	-154	40		Wood fiber insulation - dry process (German average)
005-Phenolic resin foam; 40 kg/m³; 0.022 W/(mK); 40 years	0.022	467	92	40		Phenolic resin foam
006-FASBA e.V. Construction Straw; 100 kg/m³; 0.049 W/(mK); 40 years	0.049	20	-127	40		FASBA e.V. Construction Straw
007-Cellulose fibre blow-in insulation material; 45 kg/m³; 0.04 W/(mK); 40 years	0.040	34	-73	40		Cellulose fibre blow-in insulation material
008-; kg/m³; W/(mK); years		#NV	#NV			
009-Sand-lime brick 2022; 2000 kg/m³; 1 W/(mK); 80 years	1.000	614	303	80		Sand-lime brick 2022
010-Aerated concrete P2 04 non-reinforced 2022; 300 kg/m³; 0.07 W/(mK); 80 years	0.070	285	148	80		Aerated concrete P2 04 non-reinforced 2022
011-Brick (filled with insulating material); 575 kg/m³; 0.07 W/(mK); 80 years	0.070	509	146	80		Brick (filled with insulating material)
012-Brick (unfilled); 575 kg/m³; 0.5 W/(mK); 80 years	0.500	388	113	80		Brick (unfilled)
013-UD_Steel reinforced concrete 100 kg steel; 2469.42675159236 kg/m³; 0.07 W/(r	0.070	742	309	80		UD_Steel reinforced concrete 100 kg steel
014-; kg/m³; 2.1 W/(mK); years	2.100	#NV	#NV			
015-Cement screed; 2400 kg/m³; 1.6 W/(mK); 60 years	1.600	977	438	60		Cement screed
016-Gypsum interior plaster; 900 kg/m³; 0.54 W/(mK); 40 years	0.540	616	118	40		Gypsum interior plaster
017-Lime-cement plaster; 1800 kg/m³; 1 W/(mK); 40 years	1.000	905	355	40		Lime-cement plaster
018-Clay plaster; 900 kg/m³; 0.91 W/(mK); 40 years	0.910	317	93	40		Clay plaster
019-Glue for ETICS	0.700	496	104	40	Glue for ETICS	Adhesive for gypsum board
020-Gypsum fibreboard (thickness 0.01 m); 1250 kg/m³; 0.35 W/(mK); 40 years	0.350	1437	319	40		Gypsum fibreboard (thickness 0.01 m)
021-; kg/m³; W/(mK); years		#NV	#NV			
022-Solid construction timber (generic, 15% moisture / 13% H2O content); 529 kg/m³	0.130	1434	-636	80		Solid construction timber (generic, 15% moisture / 13% H2O
023-CLT cross-laminated timber; 480 kg/m³; 0.13 W/(mK); 80 years	0.130	1015	-601	80		CLT cross-laminated timber
024-Oriented Strand Board (German average); 600 kg/m³; 0.13 W/(mK); 80 years	0.130	3027	-609	80		Oriented Strand Board (German average)
025-; kg/m³; W/(mK); years		#NV	#NV			
026-PIR high-density foam; 31 kg/m³; W/(mK); 40 years		50	12	40		PIR high-density foam
027-Extruded polystyrene (XPS); 32 kg/m³; 0.035 W/(mK); 40 years	0.035	443	95	40		Extruded polystyrene (XPS)
028-GLAPOR foamglass; 120 kg/m³; 0.04 W/(mK); 40 years	0.040	433	87	40		GLAPOR foamglass