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Multi-criteria Comparison of Insulation Materials

Condensed report, Version 1.3

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1 Spider diagrams: Relevant information at a glance

1.1 Goal and scope

There are a wide variety of insulation materials available on the European market nowadays, which all have different properties and present different advantages and disadvantages depending on the area of application. Besides the physical properties and the performance of insulation materials that are relevant for constructional reasons, criteria of sustainability are becoming increasingly important in the building sector. Opinions that some insulation materials are more sustainable than others are widespread. The claims with regards to sustainability of a material are often made in relation to one single specific property which has been chosen as a basis of comparison. Properties such as primary energy consumption or recyclability or emissions to the environment are commonly put forward. Our goal was to create a more complete, differentiated and balanced approach to assess sustainability. The purpose of this study is to present a multi-criteria evaluation and comparison of different insulation materials in common applications. The chosen criteria cover the whole life cycle of insulation materials. In addition to using the classical method of life cycle impact assessment which is closely related to the technical performance of a product, we also included criteria which are often neglected when assessing the sustainability of materials. These include installation cost, five aspects to measure how suitable a material may be for the given application, the risk for the release of hazardous substances and the recovery potential in the end of use phase.

The study is supposed to address a broad audience including specialists in the building sector as well as decision makers, political groups, associations and various stakeholders.

The result of the study are performance scores for each insulation material with regards to the criteria evaluated. Spider-diagrams were chosen for the representation of these performance scores. No attempt was made to aggregate the results into a single score. This was a conscious decision for the sake of transparency. Although a single score would be easier to interpret for the user it hides the fact that often insulation materials have advantages with regards to certain criteria considered and also drawbacks with regards to others. Any single scoring systems would have to weigh the criteria when summing them up. We wanted to leave this decision up to the reader, as it inevitably is of subjective nature.

1.2 How the Spider-Diagrams work

The spider diagram is useful to graphically represent different criteria in a consistent way. It is possible to visualize complex issues simply by following certain principles:

1. The selection of the criteria represents the whole life cycle including all aspects that are important according to common practice and standards.
2. Every criterion is represented on its own axis.
3. The criteria are based on objective characteristics and comparable data, accepted by most of the experts in the field of LCA and environmental research.
4. The interpretation should be intuitive, showing best values at the outside of the spider axes. This choice should be reflected by the terminology of the axes naming positive qualities (see Fig. 1).
5. The axes are comparing the results within a given application. It is thus not possible to compare spider diagrams between applications.

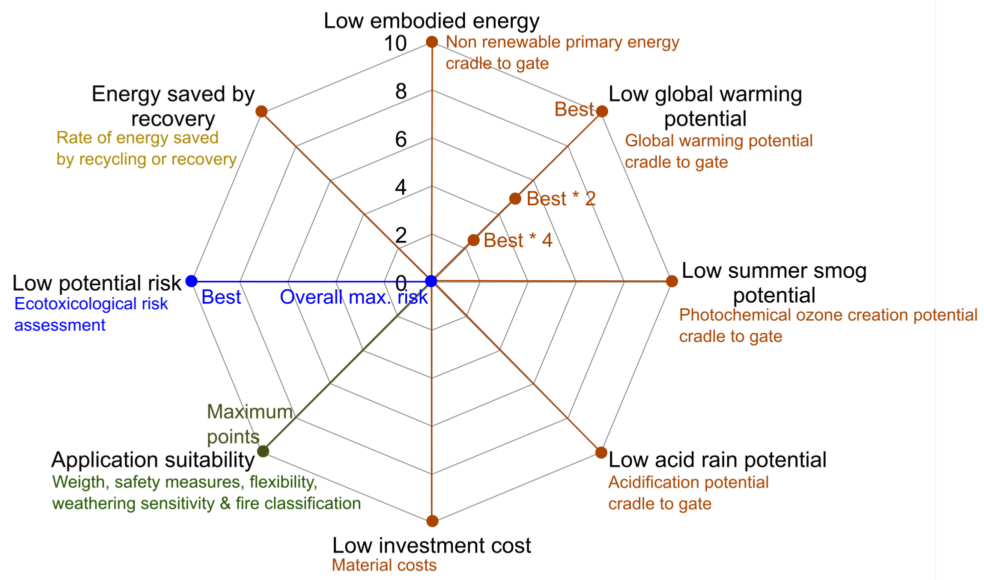


Fig. 1: Explanation of the spider axes

Starting from the top and going around the spider clockwise, the first four criteria are LCIA (Life Cycle Impact Assessment) indicators from cradle to gate. The next two axes “low investment cost” and “application suitability” are about the installation on the construction site. The axis “low potential risk” represents an assessment of the ecotoxicological risk associated with the use phase. The last axis presents the results for the end of life phase.

For the assessment of insulation materials, the functional unit is one square metre of a construction with a defined insulation performance (R-value). The calculation of the R-value includes the insulation, bearing structure and thermal bridges. The functional unit includes the insulation material and other quantities of materials that are influenced by the thickness of the insulation such as fixations, dowels and consoles. Table 1 below gives an overview of the constructional elements that were considered in the calculation of the R-values as well as the insulation materials considered for all applications. The choice of insulation materials takes into account the most commonly used materials as well as two bio-based options.

Table 1: Systems assessed

Area of application/R-value	Insulation materials
Flat roof, walkable, 7 m^2K/W (Concrete ceiling and insulation)	White EPS, Grey EPS, Stone wool, XPS, PUR/PIR, Foam glass
Ventilated façade, 5 m^2K/W (brick wall, insulation and thermal bridges)	Grey EPS, Stone wool, Glass wool, PUR/PIR, Hemp fibre
ETICS, 5 m^2K/W (concrete wall, insulation, plaster)	White EPS, Grey EPS, Stone wool, PUR/PIR, Wood fibre
Perimeter, no groundwater, 5 m^2K/W (concrete wall and insulation)	White EPS, XPS, PUR/PIR, Foam glass
Floor, insulation above concrete slab, 4 m^2K/W(concrete slab and insulation)	White EPS, Stone wool, XPS, Wood fibre

1.3 The spider axes explained

Table 2 gives an overview of the different criterions that were evaluated on the spider axes and the underlying indicators.

Table 2: The spider axes

Spider axis	Indicator	Scope
Low embodied energy	Non-renewable primary energy [MJ]	Cradle to gate
Low global warming potential	GWP [kg] CO_2-eq.	Cradle to gate
Low summer smog potential	POCP [kg] C_2H_4-eq.	Cradle to gate
Low acid rain potential	AP [kg] SO_2-eq.	Cradle to gate
Low investment costs	Material costs in €	Insulation material only, for selected applications (flat roof, ETICS, perimeter)
Application suitability	Weight of insulation per m^2 Safety measures Flexibility of slabs (only for ventilated façade) Weathering sensitivity Fire classification of slabs	Assembly, sum of five aspects
Low potential risk	Potential risk factors derived from quantities, H-phrases and exposure risk for toxic additives	Use phase
Recovery potential	Rate of recovered primary energy [MJ]	End of Life

The four criteria for **low embodied energy**, **low global warming potential**, **low summer smog potential** and **low acid rain potential** represent the environmental impact generated by the production of the materials. The higher the score, the lower is the respective impact. These impacts are evaluated using data from valid EPDs[1] according to EN 15804. The system boundaries for the LCIA data considered here are cradle to gate which means that environmental impacts that occur beyond the factory gate (installation, maintenance, deconstruction, disposal etc.) are not taken into account. The scaling of the results on these four axes follows the same underlying principle. For a given impact (for example global warming) and an application (for example flat roof) the material with the lowest impact is given the maximum score of 10 points. The other materials receive scores that are inversely proportional to the lowest impact. For example, a product that generates an impact double as high as the product with the lowest impact would receive a score of 5.

The criteria low investment costs and application suitability represent the installation phase. The criterion **low investment cost** could only be considered for the applications flat roof, ETICS and perimeter insulation. Only insufficient data was available for other applications. We considered investment cost for the insulation materials. Data from experts around Europe have been used for the evaluation. The scores are attributed to the different insulation materials in the same manner as for the environmental impact indicators. The material with the lowest price will receive a spider score of 10. All other materials will receive scores relative to the lowest price.

The score on the axis **application suitability** is aggregated from the performance of the considered materials with regards to different aspects. These include weight, safety measures necessary for installation, weathering sensitivity, fire classification and – for the application ventilated façade only – flexibility. Depending on the application some of these aspects are more relevant than others. Therefore, a maximum number of points is attributed to each aspect for each application as shown in Table 3. The sum of the maximum points in each application equals to a score of 10.

Table 3: Application suitability, maximum scores for parameters

Application	**Maximum scores application suitability parameters**				
	Insulation weight	**Safety measures**	**Flexibility**	**Weathering sensitivity**	**Fire classification**
Flat roof	3	2	N/A*)	3	2
Ventilated façade	2	2	3	1	2
ETICS	3	2	N/A	3	2
Perimeter	5	5	N/A	N/A	N/A
Floor DEO	5	2	N/A	1	2

**) N/A: not assessed*

Weight was considered being an ergonomic factor of occupational health. Heavier insulation slabs increase the risk of back injuries. Heavier slabs might also increase

[1] Institut Bauen und Umwelt e.V.http://ibu-epd.com/

the probability of errors during installation. The score for insulation weight was given in relation to the lowest weight, which received the maximum score according to Table 3. According to material safety data sheets stone wool and glass wool require personal protection equipment during handling whereas all other insulation materials considered require no safety measures. If safety measures are required a product receives 0 points for safety measures. Weathering sensitivity is closely linked to water absorption capacity. Insulation materials should be dry before installation. Materials that can absorb moisture during storage on the construction site bear a certain risk for future damage to the construction. A distinction is made between materials that are non-sensitive such as XPS, materials that show some sensitivity such as EPS and products with a higher water absorption capacity such as mineral wool. Fire classification was considered because insulation materials with a lower fire classification might require special measures according to construction law in order to ensure fire safety of the whole building. A maximum score for fire classification was given to materials with a fire classification of A1, 5/6 for a classification of A2 and so on down to 1/6 of the maximum for a classification of E.

The score on the axis **low potential risk** takes into account regulated additives in materials that might be released during the use phase. Since the flame retardant HBCD in polystyrene products has been replaced in the last couple of years mostly with Polymeric FR, there are few additives in the insulation materials considered here that are relevant with regards to impacts on the environment and human health during the use phase. In that sense, the axis expresses primarily the significant change that has occurred with regards to the use of problematic flame retardants in polystyrene insulation materials. The evaluation of the potential risk is based on a method developed for BASF in Germany[2]. Since the lowest score on this axis is zero for no risk, the scaling cannot be done in proportion to the minimum. To allow a scoring, a hypothetical maximum risk was defined, that would receive a score of 0 points. All other scores are calculated in a linear relationship between 0 and the hypothetical maximum risk.

Finally, the score on the axis **recovery potential** represents the end of life and informs on potential benefits due to recycling or energy recovery. The proportion of recovered energy has been chosen as a simple way of measuring how ecologically worthwhile a recycling option is. This choice allows us to compare recycling and thermal recovery on the same scale. The recycling option that saves the biggest share of energy of the recycled or incinerated material will receive a score of 10. Scores for materials with lower shares of saved energy will be proportional to the biggest share of saved energy.

[2] R. Landsiedel and P. Saling, Assessment of Toxicological Risks for Life Cycle Assessment and Eco-efficiency Analysis, Int J LCA, 2002

2 Flat roof

2.1 Description of application

The considered flat roof is non-accessible except for maintenance work. The roof is modelled without any additional roof loads. The target R-Value for the structure is 7 m^2K/W, corresponding to a U-value of 0.14 $W/(m^2K)$. The calculation of the required insulation thickness includes a concrete roof slab of 20 cm thickness and the insulation material itself. We have chosen the most common insulation materials for flat roofs including white EPS, grey EPS, stone wool, XPS, PUR/PIR and foam glass. All products have to fulfil the German class dm or better regarding their pressure strength. Application thicknesses for the insulation layer range from 15 cm in case of using PUR/PIR slabs up to 26 cm when using stone wool. The differences in weight per square meter are even bigger with 4.4 kg/m^2 when applying grey EPS and 41.2 kg/m^2 for stone wool insulation (Table 4).

2.2 Insights

Grey EPS has the best scores on four out of eight axes. It is most favourable regarding the impact on global warming and also creation of acid rain. Grey EPS has also the lowest investment costs based on the available data from Germany, Austria and Switzerland. The scores of **white EPS** are just slightly less favourable regarding the indicators related to the production phase and the material cost. This is due to the higher thermal conductivity of white EPS, resulting in a higher weight per functional unit. Both types of EPS may be used in recycling to produce new EPS slabs. This leads to the highest recycling potential for EPS materials of all materials assessed for flat roof insulation. The foaming step of both EPS qualities uses pentane which is partly released to the atmosphere. These emissions result in a summer smog potential that is higher than for other insulation materials.

The **stone wool** used for flat roof applications is of high density. This comes with a high material consumption and a worse performance compared to the plastics materials in the life cycle assessment. The high density is also the reason for its low score in application suitability. Shifting heavy slabs in a ducked position constitutes a certain risk for the workers. Stone wool has a noticeable low recovery potential despite its recyclability. The reason for this is the low primary energy content of the material. By replacing virgin materials in the production with used stone wool, only a small amount of energy can be saved. The primary energy consumption for the production of stone wool is largely determined by the melting process of minerals or used stone wool.

XPS receives lower scores than EPS on five axes and performs equally or better with regards to low summer smog potential, application suitability and low potential risk. The main reason for these results is the higher weight of the chosen XPS product compared to the EPS products. XPS would perform better in an application with higher loads, due to its higher pressure strength compared to the EPS products in the comparison. Like all plastics products, XPS loses some points in application suitability due to its fire classification. The recycling of XPS is more demanding than for EPS because of the extrusion step involved in its production with high requirements on the purity of the input materials. For this reason, no impure material can be recycled today. The best available option for XPS is thermal recovery. XPS still receives a high score for the energy saved by recovery due to its high heating value.

PUR/PIR-insulations have the lowest lambda values in today's market for mass products. This means that a thinner layer of insulation can be used to reach the desired thermal insulation performance. PUR/PIR has the lowest embodied energy from production and an almost equal performance to grey EPS with regards to the global warming potential. Its summer smog potential is moderate within the comparison. Investment cost are higher than for EPS variants according to the available data. Its application suitability is comparable to the other plastic foam materials considered. As both EPS, it is considered partly sensitive to weathering and can only reach half the maximum points for this aspect. Energy can be recovered during the incineration of used PUR/PIR-slabs. A smaller share of energy can be recovered compared to other plastic foams because of the nitrogen content of the material which causes a lower heating value.

Foam glass is a very pressure resistant product but also considerably heavier than the plastics foams in the given application. In addition to the insulation material about 10 kg/m^2 of bitumen are needed for the construction (compact roof). Foam glass receives good scores for a low summer smog potential and the application suitability. The relatively good result for the application suitability despite its high weight derives from its insensitivity to moisture, almost perfect fire resistance and the absence of any necessary safety measures during application. Foam glass is entirely made of mineral materials. These have zero energy content by definition. This LCA convention also leads to a score of zero for saved energy by recovery.

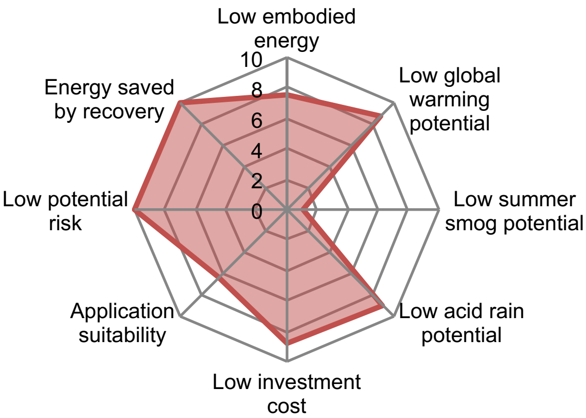
All products receive high scores for the low potential risk. They bear no environmental risk or risk for workers' health regarding any possible release of declared substances in the products. The relative score of PUR/PIR is lower due to the hazard statement (H phrase) of the flame retardant.

Table 4: Flat roof R=7 m2K/W, insulation weight per m^2

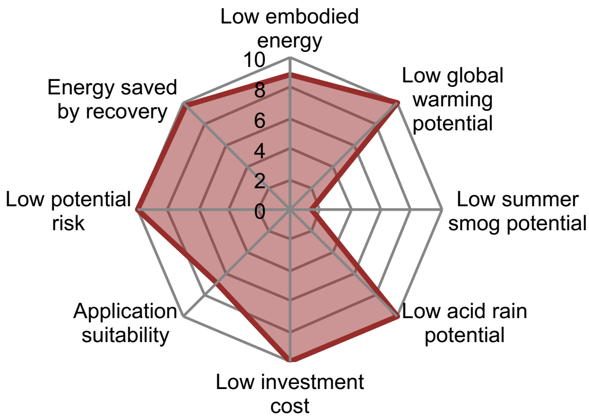
Insulation material	White EPS	Grey EPS	Stone wool	XPS	PUR/PIR	Foam glass
Weight [kg/m^2]	5.22	4.35	41.16	7.94	4.56	24.05

2.3 Spider Diagrams Flat roof, R = 7 m²K/W

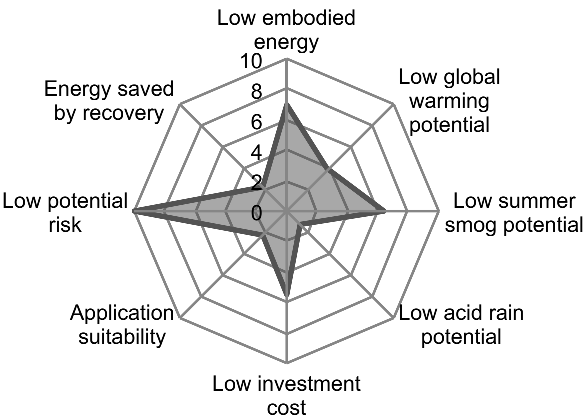
White EPS 23 cm



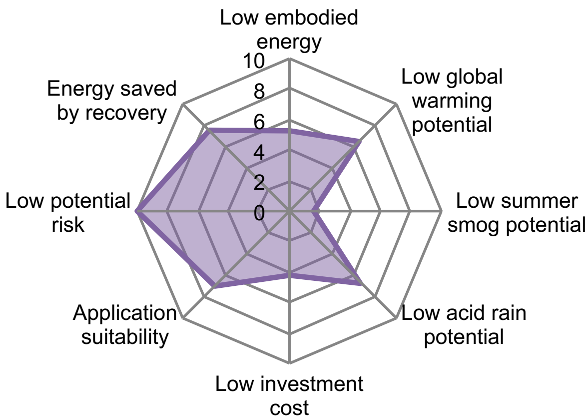
Grey EPS 21 cm



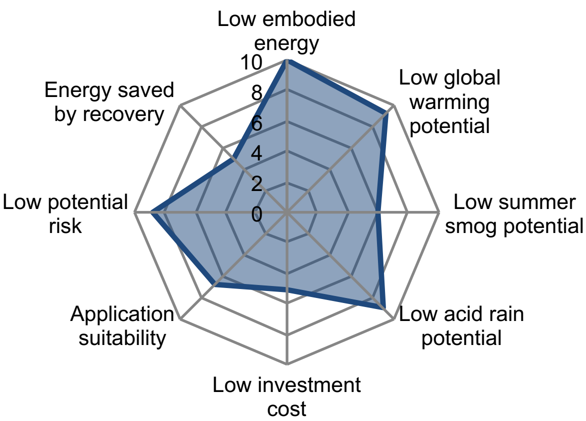
Stone wool 26 cm



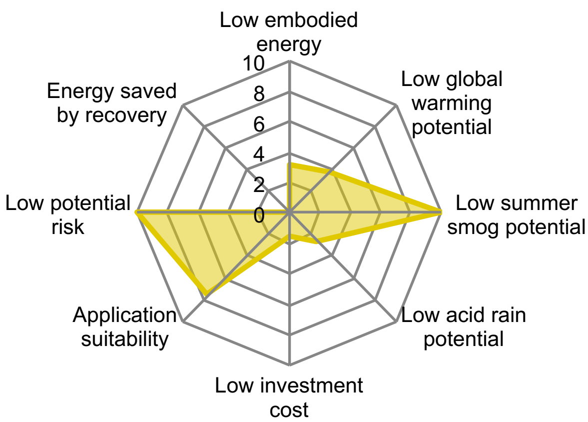
XPS 24 cm



PUR/PIR 15 cm



Foam glass 24 cm



3 Ventilated façade

3.1 Description of application

The calculation of the R-value takes into account the insulation layer, a brick wall of 0.2 m thickness and the thermal bridges caused by the fixing system (dowels or console). Console systems introduce more thermal bridges and require more insulation to achieve the same R-value than dowel systems. The target R-Value for the structure is 5 m^2K/W, corresponding to a U-value of 0.2 $W/(m^2K)$. The considered fixing system with dowels or consoles is designed to carry cladding elements up to 25 kg/m^2. The functional unit includes the insulation material and its fixation to the wall as well as the dowels or consoles. The considered insulation materials are grey EPS, stone wool, glass wool, PUR/PIR and hemp fibre. Hemp fibre is certainly not a commonly used product but was included here because it is often marketed as a product which is particularly favourable from an ecological point of view. The differences in weight per functional unit are rather small. Grey EPS is the lightest material with 2.4 kg/m^2 whereas hemp fibre with 7.7 kg/m^2 is even slightly heavier than stone wool (Table 5).

3.2 Insights

The fixing system used (dowels or console) has a significant impact on the production phase related criteria low embodied energy, low global warming potential, low summer smog potential and low acid rain potential. The use of consoles requires more insulation material to achieve the same R-value and also a higher input in metals (mainly aluminium) for the fixing system. For these reasons the scores for insulations including consoles are generally lower than for systems using dowels for fixation. The importance of the fixing systems with regards to environmental impacts is often overlooked in sustainability assessments of façade systems.

When assessing the production, **Grey EPS** achieves very good scores for low global warming potential and low acid rain potential. Its embodied energy compared to the other materials is in a medium range. Pentane emissions during production lead to a disadvantageous result regarding the summer smog potential. The score at the lower end of the comparison for application suitability is caused by the rigidity of the material which makes installation more difficult as well as its fire classification. EPS has a maximum score for low potential risk. All materials considered in this application with the exception of PUR/PIR are free of hazardous additives and receive a score of 10. EPS has also a maximum score for energy saved by recovery. Due to the recycling, all of its high heating can be saved for further products and the benefits of recycling are considerable.

Stone wool has best scores for low embodied energy, low global warming potential and low summer smog potential. Its weight per functional unit is more than double the one of grey EPS. However, its production impacts per kilogram of material are considerably lower. The score for low acid rain potential is affected by the use of coke in the cupola melting furnace during production. With regards to application suitability stone wool has the advantages of being a flexible and fire-proof material. On the downside stone wool is relatively heavy and requires safety measures during installation. The absence of hazardous additives in stone wool leads to a maximum score for low potential risk. The benefits of recycling stone wool are very small as the score for energy saved by recovery shows.

Glass wool shows very similar results to stone wool. The scores for low embodied energy, low global warming potential and low acid rain potential are less advantageous than for stone wool. Reasons for this can hardly be spotted without any deeper insight into the calculations of EPD data. One known difference in the production process is the use of electric heating when producing glass wool. It's assessment of application suitability is the same as for stone wool with a slightly lower weight in case of glass wool. The score for the saved energy by recovery is higher for glass wool than for stone wool due to a higher energy content in the underlying EPD. This difference cannott be explained without insight into the calculation details of the EPD.

PUR/PIR has the lowest λ-value of the materials considered. Therefore, the R-value of 5 m^2K/W of the system can be realised with a thinner layer of insulation material. However, the density of PUR/PIR is more than double the one of grey EPS and its weight per m^2 almost the same as for glass wool. For the criteria considered, PUR/PIR shows no particular advantages in this application. The results for the production phase are mediocre except for low acid rain potential. The rigidity and the fire classification of the material as well as the weight per functional unit lead to a medium performance with regards to the application suitability. The flame retardant used in PUR/PIR has a slightly negative impact on the risk potential. Further, the energy saved by recovery is moderate due to the relatively low heating value.

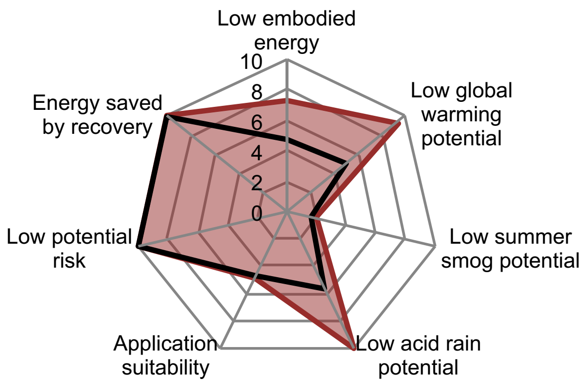
Hemp fibre has the highest weight per functional unit among the materials considered. This has an impact on the embodied energy. However, with regards to the other production phase related indicators (low global warming potential, low summer smog potential and low acid rain potential) the scores are among the highest. Application suitability is compromised by the weight and the fire classification of the material. Hemp fibre contains no hazardous additives and therefore receives a maximum score for low potential risk. Hemp fibre will be incinerated at the end of its lifespan. Due to its high heating value the share of energy saved by recovery is second to the score of grey EPS.

Table 5: Ventilated façade, R=5 m^2K/W, insulation weight per m^2

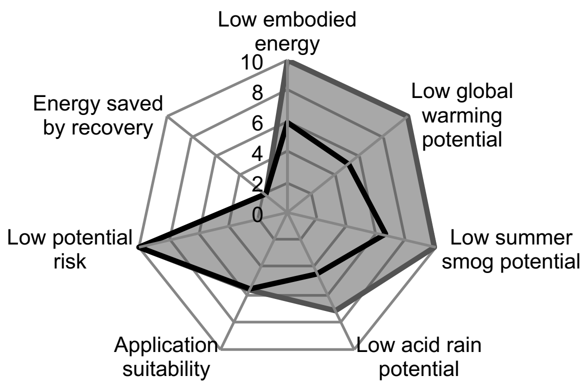
Insulation material	Grey EPS	Stone wool	Glass wool	PUR/PIR	Hemp fibre
Weight [kg/m^2] dowels	2.20	6.91	4.84	3.66	7.00
Weight [kg/m^2] console	2.42	7.59	5.31	4.03	7.69

3.3 Spider Diagrams Ventilated façade, R = 5 m²K/W

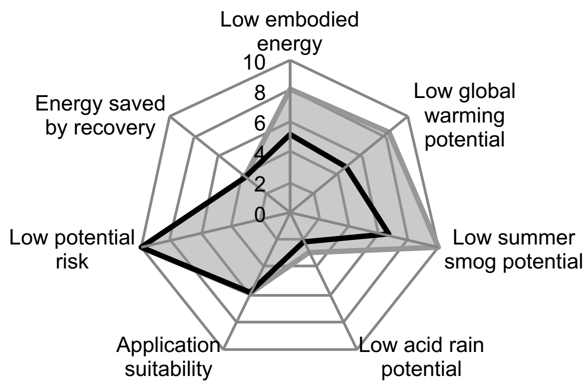
Grey EPS 15 cm (Dowels)
Grey EPS 16 cm (Console)



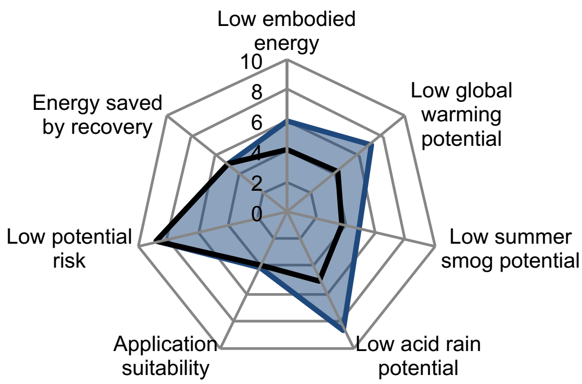
Stone wool 16 cm (Dowels)
Stone wool 18 cm (Console)



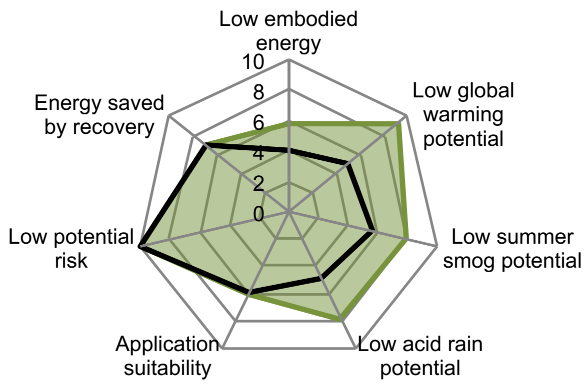
Glass wool 15 cm (Dowels)
Glass wool 16 cm (Console)



PUR/PIR 12 cm (Dowels)
PUR/PIR 13 cm (Console)



Hemp fibre 19 cm (Dowels)
Hemp fibre 21 cm (Console)



4 ETICS

4.1 Description of application

The R-value of 5 m^2K/W or U-value of 0.2 $W/(m^2K)$ for the ETICS construction corresponds to the whole system including the insulation, a brick wall of 0.2 m thickness and the plastering. The functional unit consists of the insulation material and the material necessary for the fixation of the insulation with plastic dowels and adhesive mortar. The comparison includes very commonly used materials such as white and grey EPS, stone wool and PUR/PIR. Wood fibre has been chosen as a representative for renewable insulation materials. The weight per functional unit differs considerably among the materials. Grey EPS is the lightest material with a weight of 2.5 kg/m^2. Wood fibre has the highest weight with 25.6 kg/m^2, which is ten times heavier than grey EPS (Table 6).

4.2 Insights

White EPS shows very good results with regards to low embodied energy, low global warming potential and low acid rain potential. The scores on these axes are only slightly lower than for grey EPS.

The scores for **grey EPS** are the best for low embodied energy and low acid rain potential. It also receives a score of ten for the global warming potential. With wood fibre being among the materials compared, a special situation arises when putting scores on the global warming potential. Wood fibre has a negative global warming potential, that cannot be used to scale the other results. The best score for Grey EPS thus means that it has the second-best assessment result after wood fibre. All other scores are the same or very similar to the ones for white EPS. Over all criteria evaluated, grey EPS shows the best results among the materials compared.

These results are partly due to the low weight per functional unit. White EPS is only slightly heavier than grey EPS (2.9 kg/m^2). As already seen in other applications EPS is characterised by an unfavourable score for the low summer smog potential caused by pentane emissions during production. Based on the available data, white and grey EPS have the lowest material costs among the considered insulation materials. Regarding application suitability, white EPS ranks second behind grey EPS. The advantages of EPS are the low weight, low moisture sensitivity and the absence of safety measures during installation. It only losses some points because of the materials fire classification of E. EPS contains no hazardous additives and has therefore a maximum score for low risk potential. Further EPS can be recycled and has a high heating value. As shown by indicator energy saved by recovery, the benefits of recycling EPS are very high.

Stone wool has the second-best score for low embodied energy. However, the scores for the other production phase related indicators (low global warming potential, low summer smog potential, low acid rain potential) are low to moderate. This is caused by its high weight per functional unit, which is almost eight times higher than for grey EPS. Based on the data available, the investment cost for stone wool is higher than for all other materials considered. Also, the score for application suitability is low. This result is caused by the high weight of the material, the moisture sensitivity and the required safety measures during installation to protect workers from exposition to mineral fibres. Stone wool does not contain any hazardous additives and achieves a score of ten for low risk potential. The recycling of stone wool is hardly beneficial from an energy point of view as already explained for other applications.

PUR/PIR has the lowest λ-value of the insulation materials considered. However, this advantage is compensated by a density that is about two times higher than the one for white and grey EPS. PUR/PIR achieves moderate scores on most axes. The production phase related indicators are influenced by the higher weight per functional unit than EPS and the fact that polymer foams cause higher impacts per unit of mass than the other materials considered. The investment costs for PUR/PIR are comparable to stone wool and wood fibre. The score for application suitability is moderate as well due to the fire classification and the weight per functional unit. The material does not achieve a maximum score for low risk potential due to the flame retardant used in PUR/PIR. The heating value of PUR/PIR is lower than for other polymers because of its high nitrogen content. Therefore, the score for energy saved by recovery is also moderate.

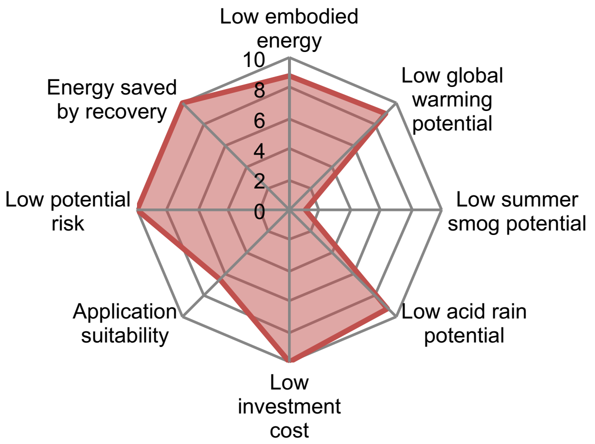
Wood fibre has the lowest global warming potential and summer smog potential among the materials compared. As trees uptake carbon dioxide during their growth, the net global warming potential for wood fibre becomes negative. As there is no way of scaling negative and positive results in a meaningful way on a spider axis, the score for wood fibre is the same as for the second-best material, grey EPS. The results for low embodied energy and low acid rain potential are moderate. The investments costs for wood fibre are about the same as for stone wool or PUR/PIR. Due to the highest weight among the products compared, the moisture sensitivity and its fire classification of E, wood fibre achieves only a low score for application suitability. There are no hazardous additives in wood fibre resulting in a maximum score for low potential risk. Wood is a good fuel. The bigger part of the embodied energy during production is effectively energy content of the raw material. This energy is released during thermal recovery and wood fibre achieves almost the same score as the recycling of white and grey EPS.

Table 6: ETICS, R=5 m^2K/W, insulation weight per m^2

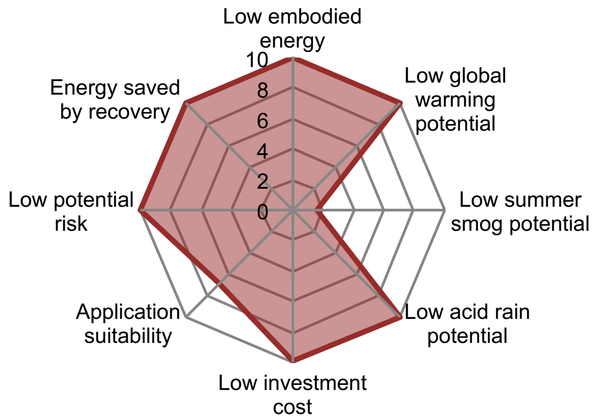
Insulation material	White EPS	Grey EPS	Stone wool	PUR/PIR	Wood fibre
Weight [kg/m^2]	2.85	2.45	19.12	3.87	25.59

4.3 Spider Diagrams ETICS, R = 5 m^2K/W

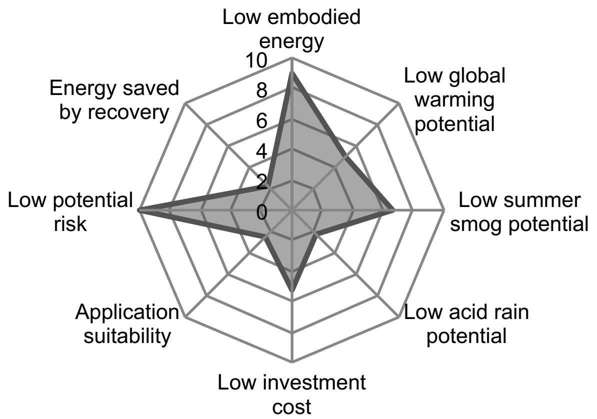
White EPS 18 cm



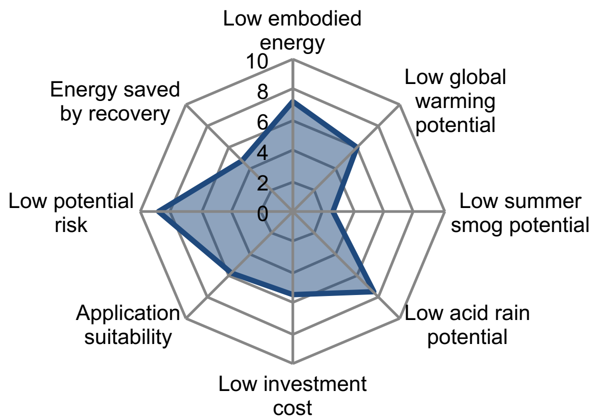
Grey EPS 15 cm



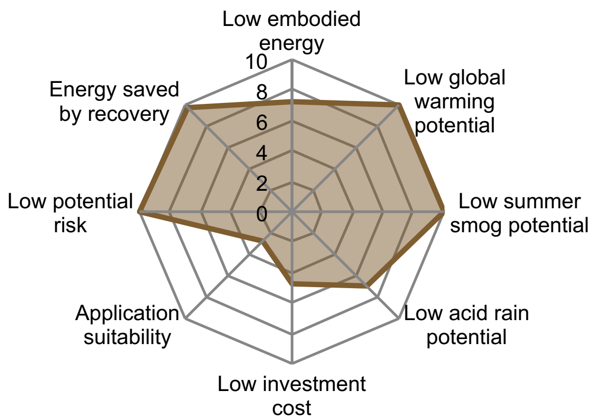
Stone wool 16 cm



PUR/PIR 12 cm



Wood fibre 18 cm



Special scaling for „low global warming potential“, please refer to 4.2

5 Perimeter

5.1 Description of application

The specified R-value of 5 m^2K/W corresponds to an U-value of 0.2 $W/(m^2K)$. It includes the performance of the insulation material and a concrete wall with a thickness of 0.2 m. The functional unit includes the necessary amount of insulation material to achieve the required R-value and the fixation of the insulation to the wall with bitumen or cement adhesive. The choice of insulation materials in this application is limited because only moisture resistant materials can be used. The materials compared are therefore white EPS with a higher density, XPS, PUR/PIR and Foam glass. The weight per functional unit varies between 5 kg/m^2 for white EPS and 22.3 kg/m^2 for foam glass (Table 7).

5.2 Insights

EPS achieves high scores for three out of four production phase related indicators. These are low embodied energy, low global warming potential and low acid rain potential. AS for all applications, the summer smog potential is the highest of all materials. Of all materials considered, EPS has the lowest investment costs. With regards to application suitability only weight per functional unit and required safety measures for installation have been assessed in this application. Among the plastic foams there is only very little difference in weight and EPS almost reaches the maximum score. The score for low risk potential is maximum because EPS contains no declared hazardous substances. In all other applications throughout this report, the end of life treatment of EPS would be recycling. However, in the perimeter application it has to be assumed that the material will be degraded after the use phase due to moisture and dirt. Therefore, thermal recovery was chosen as an end of life scenario. Since EPS has a high heating value its score for the criterion energy saved by recovery is still above nine.

XPS performs slightly better than EPS in most scores. According to the available price data, XPS is about 20 % more expensive in purchase than EPS, leading to a score on the axis for low investment cost of about eight. XPS has the lowest global warming potential and the lowest acid rain potential of the four materials. It gets a small penalty on the score for application suitability for being heavier than the lightest material PUR/PIR. The potential risk is zero for XPS using Polymeric FR as flame retardant. It also has the highest share of saved energy by recovery, although the difference to EPS is within the uncertainty of life cycle assessments.

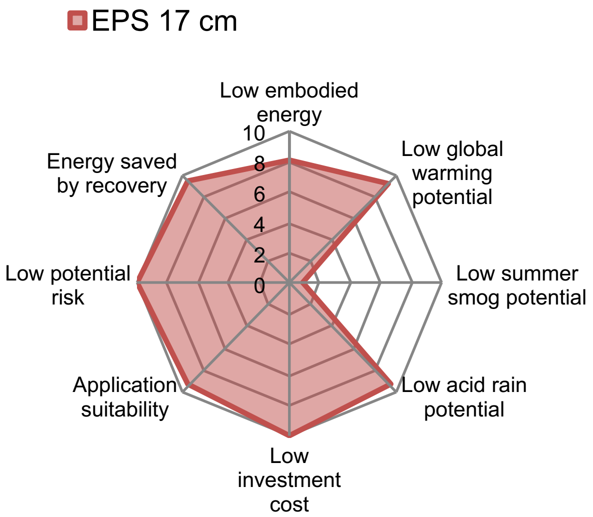
PUR/PIR has overall the lowest environmental impacts for the production phase among the insulation materials considered. Its embodied energy, global warming potential and acid rain potential are low and its summer smog potential is moderate. The investment cost associated with PUR/PIR are about the same as the ones for XPS. PUR/PIR gets the maximum score for application suitability. Due to its low λ-value and density it is the lightest product among the materials compared. Again, as in all other applications, the score for the risk potential is around nine since PUR/PIR contains TCPP as flame retardant. This substance is considered “harmful if swallowed” in the globally harmonised system. This H-Phrase may indicate possible adverse effects when the flame retardant would be washed out of the insulation material during its life span. Further, the material has a lower heating value than EPS and XPS. Therefore, the energy saved by recovery is lower than for other plastic foams.

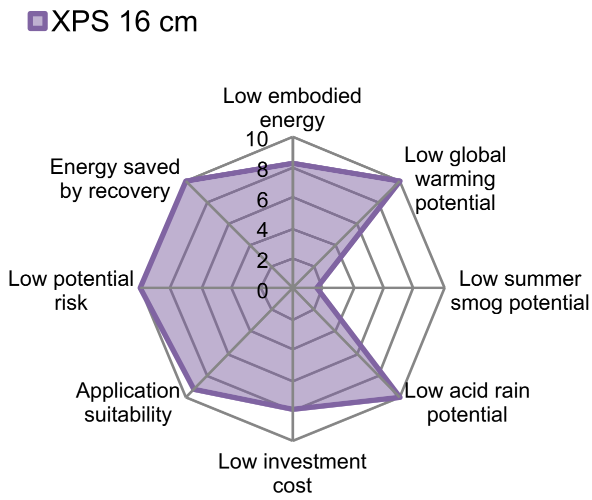
Foam glass has the best score for low summer smog potential. On the other hand, the scores for all other production phase related indicators are the lowest. This is due to the high weight per functional unit. The investment costs are higher than for the other materials. The weight affects also the score for application suitability. With five times the weight of the lightest material, it achieves only one fifth of the maximum five points for the weight aspect. Foam glass contains no hazardous substances. Therefore, it receives a maximum score for low potential risk. Since there is no primary energy chemically bound in foam glass, its recovery potential in terms of saved energy is zero.

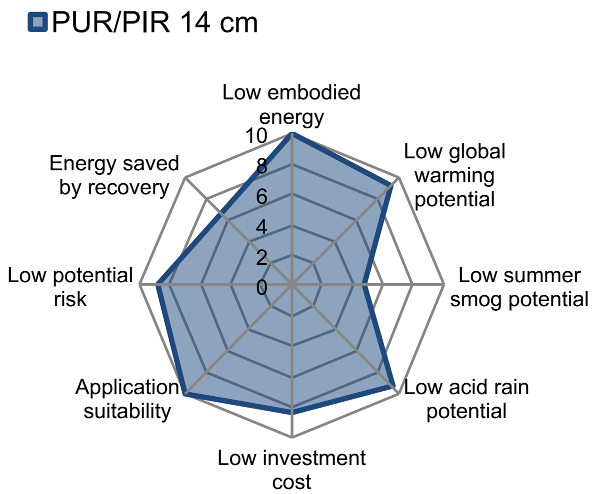
Table 7: Perimeter, R=5 m^2K/W, insulation weight per m^2

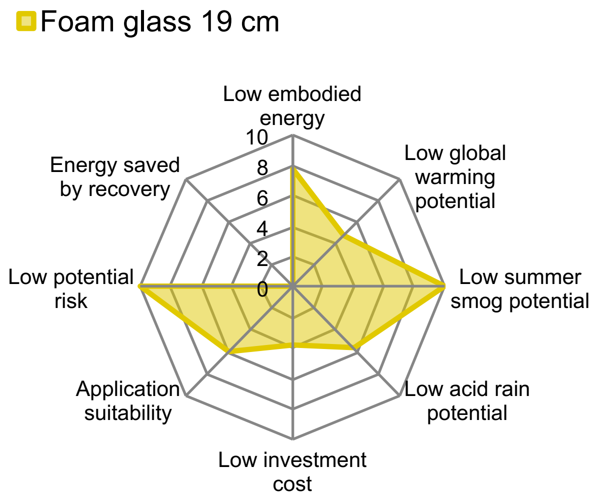
Insulation material	EPS	XPS	PUR/PIR	Foam glass
Weight [kg/m^2]	4.96	5.15	4.40	22.29

5.3 Spider Diagrams Perimeter, R = 5 m²K/W









6 Floor, above ceiling or ground slab

6.1 Description of application

The application considers a thermal insulation above a concrete slab of 0.2 m thickness. According to DIN 4108-10, this application is referred to as DEO. The calculation of the R-value of 4 m^2K/W or the corresponding U-value of 0.25 $W/(m^2K)$ takes into account the construction including the concrete slab, the insulation material and an adhesive underneath the concrete slab. The functional unit includes the insulation material only. The materials white EPS, XPS, stone wool and wood fibre were selected for the comparison. The plastic foams are considerably lighter per functional unit than the other materials; 3-4 kg/m^2 in case of white EPS or XPS versus 22-23 kg/m^2 in case of of stone wool or wood fibre (Table 8).

6.2 Insights

White EPS achieves best scores for low embodied energy, low global warming potential and low acid rain potential. The only disadvantage with regards to the production phase is its summer smog potential due to pentane emissions. With wood fibre being part of the assessed materials, a special situation is given for assessing the impact on global warming. EPS has the lowest impact on global warming with a positive net figure. The global warming potential of wood fibre is even lower, below zero. Because it is not possible to scale negative and positive values on the same spider axis meaningfully, both wood fibre and EPS have been given a score of ten. With regards to application suitability the fire classification of the material leads to a minor deduction. White EPS has no known additives with H-Phrases and scores 10 points for low potential risk. The EPS used in floor applications has the potential to be recycled. Although all energy contained in the material can be saved for future use, the score for the energy saved by recovery becomes 10 as well.

XPS is almost one kilogram heavier per functional unit than white EPS. This is reflected in the assessment of the production phase. XPS and EPS have similar environmental impacts per kilogram of material produced. When multiplied with the higher weight per square meter, all impacts are higher for XPS than for EPS. As a consequence, the scores of XPS are a bit lower than the ones for EPS. XPS has a lower application suitability because of its higher weight than EPS. XPS also receives the maximum score for its low potential risk, since the XPS product assessed in this study contains Polymeric FR as flame retardant. When it comes to end of life treatment, XPS will be incinerated. The potential to save energy is therefore determined by thermal energy recovery.

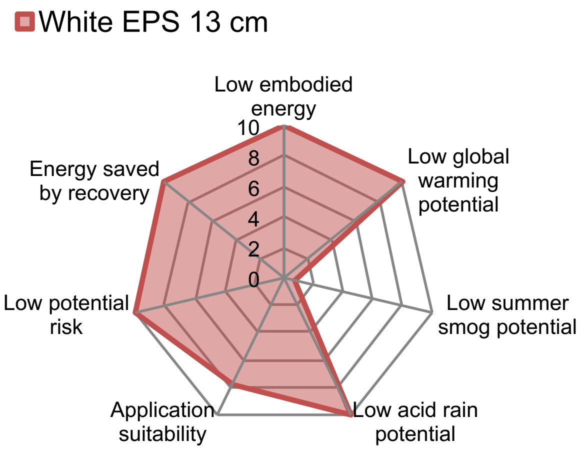
Stone wool has a comparable embodied energy to EPS and wood fibre. Its high weight leads to low scores for all other LCIA indicators that are related to the production phase. The score for application suitability is very low. Stone wool only receives two points for its fire classification of A1 and another half point in the insulation weight aspect with a weight almost eight times higher than the lightest. Stone wool does not contain any declared hazardous additives and has therefore no risk potential. Since the primary energy content of the material is very low its recycling does reap very little benefit from the point of view of energy savings.

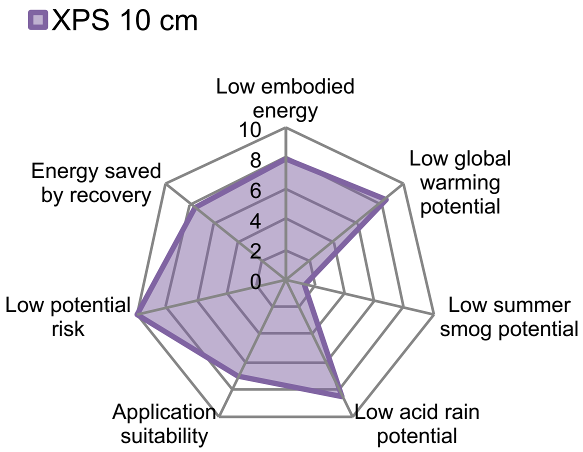
Wood fibre needs a little more energy during production than EPS. The score for low embodied energy is just below ten for this reason. Wood fibre has a negative impact on global warming. This means that wood takes up more CO_2 during its growth than the amount of CO_2 released during production. As the only material with such a favourable balance, it receives ten points. Nevertheless, it cannot be used to scale the other materials which release CO_2 during their production. The summer smog potential of wood fibre is the lowest of all products considered in this application. The high weight as well as the fire classification of wood fibre lead to a low score regarding application suitability. Wood fibre has no hazardous additives and therefore no risk potential. Due to the high heating value of wood, the energy recovery through thermal recovery is very beneficial. We are measuring the share of energy saved by recovery. Because the energy content of the wood material is considerably higher than the production energy of the slabs, the recovered share of energy by incineration with thermal recovery becomes very high. For this reason, wood fibre achieves almost the same share of energy savings as recycled EPS.

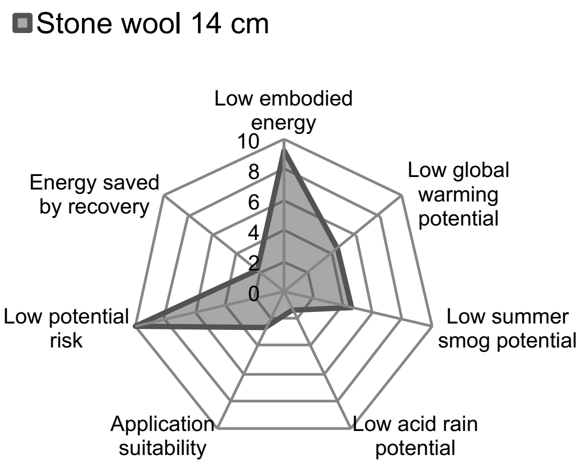
Table 8: Floor, R=4 m^{2}K/W, insulation weight per m^2

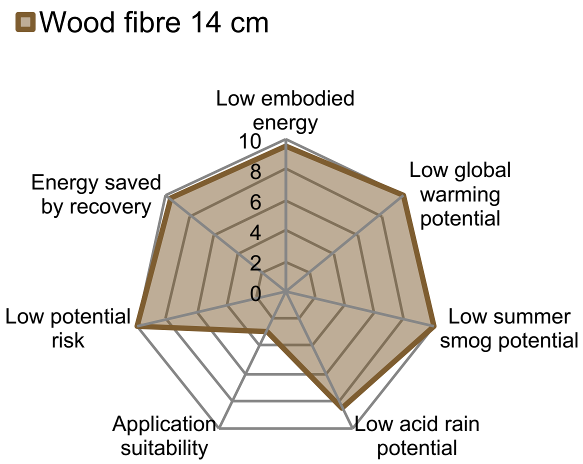
Insulation material	White EPS	Stone wool	XPS	Wood fibre
Weight [kg/m^2]	2.88	22.72	3.82	22.42

6.3 Spider Diagrams Floor, R = 4 m²K/W









Special scaling for „low global warming potential", please refer to 6.2

For further information please refer to the full report which contains a transparent description of the methodology and the documentation of all data used.