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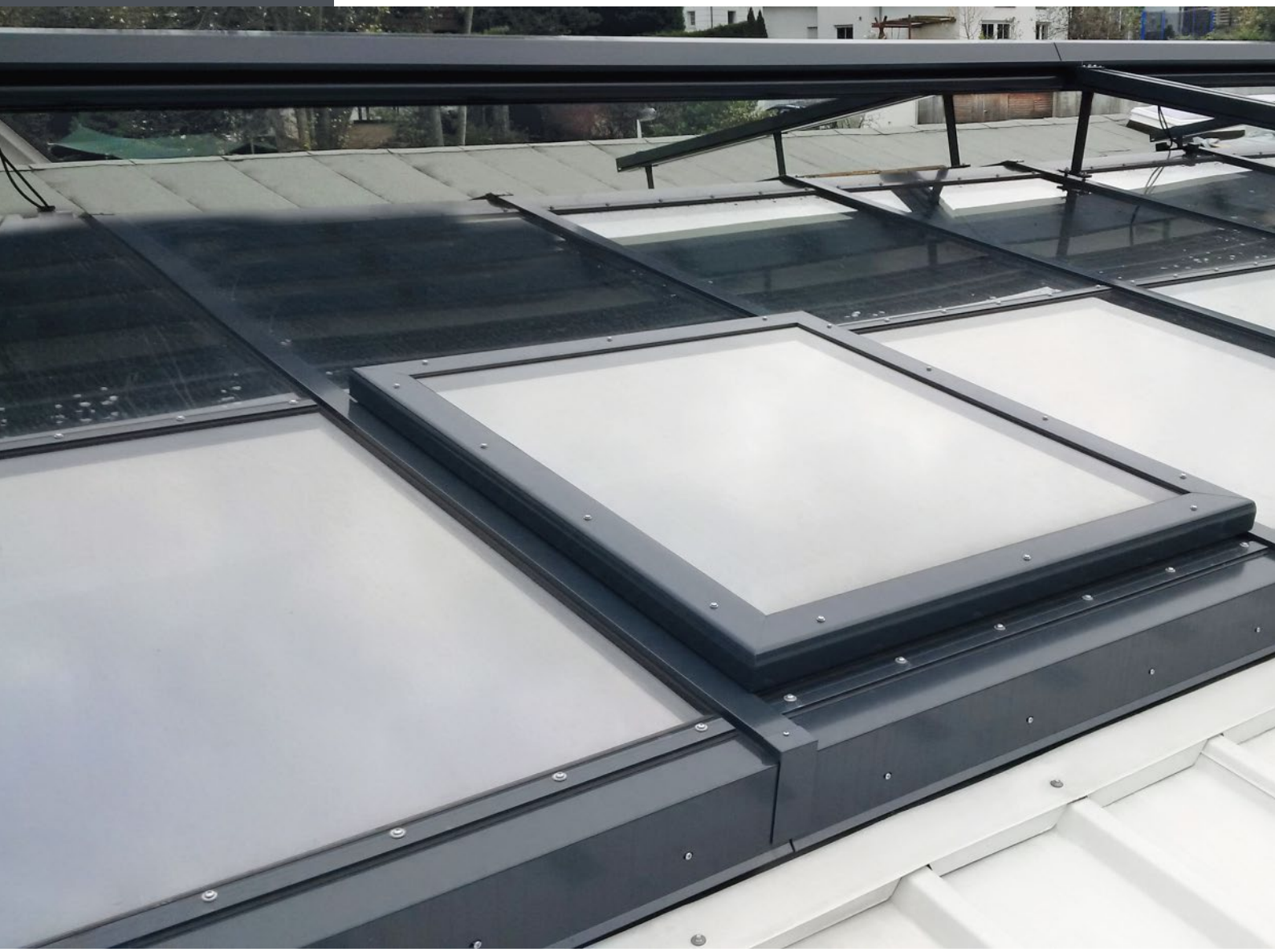

Insulation boards for utilised single-layer flat roofs: Correlation between thermal conductivity, insulation thickness, stability, and weight

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Insulation boards for utilised single-layer flat roofs: Correlation between thermal conductivity, insulation thickness, stability, and weight

Today, besides the durability of a construction, its sustainability is an increasingly important criterion, which requires precise matching of the product to the construction scheme. The sustainability aspects refer both to the quality of the construction work and to the products applied. Since improper and wasteful use of building materials has ecological and economic drawbacks, the materials must be selected according to the respective construction situation, and mounted in the right quantities at the right place.

A variety of materials is available to insulate utilised, single-layered flat roofs. This article offers insights into how the choice of insulation material influences the overall performance of utilised single-layer flat roofs (e.g. due to the material's gross density). For this purpose the following section compares properties and functions of selected insulation materials and assesses their effect in material combinations.

Choosing insulation material

For the construction of flat roofs it is vital to choose only materials that meet introduced standards, general building approvals or European technical approvals. The flat roof guideline provided by ZVDH (Zentralverband des Deutschen Dachdeckerhandwerks – Central Association of German Roofers) includes detailed descriptions on the suitability of different thermal insulation materials.

Basically, all insulation materials listed in table 1 have properties, which are beneficial under specific installation conditions. For experts to chose the right insulation material that perfectly matches the planned application, they must consider the desired mode of action and the expectations on the materials.

Flat roofs are exposed to climatic stresses. Fluctuating temperature rises on the roof surface cause temperature differences between inside and outside, which can lead to material tension and damage to the building construction.

Table 1. *Insulation materials, suitable for flat roofs, according to ZVDH flat roof guideline*

Insulating material	Standard
Polystyrene rigid foam EPS (white/grey)	DIN EN 13163 [1]
Extruded polystyrene foam, XPS	DIN EN 13164 [2]
Polyurethane rigid foam PU/PIR	DIN EN 13165 [3]
Mineral wool insulation	DIN EN 13162 [4]
Cellular glass CG	DIN EN 13167 [5]

[1] DIN EN 13163 Thermal insulation products for buildings – Factory made products of expanded polystyrene (EPS) – Specifications
[2] DIN EN 13164 Thermal insulation products for buildings – Factory made products of extruded polystyrene foam (XPS) – Specifications
[3] DIN EN 13165 Thermal insulation products for buildings – Factory made rigid polyurethane foam (PUR) products – Specifications
[4] DIN EN 13162 Thermal insulation products for buildings – Factory made mineral wool (MW) products – Specifications
[5] DIN EN 13167 Thermal insulation products for buildings – Factory made cellular glass (CG) products – Specifications

Fig. 1. *At present, millions of square metres of existing roof surfaces lie fallow – although they could be put to good use, creating new habitats and recreation areas*

Table 2. *Insulation material and range of their specific thermal conductivity (FIW Munich, Meta analysis on insulation materials, report FO12/12)*

Insulation material	Standard	Thermal conductivity [1] W/(m*K) (from–to)
Polystyrene rigid foam EPS	DIN EN 13163	0.031–0.045
Extruded polystyrene foam, XPS	DIN EN 13164	0.028–0.042
Polyurethane rigid foam PU/PIR	DIN EN 13165	0.023–0.029
Mineral wool (MW) insulation	DIN EN 13162	0.032–0.048
Cellular glass CG	DIN EN 13167	0.037–0.060

[1] Thermal conductivity values were obtained from data sheets provided by manufacturers of insulation boards for flat roofing.

An insulation layer protects the construction against extreme temperature differences, and thus reduces resulting damages.

Utilised flat roofs are intended to be used as green spaces and recreation areas. This type of flat roof is usually designed as a single-layer construction. This is to say that the individual functional layers of the roof are laid directly on top of each other without additional ventilation space. Generally, this design features an insulation layer underneath a weather-resistant waterproofing layer. In special cases, for instance in the inverted roof, the insulation layer is laid on top of the roof waterproofing. XPS (extruded polystyrene foam) is recommended for this construction; e.g. Styrodur®, since it has the required technical approval for insulation boards.

Insulation materials for utilised single-layer flat roofs must be assessed according to climatic stress, functional demands on the construction, as well as their mechanical and physical characteristics. It is important to consider the correlation of characteristics, rather than analysing isolated materials.

Thermal conductivity and insulation thickness

Insulation materials primarily serve the purpose of thermal protection. By decreasing the heat flow, they reduce heating energy during winter and cooling energy during summertime. These energy savings also result in lower CO_2 emissions.

This means, insulating has two-fold benefits – heat insulation and environmental protection.

According to its functional purpose, thermal conductivity is the key physical property of insulation material (λ). As shown in table 2, thermal conductivity values vary in different insulation materials. Hence, the thickness of insulation materials must be calculated individually to meet the thermal transmission coefficient required for the building construction. The factor for the calculation of the required insulation material thickness is called U value in short.

In this example the U value of the flat roof construction has been set to 0.125 W/(m^2K). In order to achieve the required U value of 0.125 W/(m^2K) the insulation boards with a thermal conductivity value of 0.031 W/(mK) must have a thickness of 237 mm.

Due to specific thermal conductivity values, other insulation materials require a different thickness to achieve the U value of 0.125 W/ (m^2K) (table 3).

Table 3. *Insulation thickness dependent on the material's thermal conductivity to achieve the required U value of 0.125 W/(m^2*K) for the total construction*

insulation material	Thermal conductivity [1] W/(m*K)	Required thickness of the insulation layer in mm
insulation material 026	0.026	199
Insulation material 031	0.031	237
Insulation material 033	0.033	253
Insulation material 035	0.035	268
Insulation material 038	0.038	291

[1] Thermal conductivity values were obtained from data sheets provided by manufacturers of insulation boards for flat roofing.

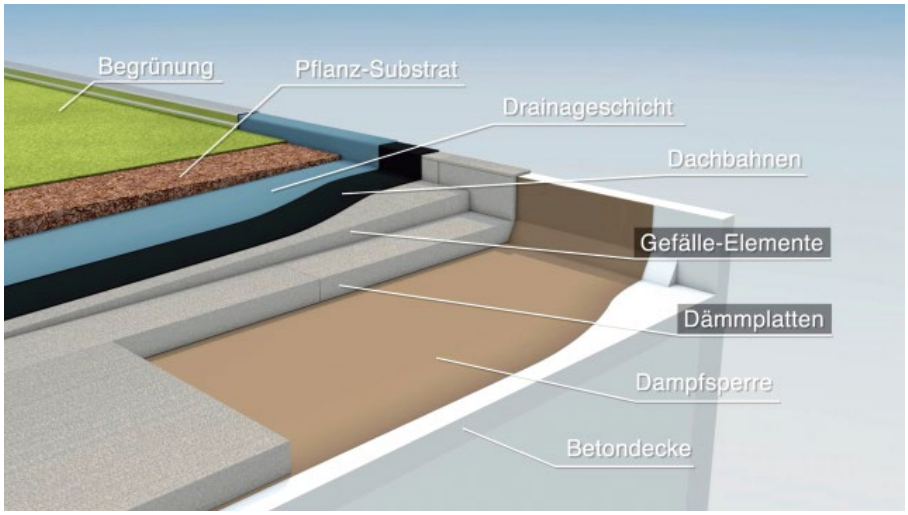

Fig. 2. *Single-layer flat roof – schematic construction of a concrete slab*

Table 4. *Common gross density of insulation material (FIW Munich, Meta analysis on insulation materials, report FO12/12)*

Insulation material	Standard	Weight in kg/m³, from–to
Polystyrene rigid foam EPS (white/grey)	DIN EN 13163	15–30
Extruded polystyrene foam, XPS	DIN EN 13164	25–50
Polyurethane rigid foam PU/PIR	DIN EN 13165	30–100
Mineral wool (MW) insulation	DIN EN 13162	15–220
Cellular glass CG	DIN EN 13167	100–200

Conclusion: In this example, with λ = 0.026 W/(mK) the insulation material 026 has the lowest thermal conductivity value and requires therefore the lowest insulation thickness. Insulation material 031 has the second favourable insulation thickness.

Compressive strength and loading conditions in flat roofs
Insulation boards for flat roofs must be resilient to endure the strains during construction and over their entire life cycle without losing their function.

The expected loads must also be considered in order to choose the right insulation material. Common loading conditions in flat roofs and the required compressive strength of the insulation materials are defined in country-specific application standards. The requirements specified in DIN 4108-10 (application-related requirements on insulation materials – factory made thermal insulation material), edition December 2015 apply in Germany. Insulation boards for utilised single-layer flat roofs have to withstand high compressive loads (table 2, DIN 4108-10 from December 2015 Differentiation of specific product properties). Constructions with load level dh – the abbreviation dh of DIN 4108-10, table 2 means: high pressure-resistance – require EPS insulation boards (expandable polystyrene stage CS (10) 150) according to DIN EN 13163, table 3 Stages of compressive load at 10 % deformation. This means that insulation boards under a compressive load of 150 kPa show a maximum deformation of 10 % (table 4, DIN 4108–10).

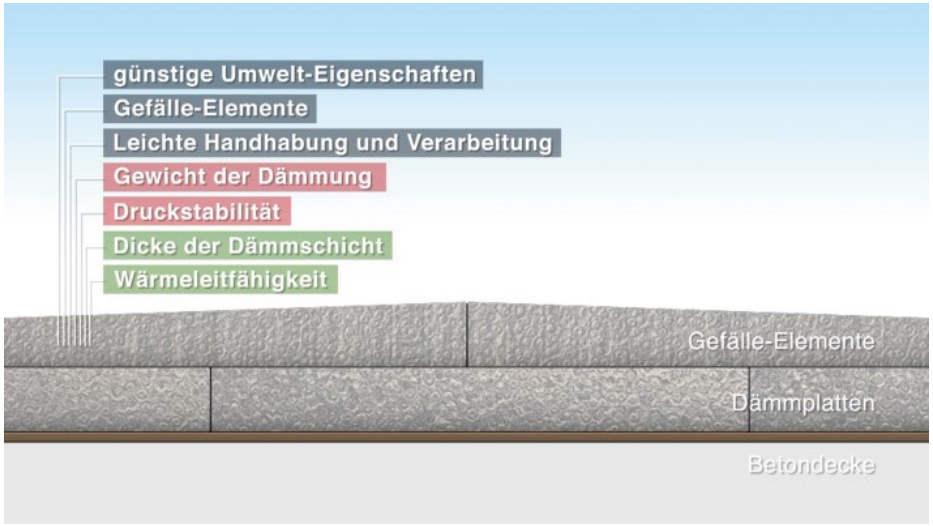

Fig. 3. *Insulation components on a concrete slab*

Table 5. *Weights of different insulation materials for flat roof surfaces of D105 (1,970 m²*

Insulation material	Thermal conductivity W/m*K	Required thickness of insulation layer	Weight in kg/m³	Tons total at 1,970 m²
Insulation material 031 (grey EPS e.g. Neopor®)	0.031	237	26	12.1
Insulation material 026 (PU)	0.026	199	32	12.5
Insulation material 035 (white EPS e.g. Styropor®)	0.035	268	25	13.2
Insulation material 033 (XPS)	0.033	253	32	15.9
Insulation material 038 (MW, SW)	0.038	291	82 [1]	47.0

[1] Often, mineral wool and rock wool insulation boards need a much higher gross density to achieve the required compressive strength. 60–70 kPa at 10 % deformation is usually the upper limit. According to the flat roof guideline the use of these is limited.

Fig. 4. *Stable insulation boards are the preferred material for utilised single-layer flat roofs, since they show no deformation, even under high loads.*

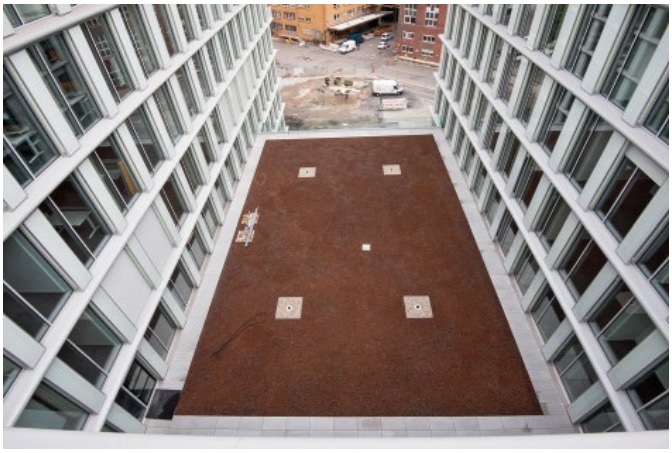

Fig. 6 *The flat roofs of building D105 are on different levels – this image shows a flat roof area on a lower level between transparent façade design; staff have a nice view on future green spaces (Images/graphics: BASF)*

Compressive strength and weight

In order to achieve the required compressive strength CS (10) 150 the insulation material's density must be specified according to the purpose (usually in kg/m^3).

Some insulation boards, for instance EPS, achieve the relevant compressive strength of 150 kPa with just 26 kg/m^3 of raw material, whilst others require significantly more to meet the demands on compressive strength.

As a general rule, all applications subjected to compression require a higher gross density, compared to insulation that is not under load, as for example between rafters.

As a consequence, all insulation materials are available with different gross densities, and weights to be deployed in various applications (i.a. wall, roof).

Balancing the properties

Only the overall balance of properties, such as thermal conductivity, thickness, and weight, shows whether insulation materials are suitable for utilised single-layer flat roofs. As can be seen from table 5, insulation boards made of grey EPS apply the least load to the flat roof, compared to other insulation materials.

This convinced the planners of the new BASF building D105 to use insulation boards made of Neopor® for the flat roof construction, and insulation boards made of PU for large parts of the curved roof surfaces. Besides the low consumption of raw materials, another reason for this choice was the load bearing structure. Since it is a significant difference, whether the load on ceilings, lintels, col-

Fig. 5. *In addition to conference rooms and a modern staff restaurant, the new BASF office building D105 in Ludwigshafen offers multi-functional office spaces for 1,200 employees*

umns, load-bearing walls, and foundations is 12 t or 47 t, which would be almost four times as much weight. Load-bearing components are designed according to their weight. This means, the higher the load, the higher the cost for structural safety measures. Due to the use of grey EPS (Neopor) and polyurethane, the design met the high standards of the German Sustainable Building Council (DGNB). D105 was awarded the DGNB Pre-certificate in Platinum.

Fire protection requirements on flat roofs

Besides structural fire protection, fire safety design for buildings also includes plant-specific, organisational, and preventive fire protection.

The applicable rules and regulations are specified in national building codes, standards, and fire protection regulations, and can differ from country to country. However, the main criteria for structural fire protection are similar in many countries. They relate to the utilisation of the building, individual building materials and components, as well as the distance to the boundary and to other buildings.

A part of the structural fire protection regulations covers the fire behaviour of building materials, and the fire resistance of components and construction types. The European Standard DIN EN 13501, part 1 to 6 "Fire classification of construction products and building elements" is the first valid standard in this field that has been adopted by all European nations. DIN EN 13501-1 differentiates building materials in seven classes ranging from non-combustible materials (A1, A2) to easily flammable materials (F). Most polystyrene foams are classified in E: normal combustibility, no flaming droplets.

In principle, insulation material of normal combustibility can be deployed in flat roofs, provided that the roofing has been identified as "hard roofing". On request, manufacturers and suppliers of roofing systems must deliver the necessary certification documents. "Hard roofing" must be sufficiently resistant to flying sparks and radiating heat. Most EU states accept a 5 cm thick gravel layer with 16/32 mm particle size as "hard roofing". Green roof systems are generally also considered to be "hard roofing".

Additional requirements on fire protection can result from the building classification, the height of the building, boundary setbacks, as well as escape and emergency routes. It is recommended to consult the respective authority for building approvals to clarify building-specific and legal issues.

Conclusion

Sustainably constructed or refurbished flat roofs offer an enormous potential – as effective floor space or as a means to save energy. Especially in the inner cities where living spaces are often scarce, the utilisation of flat roofs could create precious spaces, e.g. rooftop gardens or recreation areas. Nevertheless, many million square metres of existing flat roofs are currently lying fallow. The industry and specialist trade have plenty of validated and suitable building systems and materials for the construction of flat roofs on offer. All of the available flat roof systems need an insulation layer to meet the legal requirements on energy saving. For the design of a utilised flat roof it is paramount that the building and insulation materials are selected with regard to their function, since this is the only way to guarantee the durability and sustainability of a building.

Choosing the right insulation boards means assessing their properties, such as thermal conductivity, compressive strength, pressure resistance, and weight. It is of particular importance to answer the question, how these individual factors influence the thickness of the insulation layer, the gross density, and the consumption of raw material. Whenever insulation materials have been calculated according to the criteria listed above, it has a positive effect on the sustainability of the flat roof and on the classification of the entire building.

Besides mechanical and physical properties, other aspects have to be considered in the assessment of insulation materials. Insulation material should be cost-efficient, that is to say it should have a good price/performance ratio. A first indicator on this can be found in price lists and quotes from firms who offer insulation work. A review of the building's load-bearing structure can also influence the price/performance ratio. As a general rule: the lower the weight of the insulation material, the lower the costs for structural safety measures. Particularly for the modernisation of existing roof surfaces this can be of benefit. Insulation boards that are stable and light-weight at the same time can reduce costs, because additional, expensive structural work may be dispensed with.

Furthermore, the handling on the construction site must be taken into account. Incline components or a lower weight can facilitate the installation of insulation layers. For the relevant matter of safety: the different requirements depend on the design of the building construction.

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