ENERGY SAVING WITH POLYURETHANE RIGID FOAM

7 Energy optimization of the building shell

Housing ultimately means making sure that people feel comfortable in their own homes, all year round.

A high quality of life requires comfortable accommodation. This includes comfortable temperatures throughout the house, neither too hot nor too cold. The temperature difference between the air in the room and the wall surface must not be too great, or the environment will become unpleasant, uncomfortably cold in winter and uncomfortably hot in summer.

Comfortable living conditions must be provided throughout the house, from the basement to the roof.

7.1 The physical structural principles behind the optimum building shell

All the experts agree that increasing the thermal insulation of the building shell is the most effective measure for reducing the annual heating requirement. Thermal insulation thus remains an important part of the "magic formula" for energy saving (see Chapter 4, page 16).

The optimum building shell has to meet three basic requirements:

- lowest possible U-value
- air-tightness and wind-tightness
- avoidance of thermal bridges.

Because of their high insulating capacity, insulating materials made of polyurethane rigid foams can be used for many purposes (roofs, walls, floors and ceilings). There is a wide range of products, including insulating boards, window frames, bonding foam and metal sandwich panels for industrial building.

The thermal conductivity λ is the crucial factor in the insulating effect of a building product. Polyurethane rigid foam has the lowest thermal conductivity of all commercial insulating materials and is sold in thermal conductivity groups (WLG) 025 and 030. The high insulating capacity is achieved is achieved using blowing agents with a considerably lower thermal conductivity than air. Because of the exceptional closed-cell structure of the insulating material (≥ 90 %), the blowing agents remain in polyurethane rigid foam in the long term.

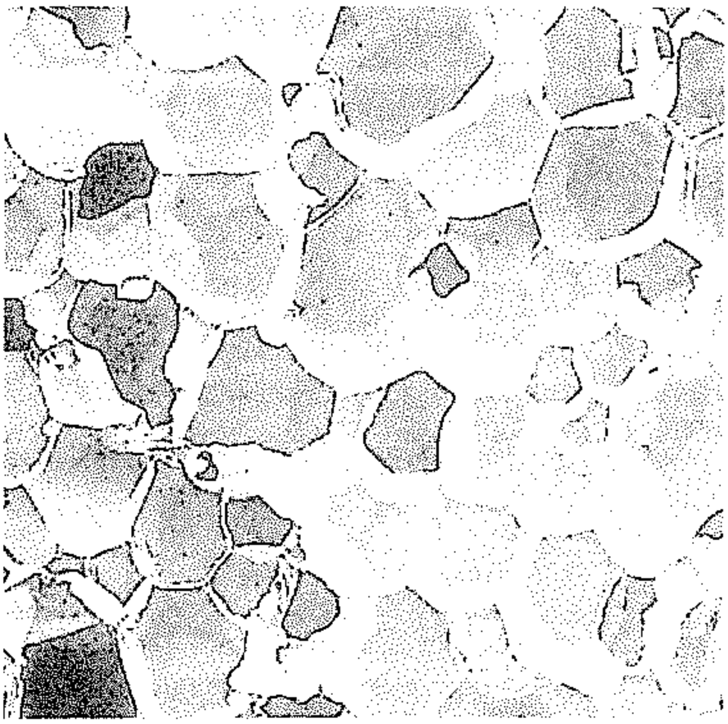


Fig. 17: Cell structure of polyurethane rigid foam

The insulating capacity of polyurethane rigid foam is therefore very high even with low thicknesses of insulating material. WLG 040 insulating materials must be 200 mm thick to achieve a U-value of 0.20 W/(m^2·K). With WLG 025 polyurethane rigid foam insulating boards, 125 mm is already sufficient to achieve the same insulating effect (ignoring heat transfer resistance).

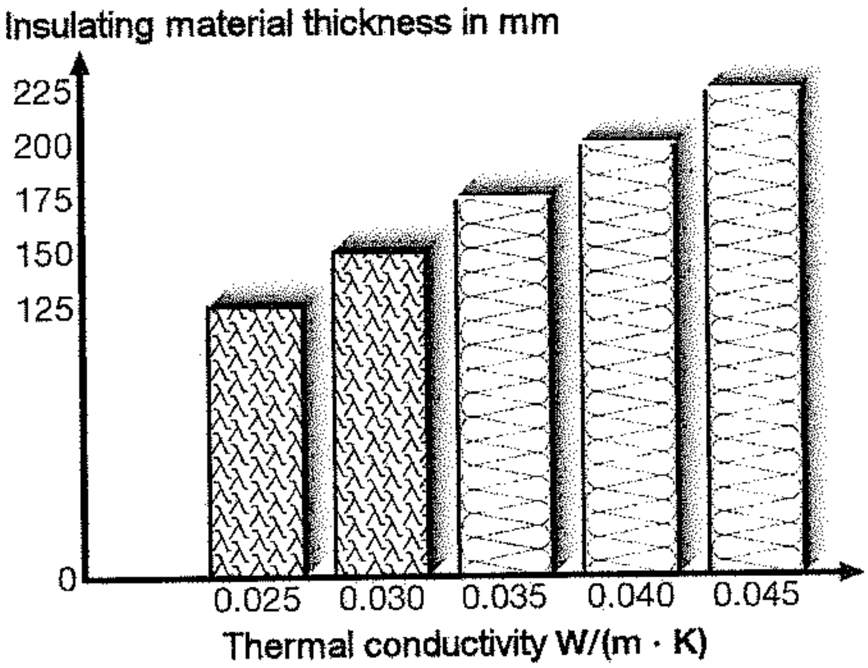


Fig. 18: Insulating material thicknesses as a function of thermal conductivity for a U-value of 0.20 W/(m^2·K), ignoring heat transfer resistance

Polyurethane rigid foam also meets important demands made on modern building materials:

- high compressive strength (for walking on) despite low density (30-35 kg/m^2)
- good long-term stability
- resistant to mildew and rot
- odorless and physiologically safe
- will not drip in the event of fire, does not smolder, so no hidden source of fire
- quick and easy processing
- multifunctional (for example thermal insulation with vapor barrier)
- positive life cycle assessment
- recyclable

<u>Requirement 1: Minimum U-value</u>

The Thermal Insulation Regulation of 1995 placed requirements on the k-values of individual external components in small residential buildings. In the Energy Saving Regulation, requirements on individual components are only retained for existing buildings; In the case of new buildings only the balance requirements apply.

As a preliminary guideline, the Industrial Federation for Polyurethane Rigid Foam (IVPU) gives U-value recommendations for various components, along with the corresponding polyurethane insulating material thicknesses.

These recommendations are "on the safe side" for the balance principle, and planning engineers can use them directly for calculations ("magic formula", see Chapter 4, page 16). In the design of the building shell, polyurethane rigid foam gives the designer plenty of freedom in the optimization process; with low insulating material thicknesses, there are numerous opportunities for compensation between the different components and their various U-values.

Component **U-value W/(m² · K)** **Polyurethane insulating materials thickness mm**		**New building EnEV**		**Old building EnEV**		**New-build passive house**	
Pitched roof (Insulation on the rafters)		≤ 0.20		≤ 0.30		≤ 0.10	
	WLG 025		120		080		240
	WLG 030		140		100		280
Flat roof		≤ 0.20		≤ 0.25		≤ 0.10	
	WLG 025		120		100		240
	WLG 030		140		120		280
Ceiling of top floor		≤ 0.20		≤ 0.30		≤ 0.10	
	WLG 025		120		080		240
	WLG 030		140		100		280
External wall		≤ 0.30		≤ 0.35		≤ 0.15	
	WLG 025		080		060		160
	WLG 030		100		080		200
Floor/cellar ceiling (against ground or unheated cellar)		≤ 0.30		≤ 0.40		≤ 0.15	
	WLG 025		080		060		160
	WLG 030		100		080		200
Perimeter insulation		≤ 0.30		≤ 0.40		≤ 0.20	
	WLG 030		100		080		160

Fig. 19: IVPU U-value recommendations for various components with corresponding polyurethane insulating material thicknesses

Only the rated values (previously characteristics) laid down in DIN 4108-4 "Thermal insulation and energy saving in buildings" for the thermal conductivity of an insulating material may be used to calculate the U-value of components.

Requirement 2: Air-tightness and wind-tightness

As thermal insulation requirements increase, air losses through joints and gaps become more significant.

Pitched roof insulation with polyurethane rigid foam has been selected as an example of an air-tight construction. With over-rafter thermal insulation systems consisting of polyurethane rigid foam insulating boards, air-tight structures can be produced in a simple manner.

In a pitched roof construction in which the thermal insulation layer of polyurethane rigid foam boards is laid on visible timber cladding, the required air-tightness in the surface is provided by laying an underlay, for example a bitumen layer, on the visible timber cladding (see Fig. 20).

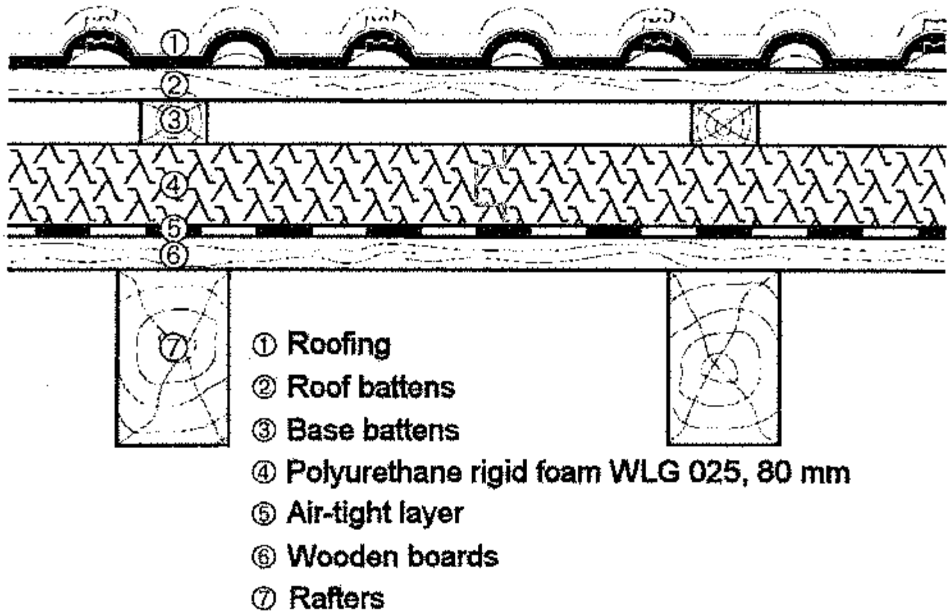


Fig. 20: Polyurethane pitched roof insulation with air-tight layer on visible timber cladding

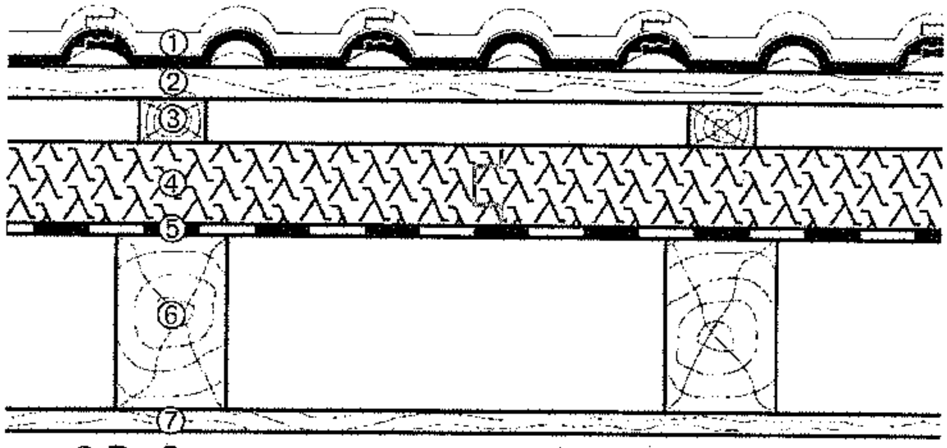
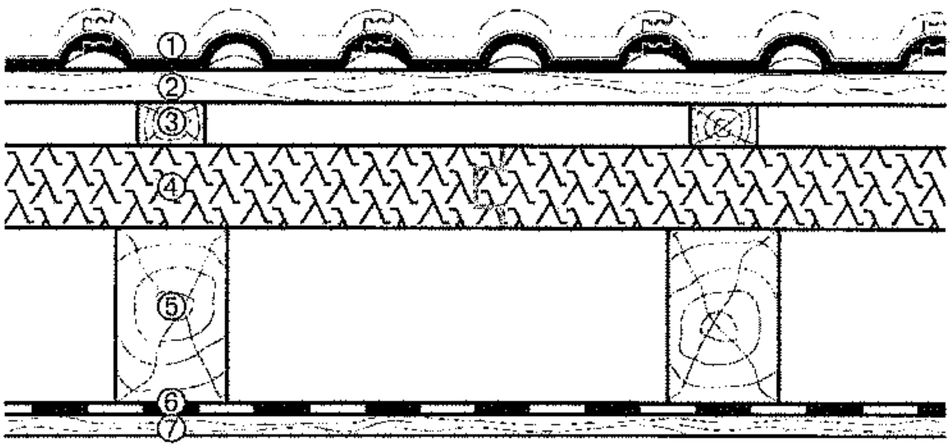


Fig. 21: Polyurethane pitched roof insulation with an air-tight layer above the rafters

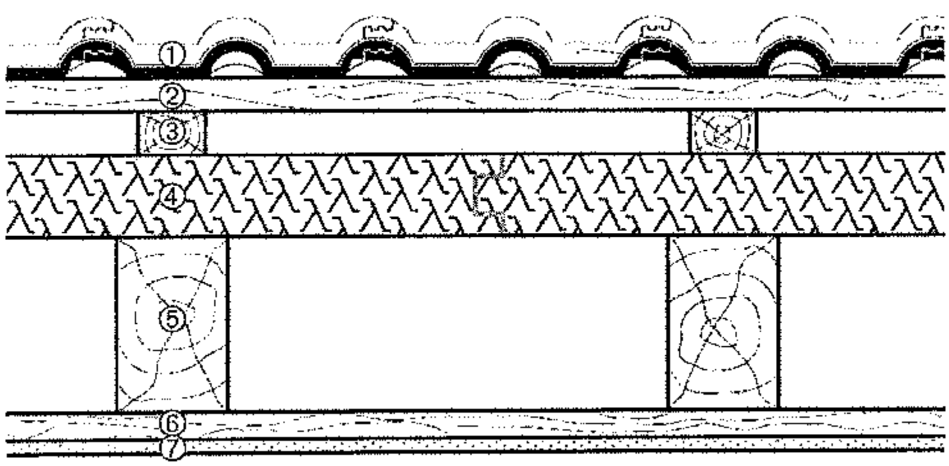
If the polyurethane rigid foam panels are laid directly on the rafters, a film can be placed above or below the rafters as an air-tight intermediate layer (see Figs. 21 and 22).



① Roofing
② Roof battens
③ Base battens
④ Polyurethane rigid foam
WLG 025, 80 mm

⑤ Rafters
⑥ Air-tight layer
⑦ Cladding with
profiled boards

Fig. 22: Polyurethane pitched roof insulation with an air-tight layer below the rafters



① Roofing
② Roof battens
③ Base battens
④ Polyurethane rigid foam
WLG 025, 80 mm

⑤ Rafters
⑥ Lath
⑦ Plasterboard

Fig. 23: Polyurethane pitched roof insulation with plasterboard below the rafters

If the rafters are lined underneath with plasterboard, the air-tight layer can be omitted as long as the abutting edges of the plasterboard are sealed with joint sealing materials and all connections to the brickwork and to penetrating components are made air-tight (see Fig. 23).

Gaps in problematic, complex areas (such as rafters, roof beams, fixtures) can be sealed reliably and permanently by corresponding constructional measures, for example by using rafter tails or by sealing with joint sealing tapes or with permanently elastic compositions.

Energy Saving Regulation § 5 (1) – Tightness

New buildings shall be designed in such a way that the heat-transferring external surface, including the joints, is sealed so as to be permanently impermeable (air-tight) in accordance with the state of the art. The joint permeability of external windows, French windows and skylights must satisfy Appendix 4 No. 1 (building with up to two stories Class 2, with more than two stories Class 3 of DIN EN 12 207-1:2000-06).

Requirement 3: absence of thermal bridges

Thermal bridges are localized weak points in a construction, where more heat can escape than in the surrounding areas. Thermal bridges lead to heat losses and lower surface temperatures, and ultimately result in an increased heating energy requirement. The reduced surface temperatures lead to the formation of condensation water, which can result in water damage and the formation of mold fungus.

Thermal bridges can be caused by materials, geometry, the environment and mass flow. Thermal bridges caused by materials are the most common in practice, and may occur for example in insulation between the rafters (see Fig. 24).

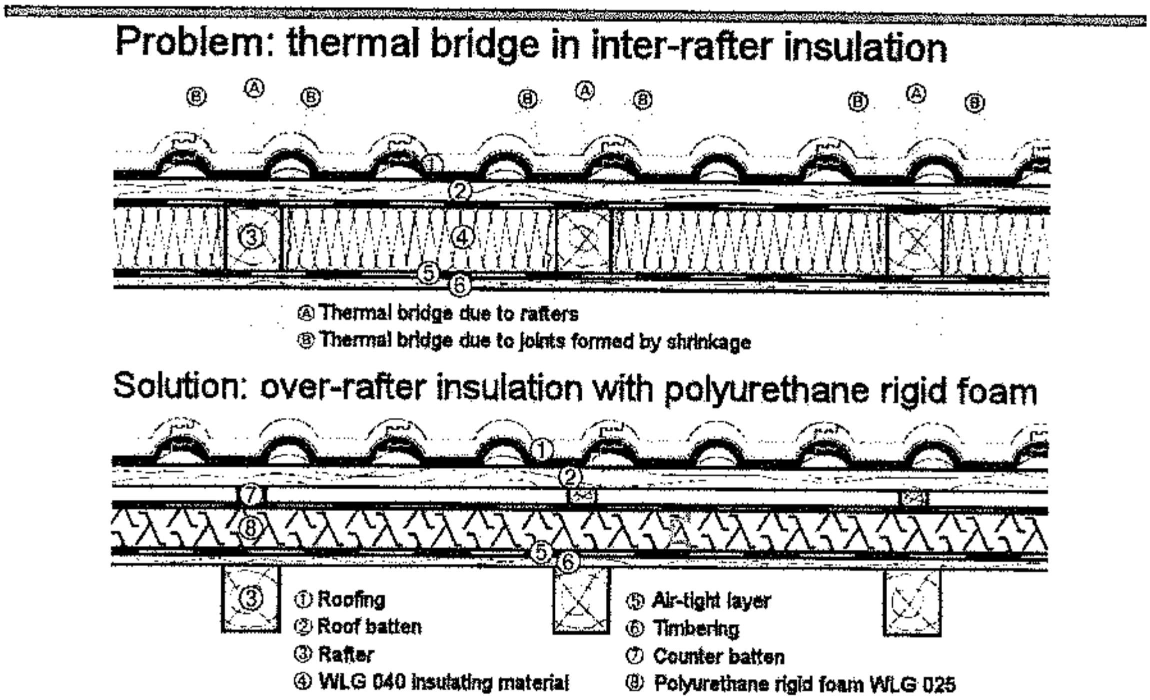


Fig. 24: Thermal bridges caused by materials
Energy losses due to rafters with lower insulating effect (A) and joints formed by shrinkage between the insulating board and the rafters (B).

Thermal bridges are also caused by geometry, and these occur predominantly in uninsulated external wall corners (see Fig. 25).

Polyurethane rigid foam panels can often offer a technical solution to the numerous problem points that continue to occur despite all attempts to prevent thermal bridges in construction. Thus, thermal bridges that cannot be avoided using between-rafter insulation in pitched roofs can be prevented without difficulty by using polyurethane rigid foam insulation with a peripheral tongue-and-groove edge on top of the rafters. Again, the low insulating material thickness and high insulating capacity have a positive effect on the design of the construction.

Energy Saving Regulation § 6 (2) – Thermal bridges

New buildings shall be designed in such a way that the effect of structural thermal bridges on the annual heating requirement is kept as low as possible in accordance with the technological standards and the measures which are reasonable in the individual case. ...

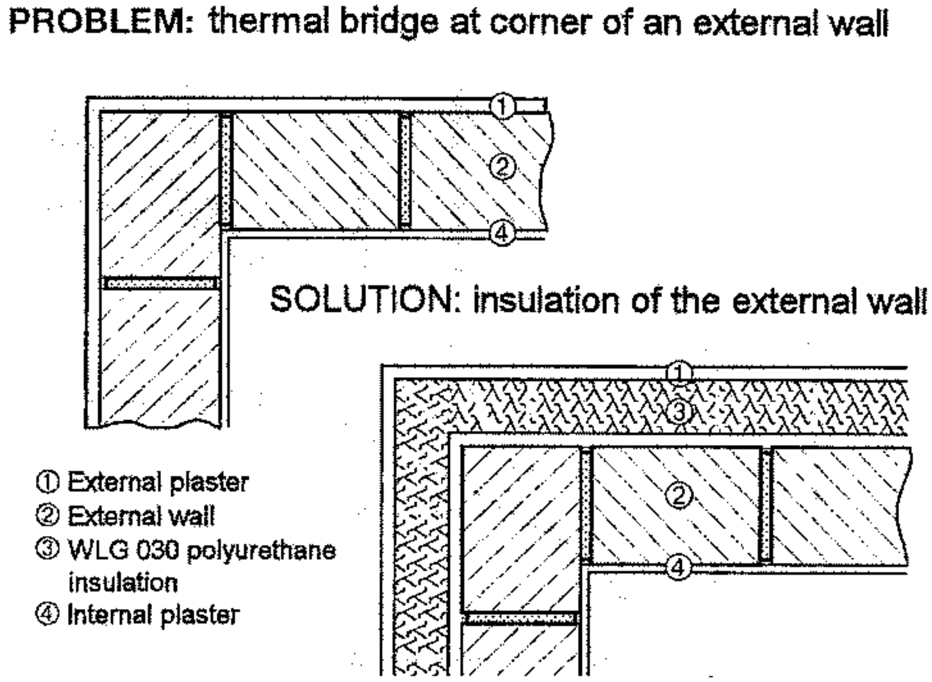


Fig. 25: Thermal bridges caused by geometry

Energy losses through an uninsulated external wall corner.

7.2 Polyurethane rigid foam insulation solutions

7.2.1 Roofs

Pitched roofs

With pitched roofs, the thermal insulation can be installed over the rafters, under the rafters or between the rafters – or by a combination of several measures. Insulation over the rafters is the best method in all cases from a structural physics and economic point of view.

In over-rafter insulation, the whole construction is clad with the polyurethane insulation over the entire surface. This protects the roof structure from thermal effects and has the added advantage that the rafters do not act as thermal bridges. Self-adhesive overlaps between polyurethane insulating elements ensure a tight seal all round.

Large polyurethane rigid foam panels with rebated joints can be rapidly laid to produce a "slim" layer of insulation that covers the whole surface and is wind-tight and free from thermal bridges.

With insulation over the rafters, the U-value of 0.20 $W/(m^2{\cdot}K)$ is achieved with 120-mm thick polyurethane rigid foam insulating boards of thermal conductivity group 025. An insulating material of thermal conductivity group 040 would have to be 190 mm thick in this case.

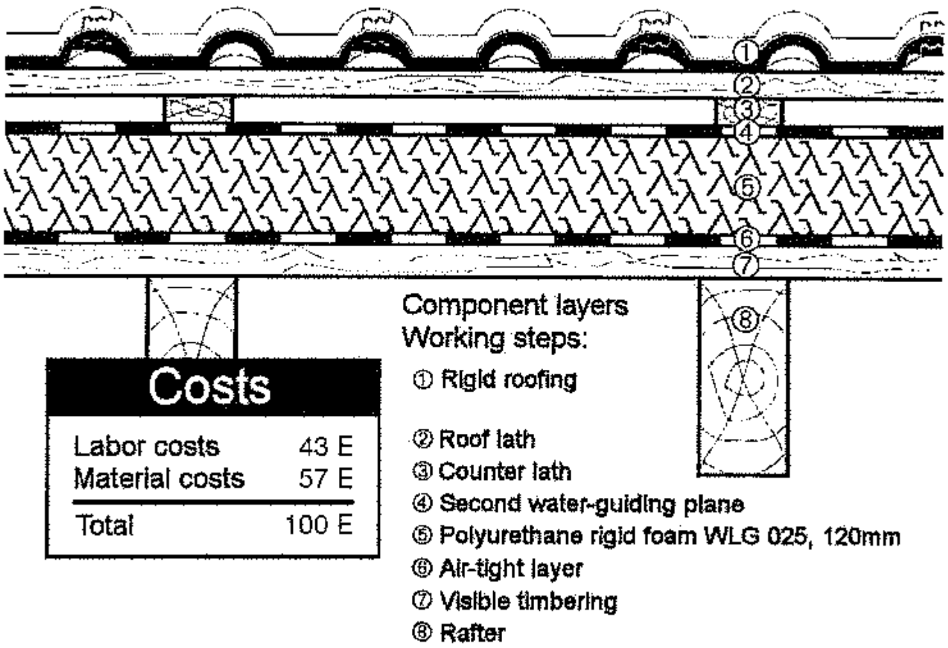
Applying thicker insulating boards to the rafters entails considerable technical complexity (longer special fasteners, deeper lining of the skylight etc.) and cost-intensive solutions to compensate for the height difference in the eaves and gable region.

WLG 040 insulating boards are therefore laid either between the rafters or in a combination of between-rafter insulation with under-rafter or over-rafter insulation.

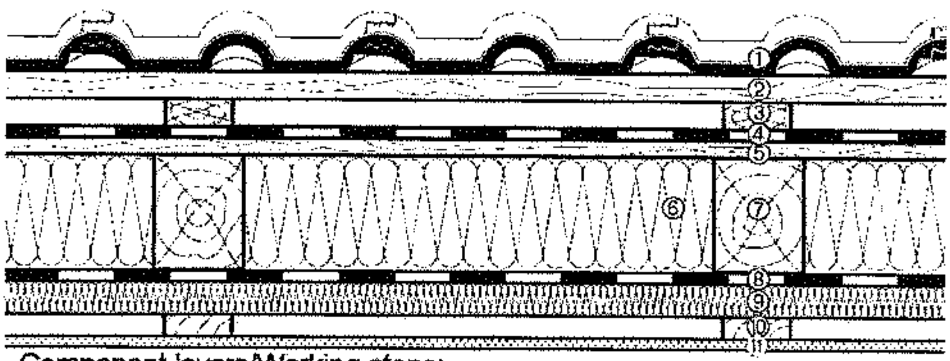
However, to achieve the U-value of 0.20 $W/(m^2{\cdot}K)$ with between-rafter insulation alone would require 240 mm thick WLG 040 insulating boards, and also therefore 240 mm high rafters.

With pitched roofs, practical economic considerations cannot just focus on the price of the insulating material, but must also take into account the costs of the extra material and the processing. This applies above all to the costs of a wind-tight and vapor-diffusion-tight construction.

The superiority of over-rafter insulation with polyurethane rigid foam insulating boards over WLG 040 insulation (between-rafter insulation combined with under-rafter insulation) for a roof U-value of 0.20 W/(m²·K) is clear from a cost comparison.



Over-rafter insulation with WLG 025 polyurethane foam



Component layers/Working steps:

① Rigid roofing
② Roof lath
③ Counter lath
④ Second water-guiding plane
⑤ Slate boarding
⑥ Insulation between rafters, WLG 040, 140 mm
⑦ Rafter
⑧ Vapor barrier
⑨ WLG 040 insulation, 40 mm, under the rafters between the cross laths
⑩ Lath for plasterboard
⑪ Plasterboard, plaster, papering, paint etc

Costs	
Labor costs	71 E
Material costs	39 E
Total	110 E

WLG 040 between-rafter/under-rafter insulation

Fig. 26: Total cost (units for labor and material costs) of polyurethane rigid foam insulation over the rafters compared with WLG 040 insulation using a combination of between-rafter and under-rafter insulation.

Even when insulation is retrofitted in old buildings, insulation over, under and between the rafters is possible.

<u>*Top floor ceilings*</u>

According to the Energy Saving Regulation, inaccessible top floor ceilings of heated rooms must be insulated in such a way by December 31, 2006 that the U-value will not exceed 0.30 W(m^2·K). A simple and cost-effective solution for meeting this requirement is to fit 100 mm thick WLG 030 polyurethane rigid foam insulating boards or 800 mm of WLG 025.

<u>*Flat roofs*</u>

Polyurethane rigid foam insulating boards provide an outstanding insulating material for flat roofs because of their beneficial properties.

Polyurethane rigid foam insulating boards

- are temperature-resistant from -30 to +90 °C; the temperature variations that occur in flat roofs do not have any adverse effect on the insulating boards;
- are heat-resistant up to +250 °C over short periods, and are therefore extremely suitable for laying with hot bitumen. The high heat resistance makes it possible to install them on flat roofs using casting and rolling methods or with waterproof bituminous sheeting;
- are chemically resistant to benzene, toluene and other solvents that are present in bituminous cold coats, adhesives, welding solvents, wood preservatives, sealants and plastic roofing felts. They can be laid quickly and easily with a polyurethane cold adhesive;
- are extremely compression-proof and can thus be walked on; they can be used under gravel, under terrace coverings laid over the whole area, and under green roofs. If the flat roof is to be used as a terrace, a parking area etc., polyurethane insulating boards with an even higher compressive strength can be installed;
- are easy to work with; they can easily be cut out and adjusted using a fine-toothed saw or a knife;
- are resistant to rot and mildew and have a high resistance to ageing.

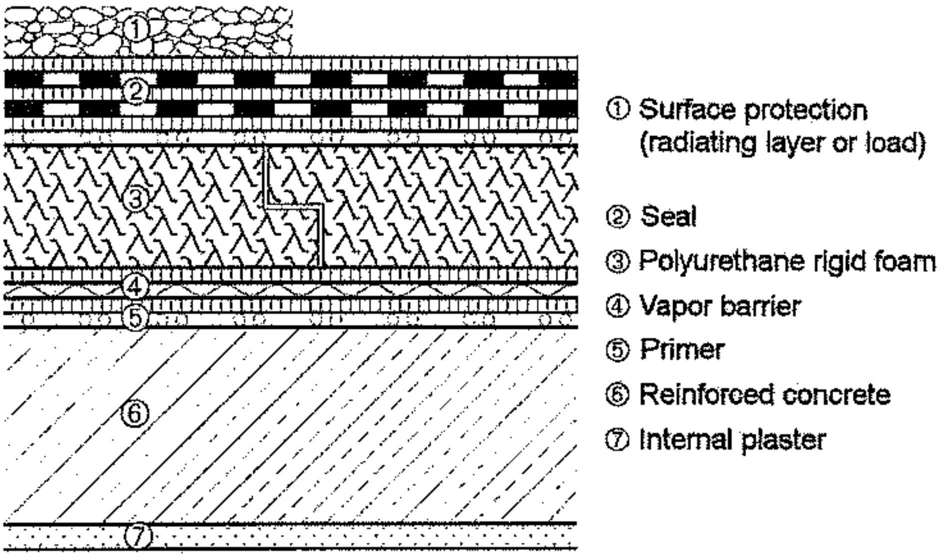


Fig. 27: Flat roof with polyurethane rigid foam insulation

The polyurethane rigid foam insulating boards are installed in accordance with the "technical standards for sealed roofs – flat roof guidelines"[8].

Polyurethane rigid foam boards without facings, or with facings consisting of mineral mats, compound sheets, special papers or aluminum foils, are used for flat roof insulation. Rebated panel edges ensure good joint closure and thus prevent thermal bridges.

The insulating boards are laid either by adhesion with a hot-melt bitumen composition or by cold adhesion with a moisture-curing polyurethane adhesive. Mechanical fastening or loose laying under an appropriate load is also possible.

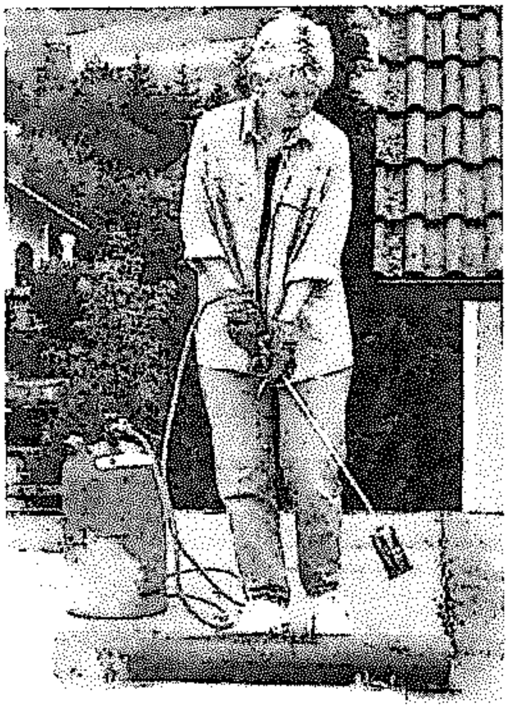


Fig. 28: Laying polyurethane rigid foam insulating boards on a flat roof

To achieve the U-value of 0.20 W/(m^2·K) recommended for new buildings, either 140 mm thick WLG 030 panels or 120 mm thick WLG 025 panels should be used.

With special WLG 030 polyurethane rigid foam tapering insulating boards, a sloping roof that carries off water can also be produced together with the thermal insulation in one go. Heat-insulated roof gullies may also be provided to remove water and air from the roof. Firms which are members of the federation also supply special polyurethane flat roof insulating elements for refurbishing flat roofs.

7.2.2 *Walls*

<u>*Composite thermal insulation system*</u>

Nowadays, the external walls of a house are often insulated with a composite thermal insulation system (WDV). For this purpose, the thermal insulation is applied to the outside of the wall (brickwork, concrete walls, timber frame walls).

Unlaminated WLG 030 polyurethane rigid foam insulating boards are suitable for use in WDV systems.

Depending on the WDV system used and the height of the building, the insulating boards may be dowelled and glued or just glued.

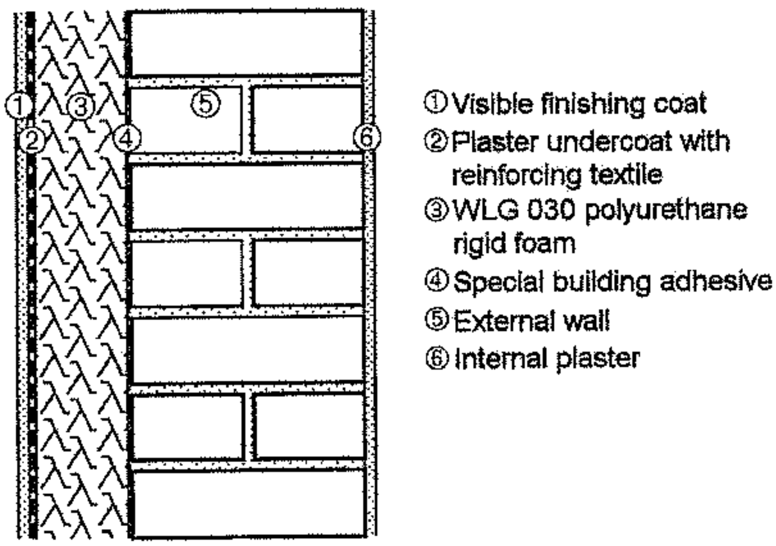


Fig. 29: Polyurethane composite thermal insulation system

A plaster undercoat with reinforcing fabric is initially applied to the insulating boards, followed by a visible final rendering. All parts of the system (insulating material, adhesive, dowels, reinforcing fabric, plasters etc.) must be fitted to one another and be tested as an overall package. The WDV system can be used in both new and old buildings.

In new buildings, the IVPU recommends the use of 100 mm thick WLG 030 polyurethane rigid foam panels (U-value = 0.30 $W/(m^2 \cdot K)$).

The "slim" construction of the polyurethane composite thermal insulation system, due to the low insulating material thicknesses, facilitates the construction of the joints and makes it possible to maintain the esthetic quality of the façade.

Rear-ventilated façades

An externally insulated wall may additionally be clad with slate, fiber cement panels, wooden shingling or a curtain-type wooden façade. In these cases a rear-ventilated construction is always required. The purpose of the rear ventilation space in this case is to carry off moisture and any penetrating precipitation.

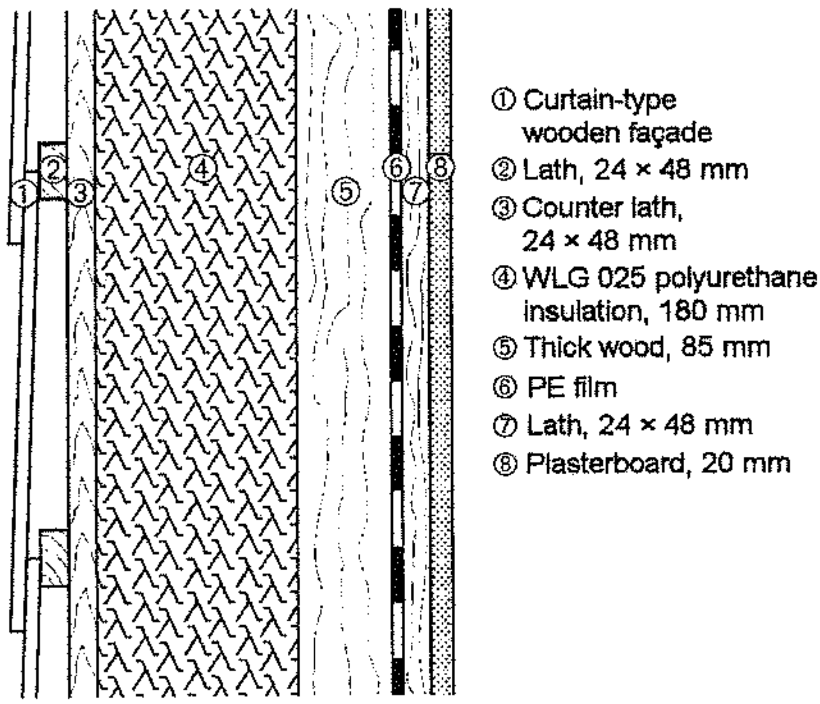


Fig. 30: Polyurethane passive house with a rear-ventilated façade

For the façade of a polyurethane passive house, the architect has selected a curtain-type wooden façade. During final assembly on site, prefabricated wooden elements were provided with the openings according to the design, to which thermal insulation panels of polyurethane rigid foam, the lath and counter lath and the curtain-type wooden façade were attached.

A 180 mm polyurethane rigid foam insulating layer (WLG 025) gave a U-value of 0.124 $W/m^2{\cdot}K$) in this case. A WLG 040 insulating material only achieves this value at a thickness of 320 mm. Reducing the thickness of the construction by 140 mm provides both an increase in space and a more attractive design.

The type of rear-ventilation construction depends on the type of cladding, the materials used and where applicable on the insulating material thickness. For sufficient rear ventilation, the distance between the thermal insulation and the cladding must be at least 20 mm in each case [9]. WLG 025 and WLG 030 polyurethane rigid foam insulating boards may be used in the rear-ventilated façade.

The high insulating efficiency of polyurethane rigid foam is particularly advantageous when it is used in this field. Using polyurethane rigid foam makes it possible to minimize the thickness of the external wall.

Core insulation

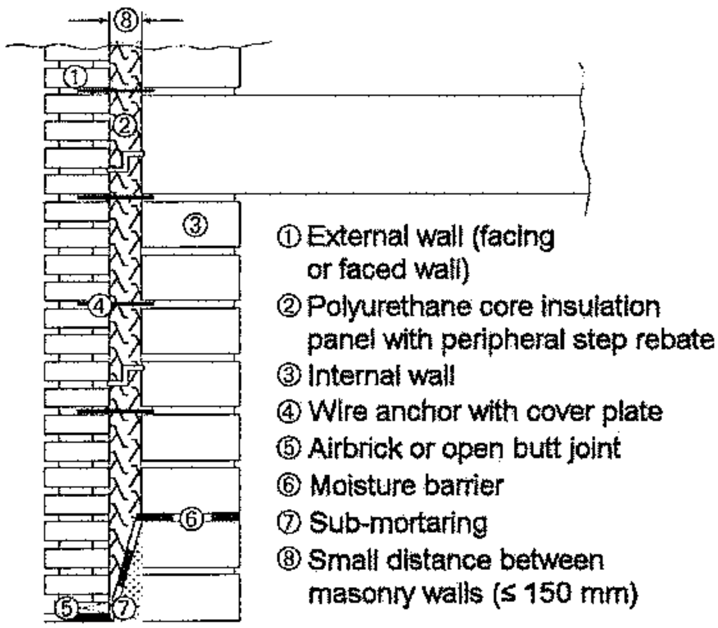
In the core insulation of double-wall masonry, an insulating layer is installed between two wall layers, the load-bearing internal wall and the non-load-bearing external wall.

A distinction is made between:

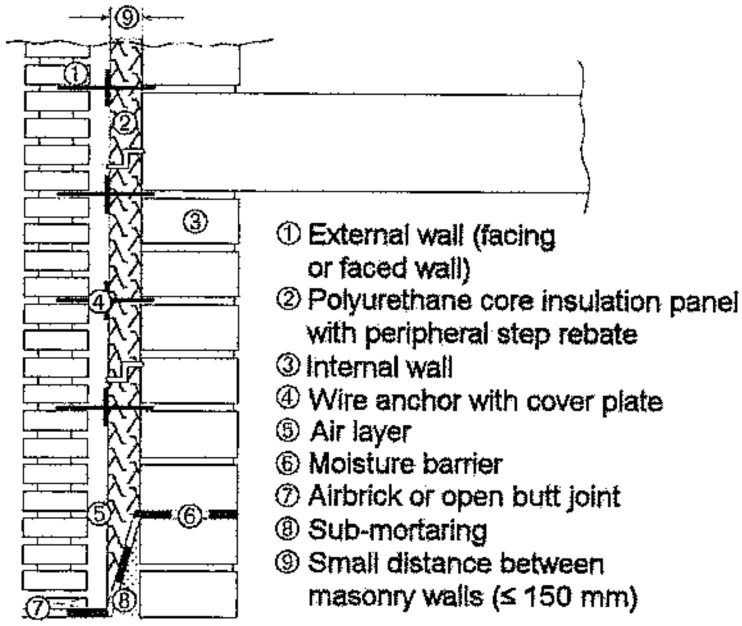
- core insulation without an air layer and
- core insulation with an air layer.

In accordance with DIN 1053-1 "Masonry – design and construction", the minimum thickness of the non-load-bearing external wall must be 115 mm in the case of core insulation without an air layer and 90 mm in the case of core insulation with an air layer. The small distance between the internal and external wall must not be more than 150 mm. The thickness of the air layer in core insulation with an air layer must be at least 40 mm. Therefore, the insulating materials used between the two walls must not be thicker than 150 mm (without air layer) or 110 mm (with air layer).

WLG 030 polyurethane rigid foam insulating boards with edge profiling (for example a step rebate) are extremely suitable as an insulating layer in double wall masonry, i.e. as core insulation with and without an air layer.



Without air layer



With air layer

Fig. 31: Core insulation with polyurethane rigid foam – without and with an air layer

If the insulating boards are mounted without an air gap, using the greatest possible insulating material thickness, in this case 150 mm, this results in a U-value of 0.18 W/(m^2·K) for the external wall. In the design with an air layer, with the applicable maximum permissible insulating material thickness of 110 mm, the U-value is 0.22 W/(m^2·K).

With WLG 040 insulating materials – making the same assumptions – it is only possible to achieve U-values of 0.23 W/(m^2·K) and 0.27 W/(m^2·K) respectively.

Since the maximum installation thicknesses of the insulating boards are limited to 150 mm and 100 mm by the provisions of DIN 1053-1, the extremely favorable U-values (0.18 and 0.22 W/(m^2·K)) of the insulated external wall can only be achieved with polyurethane rigid foam.

Internal insulation

When improving the thermal insulation of external walls in old buildings, internal insulation may be a cost-effective solution. This is especially the case if external insulation is not possible because of a preservation order or for reasons of urban conservation. Composite panels of plasterboard and WLG 030 polyurethane rigid foam have been found to be effective as insulating elements for this application, and can also be provided with an integrated vapor barrier.

Internal insulation always leads to a reduction in the usable space. In this context, polyurethane rigid foam has the advantage that the loss of space is less than when using other insulating materials with higher thermal conductivity. Thinner polyurethane rigid foam elements can be used to achieve the same insulating efficiency.

7.2.3 Basements and floors

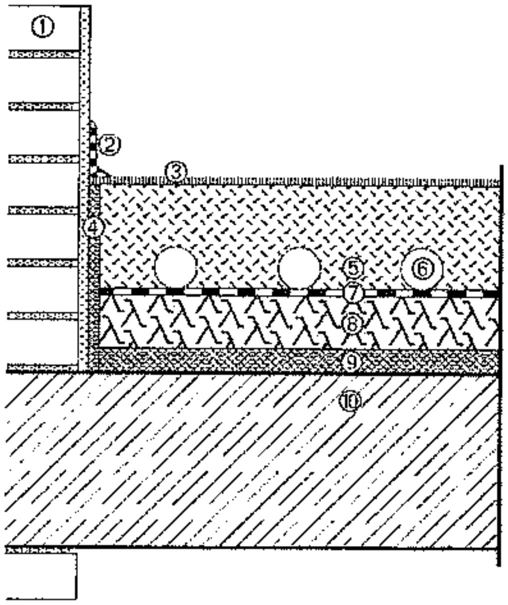
Floors

Professional thermal insulation in the floor saves heating energy and increases the level of comfort, especially

- above unheated basement spaces
- on floors directly adjacent to the ground
- on floors above open passages.

Polyurethane rigid foam is extremely effective as a thermal insulating material in the floor. It provides optimum thermal insulation with thin panels and thus provides favorable building conditions for achieving low construction heights. Polyurethane floor panels are quick and easy to lay, and can readily be cut to size with standard flooring tools.

The recommended U-value of 0.30 $W/(m^2 \cdot K)$ for new buildings can be achieved with only 80 mm thick aluminum-laminated WLG 025 polyurethane rigid foam panels or 100 mm thick WLG 030 mineral-mat-laminated polyurethane panels.



① Brickwork
② Skirting board
③ Carpet, parquet etc.
④ Edge insulation strips
⑤ Composition floor
⑥ Floor heating
⑦ Cover
⑧ Polyurethane rigid foam
⑨ Impact sound insulation
⑩ Bare floor (concrete)

Fig. 32: Floor insulation with polyurethane rigid foam insulating boards

Perimeter insulation

The external thermal insulation of components in contact with the earth is known as "perimeter insulation". Energy losses through the external walls, the basement and the floor are reduced considerably by perimeter insulation. Perimeter insulation provides a pleasant room climate in inhabited basements (for example in a self-contained apartment).

Fig. 33: Laying polyurethane perimeter insulating boards

Polyurethane rigid foam is exceptionally suitable as an insulating material for perimeter insulation. Polyurethane perimeter insulating boards do not decompose, are resistant to mildew and rot, and have an excellent mechanical strength. Because of their resistance to solvents, polyurethane perimeter insulating boards can readily be glued into the wall region on the seal.

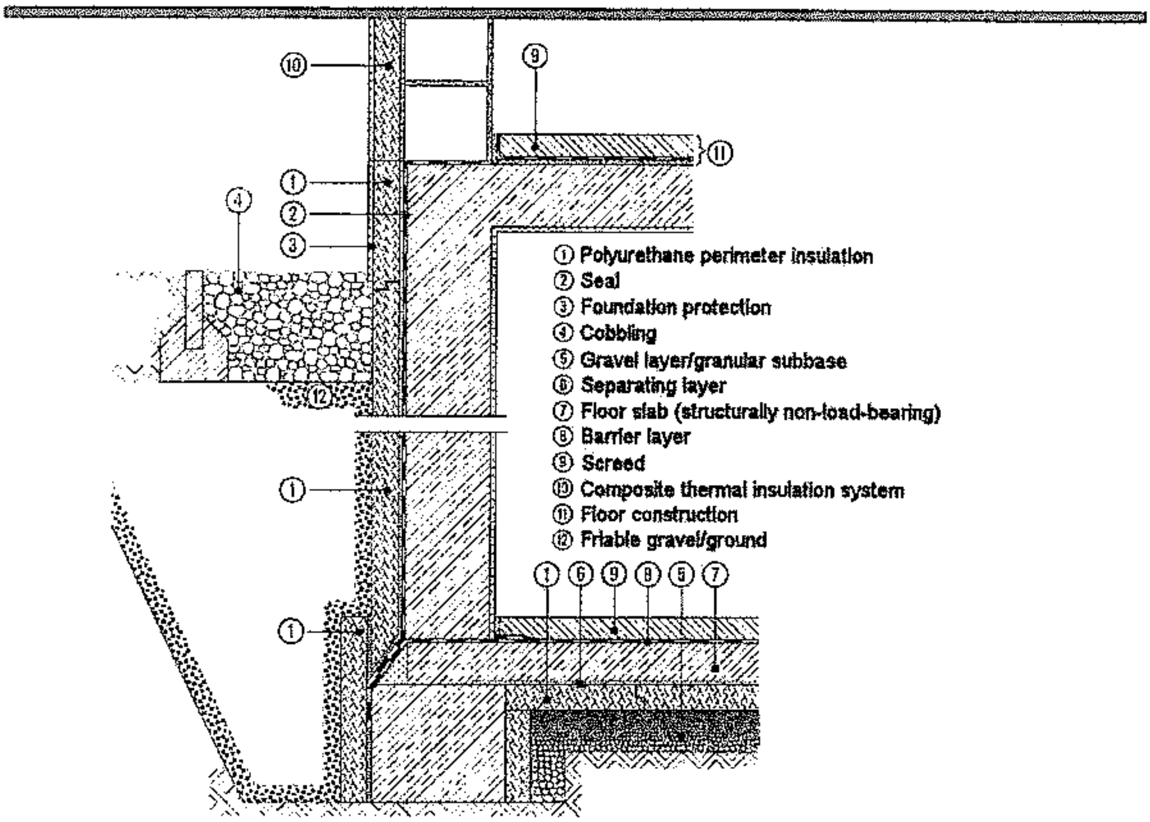


Fig. 34: Perimeter insulation with polyurethane rigid foam

Mineral-mat-laminated WLG 030 polyurethane rigid foam boards are used for perimeter insulation. An external basement wall of 30 cm sand-lime brick, insulated with 100 mm thick polyurethane perimeter insulating boards, complies with the recommended U-value of 0.30 $W/(m^2 \cdot K)$. There is building inspectorate approval for the application of polyurethane rigid foam insulating boards as perimeter insulation (Z-23.33-1259). This approval also covers thermal insulation of structurally non-load-bearing floor panels.