9 *Polyurethane buildings of the future: new-build and refurbished low-energy and passive houses*

In recent years, the polyurethane rigid foam federation (IVPU) and its members have developed various designs for new-build and refurbished low-energy and passive houses.

With a design by the architect Prof. Josef Lenz, the IVPU took part in the WEKA architecture competition in 1996 and in the BHW-Bausparkasse "STARTER HOUSE" competition in 1998.

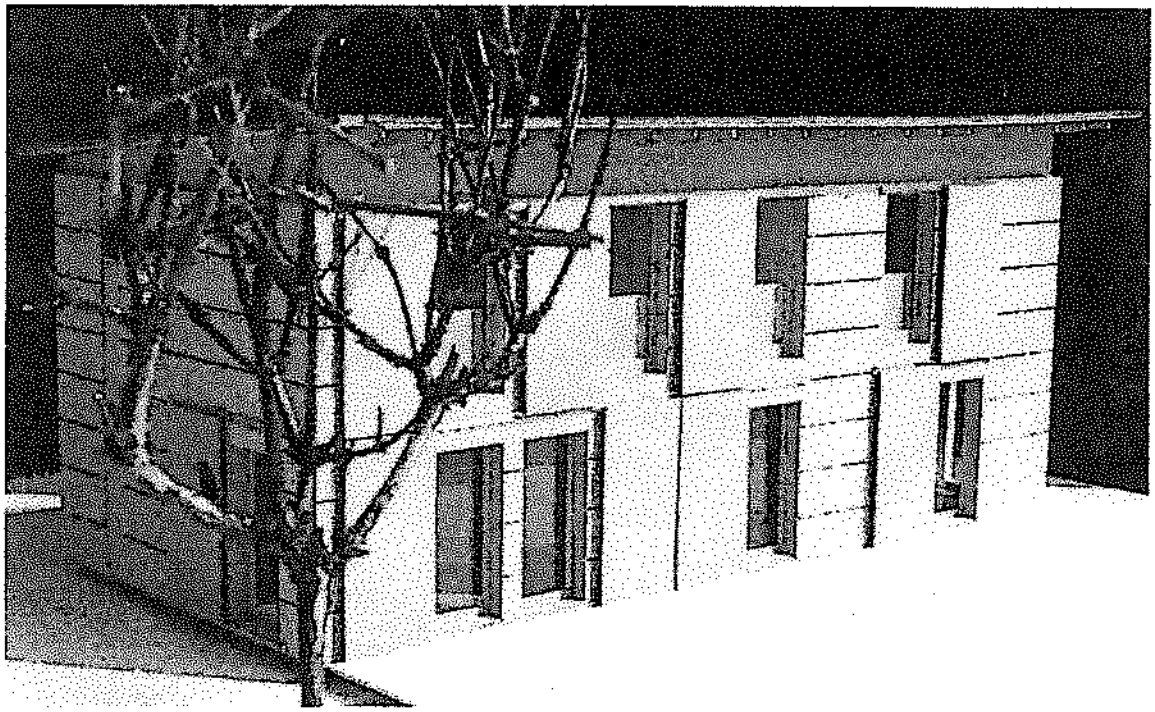


Fig. 39: Three-liter house of timber construction with polyurethane rigid foam insulation

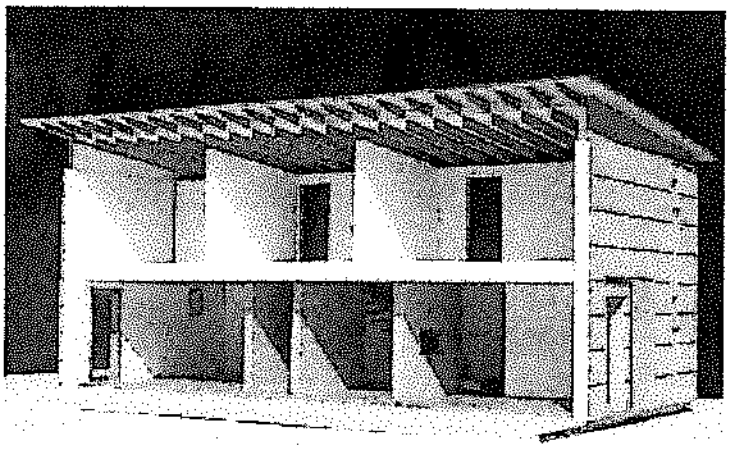


Fig. 40: Three-liter house with concrete wall panels as heat stores

In 2000, the IVPU announced the "resource architecture" prize. The winning projects show objects at the design or construction stage, and designs and ideas that represent a successful synthesis of ambitious architecture, energy optimization and cost-effective construction.

The competition requirements included the use of polyurethane rigid foam for thermal insulation measures. The prize-winners attested that, because of its high insulating efficiency, its versatility in various fields of use and its high energy saving potential, this building material is optimally suited for use in low-energy and passive houses.

In parallel with these design studies, the IVPU appointed the Institute for Housing and Environment (IWU) in Darmstadt to carry out EnEV certification of five buildings. [10]

In each case a comparison was made between polyurethane rigid foam (WLG 025/030) and other insulating materials (WLG 035/040). Two questions were of particular interest here:

1. With the same level of thermal insulation, how much living area can be gained by insulating with polyurethane rigid foam?

2. Assuming that the insulating materials have the same thickness, how much can the heating energy requirement be reduced by using polyurethane rigid foam?

The EnEV certification took into account the parameters of DIN V 4108-6 "Thermal insulation and energy saving in buildings; calculation of annual heating and energy use."

The investigation showed that thermal insulation still retains its high importance in the Energy Saving Regulation. The developments presently under way in parts of the building industry go considerably further, towards three-liter houses and passive houses. In these cases, 200- to 400-mm-thick insulating material is standard. If these buildings are built as lightweight constructions, the external walls are no thicker than conventional monolithic constructions (for example 36.5 cm masonry). However, a solid construction results in considerably greater wall thicknesses, which are sometimes not readily accepted on the market. In this regard, the high-performance insulating material polyurethane rigid foam, with its outstanding insulating efficiency (thermal conductivity groups 025 and 030), has specific advantages over other commercially available insulating materials:

- With the same level of thermal insulation, construction thicknesses are reduced by up to 120 mm.
- With insulating materials of the same thickness, 40 % more energy can be saved.

In practice, this means that if it is necessary to use given building lots or adhere to given floor areas for new buildings, the usable area can be increased while respecting the same external dimensions and the same energy standard.

Fully utilizing the area leads to increases of between €1,000 and €10,000 in the value of the building. The improved thermal insulation results in higher sales revenues, and in rented apartments results directly in a higher rent. In existing buildings, the loss of living area can be reduced in particular by fitting internal insulation.

If the construction thickness is subject to limitations, the energy saving can be maximized by using polyurethane rigid foam insulation; the following specimen calculations show that a reduction of up to 33 % in the annual heating requirement is possible. Moreover, polyurethane rigid foam has particular advantages when modernizing existing buildings, where there are often restrictions in the form of existing roof overhangs, passageways, walkways and lot boundaries.

Three single-family houses (new-build), a multi-family house (refurbished), and a semi-detached house (refurbished) were chosen for the investigation. The Energy Saving Regulation calculations for these buildings are explained in the following.

9.1 Polyurethane low-energy house standard according to The Energy Saving Regulation (Paderborn single-family house)

This detached, two-story single-family house, with 218 m^2 of heated living area, has a shallow-pitched roof over the single-story part of the first floor and a steep-pitched roof on the top floor. The basement is unheated. The external walls are solid and partially clad with clinker bricks. Elsewhere, the walls are clad with timber cladding. In the case of the steep-pitched roof, the intermediate spaces between each of the rafters and battens are fully insulated. In the case of the shallow-pitched roof, the reinforced concrete ceiling is insulated from above. In the basement region, the insulating layer is located between the reinforced concrete ceiling and the composition floor.

At 108.6 kWh/(m^2·a), the primary energy requirement of this building is 6 % less than the value permitted by the Energy Saving Regulation for the given surface area to volume ratio.

By using polyurethane rigid foam insulating boards instead of WLG 035/040 insulating materials, approximately 2000 kWh of fuel are saved per year, with the same construction thickness and thus the same living area. At a price of €40 per MWh, the heating costs are reduced by approximately €80 per year, to €680. This can save approximately €2,400 over a period of 30 years, assuming energy prices remain constant in real terms.

Building:

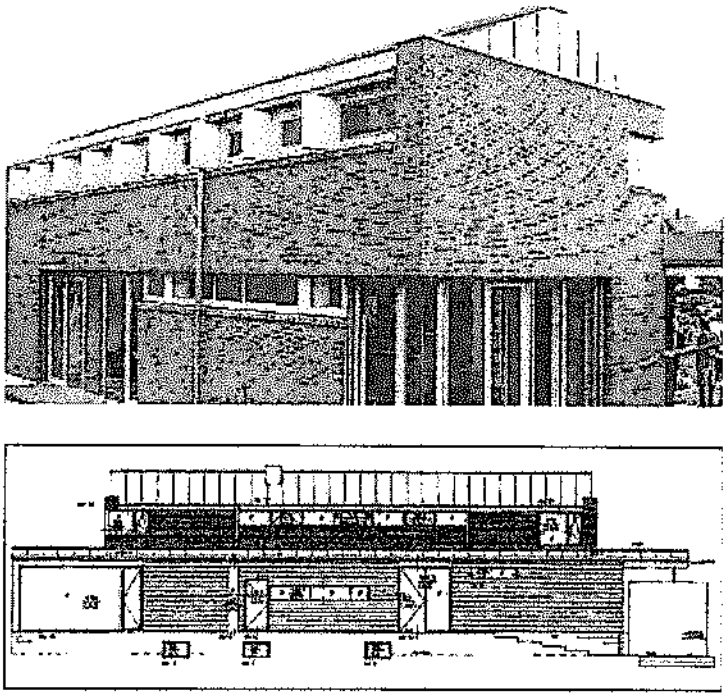


Fig. 41: Paderborn single-family house (NEH standard)

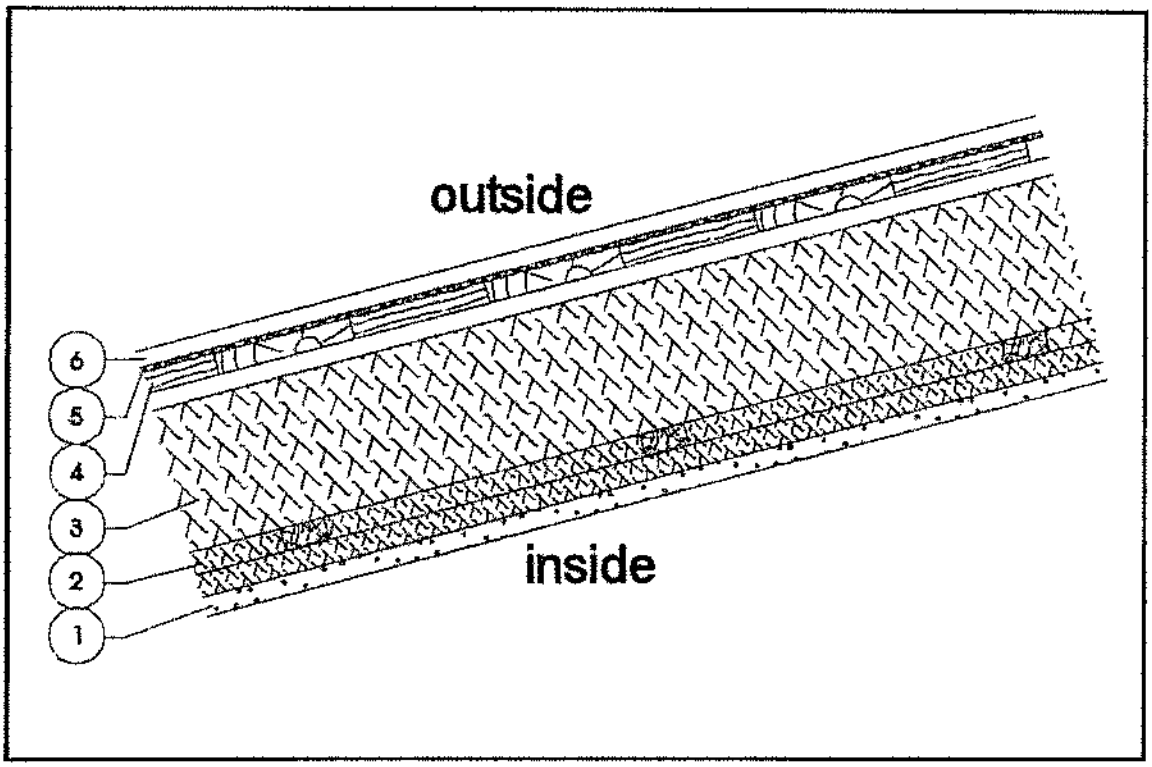
Energy characteristics:

Heating requirement:	72.5 kWh/(m²·a)
End-user energy requirement:	93.6 kWh/(m²·a)
Primary energy requirement:	108.6 kWh/(m²·a)

Construction detail:

	Paderborn single-family house	
Reduced construction thickness with equal thermal insulation using polyurethane rigid foam		
	Standard insulation	Polyurethane insulation
Steep-pitched roof	Component composition from inside to outside	
1	Plasterboard 20 mm	
2	Batten/air layer	
3	WLG 040 insulating board 50 mm	WLG 025 polyurethane insulation 30 mm
4	Rafters/ WLG 040 insulating	Rafters WLG 025

	board 183 mm	polyurethane insulation 120 mm
5	Boarding 24 mm	
6	Separating layer	
7	Titanium zinc	
d = 30 cm		24 cm
U = 0.074 W/(m^{2}K)		0.074 W/(m^{2}K)



9.2 Low energy house PLUS with polyurethane rigid foam insulation (end-of-terrace house)

This low-energy house is one of the winners of the IVPU "resource architecture" prize 2000. It can be used for either detached or terraced houses that are arranged on a 6.30-meter square grid. The resulting gardens and roof terraces are characteristic features.

Building:

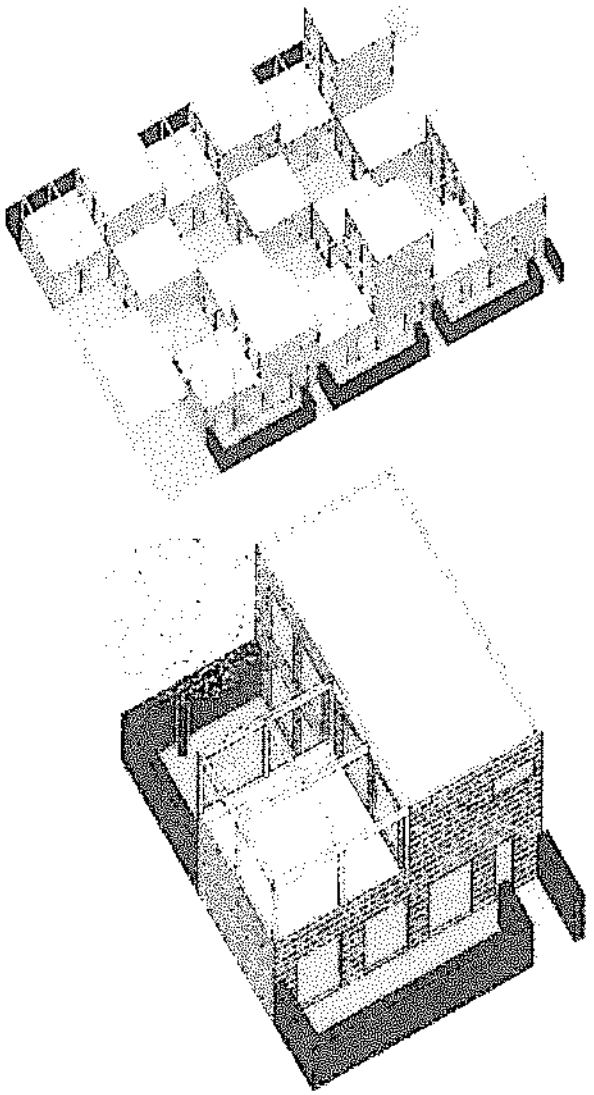


Fig. 42: Terraced housing development – a low building with the quality of a single-family house

The thick timber elements used for walls and ceilings act as a supporting layer and are air-tight. The polyurethane insulating boards used are arranged on the outside in each case. The ceilings adjacent to the external air are formed as either a roof terrace or a flat roof.

At 53.2 kWh/(m^2·a), the primary energy requirement is 57 % less than the value permitted by the Energy Saving Regulation for the given surface-area-to-volume ratio.

By using polyurethane rigid foam insulating boards instead of WLG 035/040 insulating materials, approximately 700 kWh of fuel are saved per year, with the same construction

thickness and thus the same living areas. At a price of €40 per MWh, the heating costs are reduced by approximately €30 per year, to €110. This can save approximately €900 over a period of 30 years, assuming energy prices remain constant in real terms.

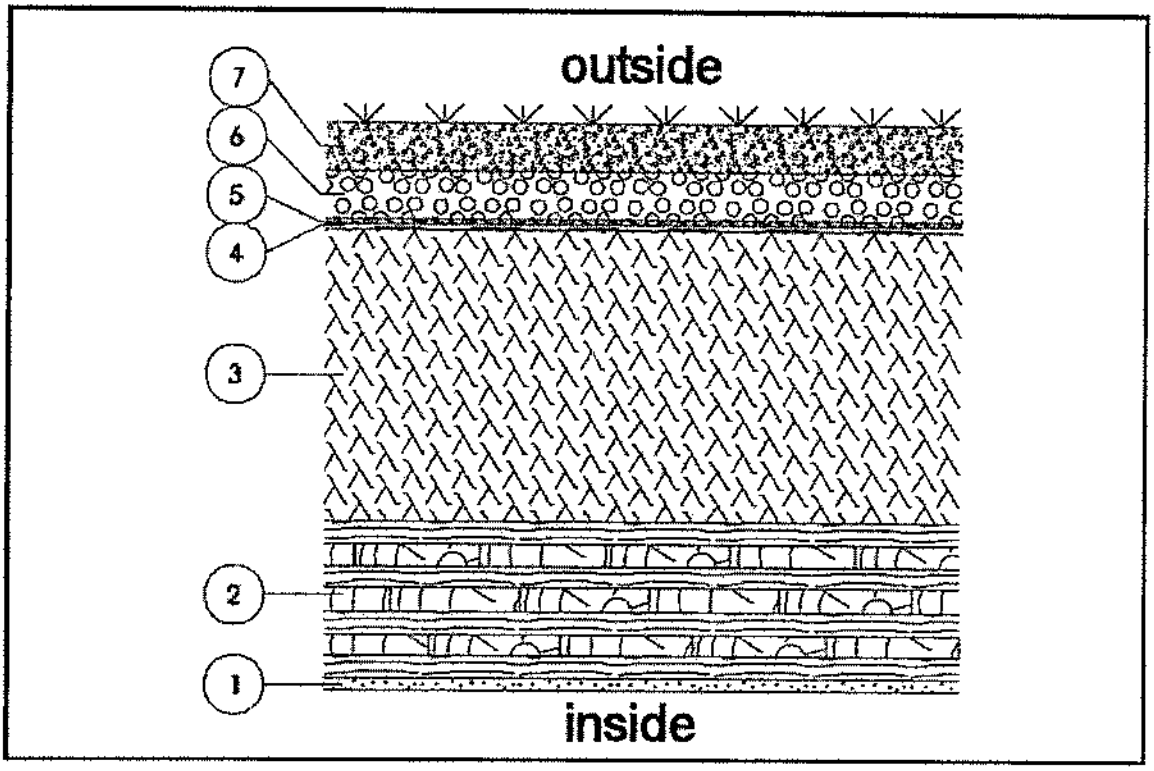
With polyurethane rigid foam insulation, the building achieves an annual heating requirement of 15.0 kWh per m^2 of heated living area, as in a passive house. The increase in living area when using WLG 025 and 030 polyurethane rigid foam insulating boards is 2.2 m^2 (approximately 1.4 % of the living area).

Energy characteristics:

Heating requirement:	15.0 kWh/(m^2·a)
End-user energy requirement:	36.6 kWh/(m^2·a)
Primary energy requirement:	53.2 kWh/(m^2·a)

Construction detail:

	End-of-terrace house	
Reduced construction thickness with equal thermal insulation using polyurethane rigid foam		
	Standard insulation	Polyurethane insulation
Flat roof, ext. green roof	Component composition from inside to outside	
1	Plasterboard 12.5 mm	
2	Merk thick timber element 160 mm	
3	WLG 035 insulating board 420 mm	WLG 025 polyurethane insulation 300 mm
4	Bitumen layer	
5	Wolfin IB nominal thickness 1.5 mm	
6	Drainage layer	
7	Substrate layer 50 mm	
	d = 64 cm	52 cm
	U = 0.074 W/(m^2K)	0.074 W/(m^2K)



9.3 Polyurethane passive house (single-family house in Schorndorf)

This passive house is a three-story single-family house with a gable roof on a south-facing slope. On the first floor, the southern part is used as a living and study area, whilst the northern part adjacent to the ground is used as a basement. The loft has been converted. Because of the constraints of the local development plan, the narrow face of the house faces south.

At 46.3 kWh/(m^2·a), the primary energy requirement of this building is 58 % less than the value permitted by the Energy Saving Regulation for the given surface-area-to-volume ratio. At 14.7 kWh per m^2 of heated living area per year, the building meets the passive house criterion of the Darmstadt Passive House Institute (15 kWh per m^2 per year). [11]

By using WLG 025/030 polyurethane rigid foam insulating boards instead of WLG 035/040 insulating materials, approximately 1400 kWh of fuel are saved per year, with the same construction thickness and thus the same living areas. At a price of €40 per MWh, the heating costs are reduced by approximately €56 per year, to €140. This can save

approximately €1,600 over a period of 30 years, assuming energy prices remain constant in real terms.

Moreover, by using WLG 025 and 030 polyurethane rigid foam insulating boards the construction thickness in the external wall can be reduced by 60 mm and the living area can be increased by almost 10 m^2, that is approximately 4 %.

Building:

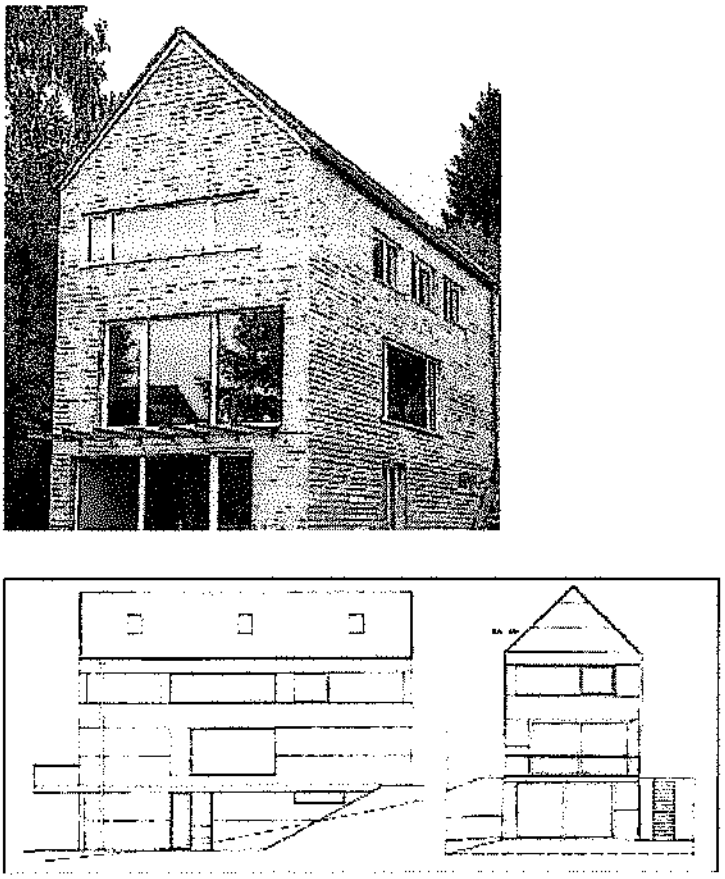


Fig. 43: Polyurethane passive house in Schorndorf

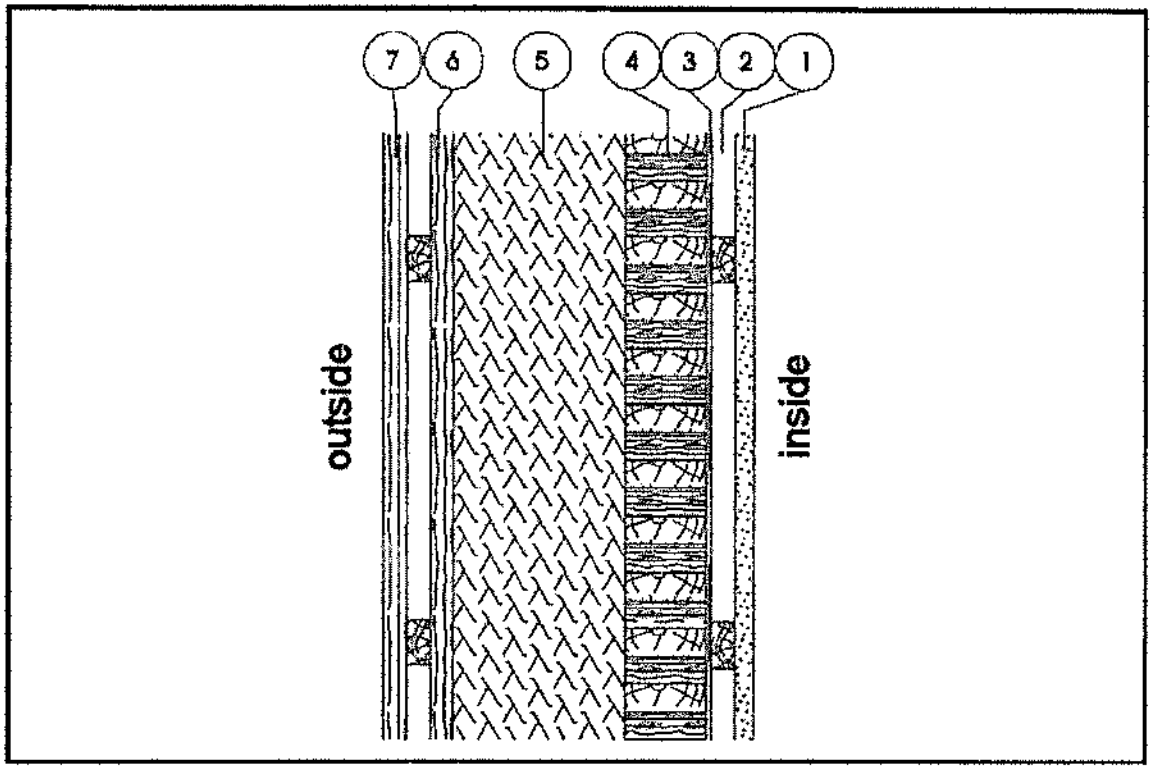
Energy characteristics:

Heating requirement:	10.8 kWh/(m^2·a)
End-user energy requirement:	31.3 kWh/(m^2·a)
Primary energy requirement:	46.3 kWh/(m^2·a)
Characteristic energy value according to passive house forecast by Passive House	14.7 kWh/(m^2·a)

Institute in Darmstadt

Construction detail:

	Schorndorf single-family house	
Reduced construction thickness with equal thermal insulation using polyurethane rigid foam		
	Standard insulation	Polyurethane insulation
External wall 2nd + 3rd floor	Component composition from inside to outside	
1	Plasterboard 20 mm	
2	Battens 24 × 48 mm	
3	PE film	
4	Merk thick timbers 85 mm	
5	WLG 040 insulating board 240 mm	WLG 025 polyurethane insulation 180 mm
6	Battens + counter battens 24 × 48 mm	
7	Curtain-type timber façade	
	d = 42 cm	36 cm
	U = 0.124 W/(m²K)	0.124 W/(m²K)



9.4 Polyurethane modernization of existing buildings (semi-detached house in Bexbach)

This semi-detached house built in Bexbach, Saarland in 1967 with a total living area of 135 m^2 was modernized in energy terms by replacing the windows and by insulating the external walls, the basement ceiling from below, and the roof with between-rafter insulation.

At 103.3 kWh/(m^2·a), the primary energy requirement of this building modernized with polyurethane rigid foam is 31 % less and the specific transmission heat loss is 44 % less than the limit set by the Energy Saving Regulation for comprehensive refurbishment. In fact, this even meets the Energy Saving Regulation requirements for new buildings.

Before the thermal insulation measures were carried out, the end-user energy requirement according to the Energy Saving Regulation was 208 kWh/(m^2·a), including provision of hot water. The building consumed 3,800 m^3 of natural gas per year.

By improving the thermal insulation with polyurethane rigid foam, fuel consumption was reduced by 58 %, resulting in an annual saving of 2200 m^3 of natural gas or €900 in heating costs.

Building:

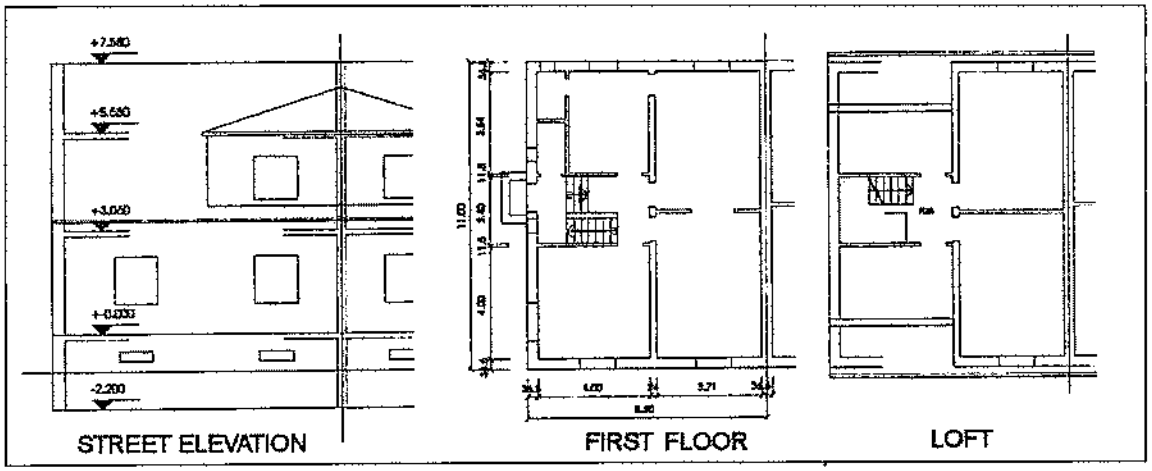


Fig. 44: Semi-detached house in Bexbach (existing building)

Energy characteristics:

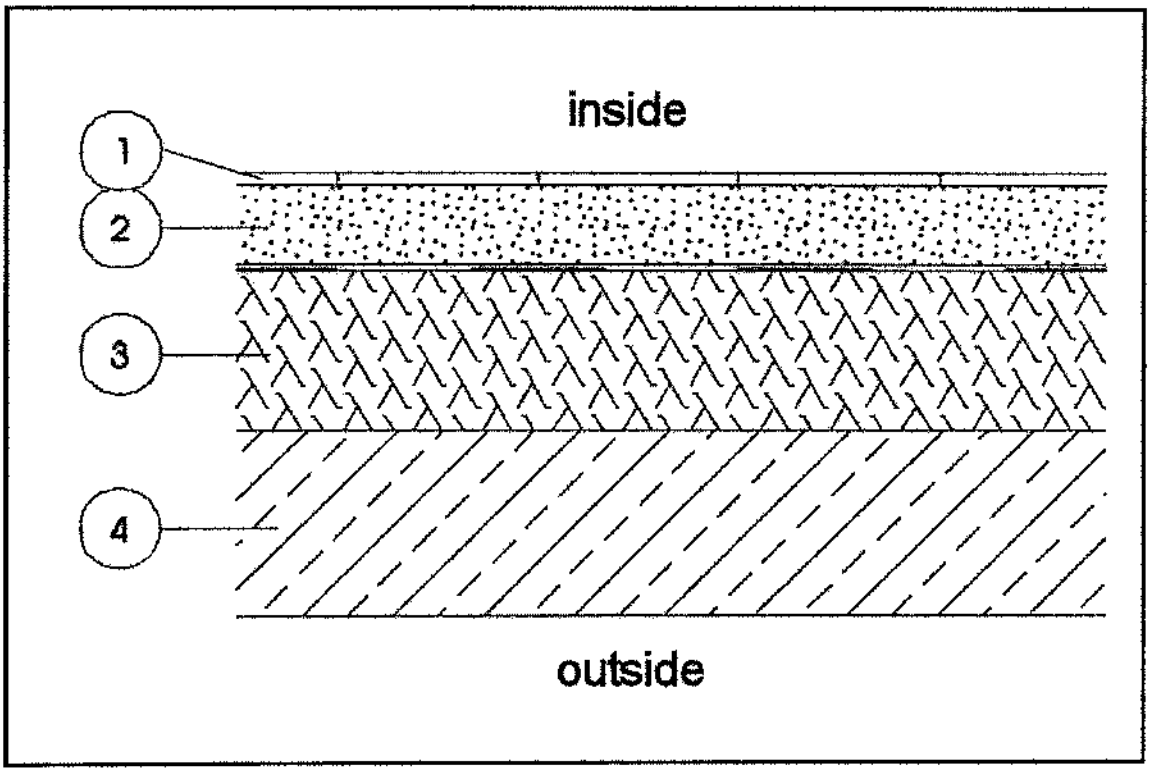
Heating requirement: 65.5 kWh/(m²·a)

End-user energy requirement: 87.8 kWh/(m²·a)

Primary energy requirement: 103.3 kWh/(m²·a)

Construction detail:

	Bexbach semi-detached house	
Improved thermal insulation with equal thermal insulation using polyurethane rigid foam		
	Standard insulation	Polyurethane insulation
Basement ceiling	Component composition from inside to outside	
1	Tiles	
2	Composite floor 60 mm	
3	WLG 040 insulating board 110 mm	WLG 025 polyurethane insulation 110 mm
4	Reinforced concrete ceiling	
	d = 33 cm	33 cm
	U = 0.311 W/(m²K)	0.205 W/(m²K)



9.5 Energy-saving modernization of an existing building with polyurethane internal insulation (multi-family house in Frechen)

This multi-family house, built in 1964, has 184 m^2 of heated living area, divided between two complete stories and a converted loft. Each of the gable walls is adjoined by neighboring buildings.

During modernization, the windows were replaced, and the external walls were provided with polyurethane internal insulation, the basement ceiling and the ceiling of the passageway were insulated from below and the roof areas were insulated from the room side.

At 97.1 kWh/(m^2·a), the primary energy requirement of this building is 28 % less and the specific transmission heat loss is 52 % less than the limit set by the Energy Saving Regulation for comprehensive refurbishment. This almost meets the Energy Saving Regulation requirements for new buildings.

Before the thermal insulation measures were carried out, the end-user energy requirement according to the Energy Saving Regulation was 169 kWh/(m^2·a), including provision of hot water. The building consumed 4,000 m^3 of natural gas per year.

By improving the thermal insulation with polyurethane rigid foam, the fuel consumption was reduced by more than 50 % to 75 kWh/(m^2·a), resulting in an annual saving of more than 2300 m^3 of natural gas or €900 in heating costs.

Building:

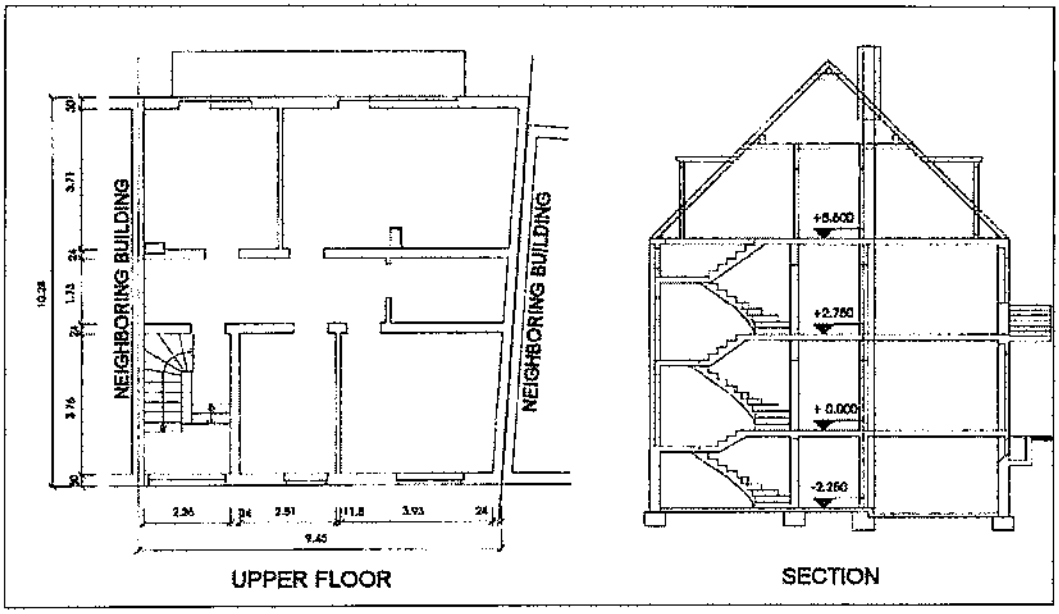


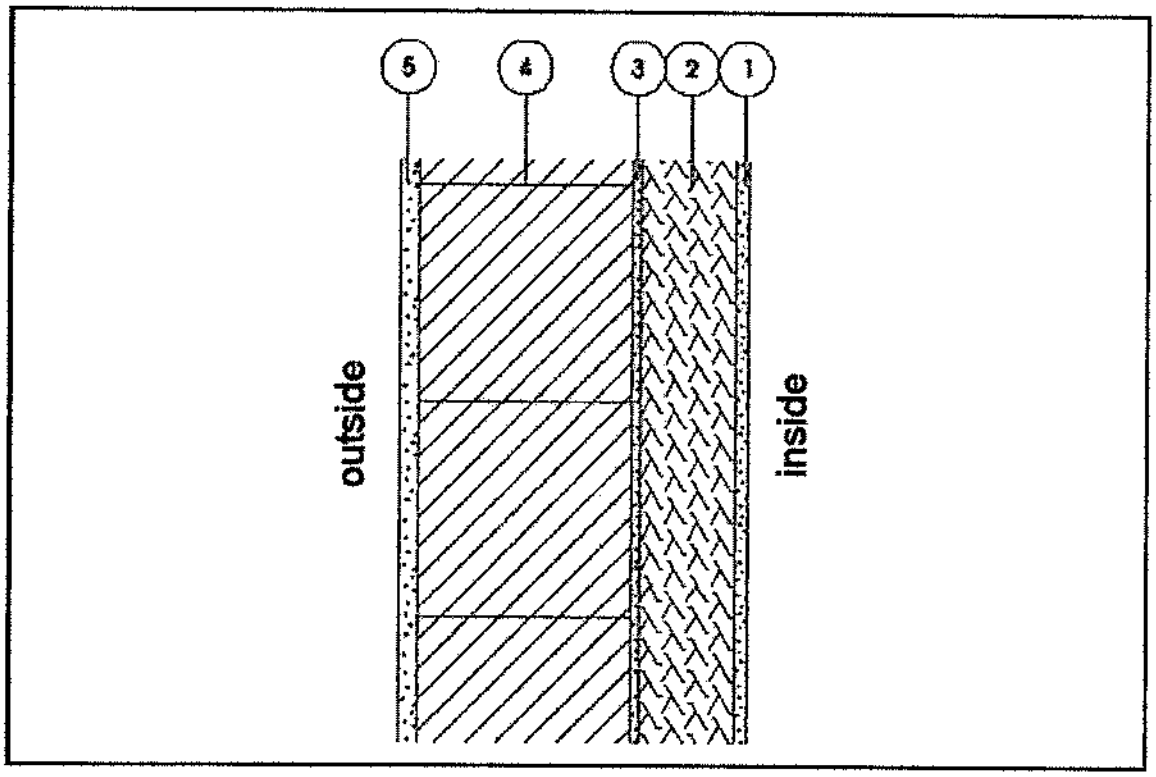
Fig. 45: Multi-family house in Frechen (existing building)

Energy characteristics:

Heating requirement: 50.8 kWh/(m²·a)
End-user energy requirement: 81.2 kWh/(m²·a)
Primary energy requirement: 97.1 kWh/(m²·a)

Construction detail:

	Frechen multi-family house	
Reduced construction thickness with equal thermal insulation using polyurethane rigid foam		
	Standard insulation	Polyurethane insulation
External wall	Component composition from inside to outside	
1	Plasterboard	
2	WLG 040 insulating board 107 mm	WLG 025 polyurethane insulation 80 mm
3	Gypsum plaster 10 mm	
4	Airbricks 240 mm	
5	Render 20 mm	
	d = 39 cm	36 cm
	U = 0.308 W/(m²K)	0.308 W/(m²K)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