Federation of European Rigid
Polyurethane Foam Associations

Report N°1 (October 06)

Thermal insulation materials made of rigid polyurethane foam (PUR/PIR)

Properties - Manufacture

Rigid polyurethane foam (PUR/PIR) is one of the most efficient, high performance insulation material, enabling very effective energy savings with minimal occupation of space.

Better insulation in buildings is a significant contributor towards the implementation of the Kyoto protocol and will also bring additional benefits:

- energy savings, resulting in lower energy bills both for individuals and for countries. This will help to improve competitiveness of Europe as a whole
- protection of the environment: more stringent insulation regulations can cut European CO_2 emissions by 5 % (60 % of the present European Kyoto target)
- a positive impact on job creation
- a boost to the European economy

This report describes the properties and manufacture of **rigid polyurethane foam (PUR/PIR)**, one of the most effective insulants.

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Introduction

Polyurethane – enhancing the quality of our lives

Whether shoe soles, mattresses, steering wheels or insulation – our world today is unthinkable without polyurethane. In the world of sports or leisure activities, in the home or in the car, polyurethanes have a positive impact on our daily lives. They are needed everywhere. Depending on the formulation and basic chemical mix, the property spectrum of polyurethanes can be precisely determined during manufacture – rigid, soft, integral or compact. The result: tailor-made and cost-efficient solutions for (almost) every field of application.

Picture 1: Polyurethane – a versatile material

Insulation made to measure

When it comes to insulating buildings, rigid polyurethane foam (PUR/PIR) is the cost-effective insulant for new construction because it has low thermal conductivity, unmatched by any other conventional product. Further, rigid polyurethane foam (PUR/PIR) is ideal for renovation when the emphasis is on energy efficiency. Retrofitting insulation in the shells of existing buildings can cut average energy consumption by more than 50% and rigid polyurethane foam (PUR/PIR) simplifies the installation. Low thermal conductivity means thinner insulation for any specified insulation level and thinner insulation means it is easier to fit into the building cavity. The insulation performance is exceedingly high even with modest material thicknesses. Finally, good mechanical properties and excellent adhesion to other materials opens up a broad field of applications.

With their optimal insulating performance, insulation materials made of rigid polyurethane foam (PUR/PIR) are very versatile. The products range from insulation boards for roofing, walls, floors and ceilings, to window frame insulation and foam sealants, through to metal-faced sandwich panels for industrial buildings.

Efficient thermal insulation to last a lifetime

The term rigid polyurethane foam (PUR/PIR) stands for a family of insulation materials that, in addition to polyurethane (PUR) also includes polyisocyanurate (PIR) rigid foam.

The excellent thermal insulation properties of closed-cell rigid polyurethane foam (PUR/PIR) are achieved today mainly with blowing agents such as pentane (hydrocarbon) or CO_2.

In addition to the low thermal conductivity, rigid polyurethane foam (PUR/PIR) is stable and durable. It will function for as long as the building stands and has a useful life beyond 50 years.

Thermal insulation with rigid polyurethane foam (PUR/PIR) conserves resources, saves energy and has no significant emission to the environment.

Rigid polyurethane foam (PUR/PIR) is the right investment for the future as it:

- offers optimal, long-life insulation with no drawbacks, maintenance or repairs
- enhances the value of property and the quality of life
- leads to large energy savings and reduced heating costs
- is cost-effective and easy to install

1 What is rigid polyurethane foam (PUR/PIR)?

Rigid polyurethane foam (PUR/PIR) is a closed-cell plastic. It is used as factory-made thermal insulation material in the form of insulation boards or block foam, and in combination with various rigid facings as a constructional material or sandwich panel. Polyurethane in-situ foams are manufactured directly on the building site.

Picture 2: Rigid polyurethane foam insulation materials (PUR/PIR)

In modest material thicknesses, rigid polyurethane foam (PUR/PIR) offers optimal thermal insulation coupled with an exceptional space-utility advantage.

For architects and planners, rigid polyurethane foam (PUR/PIR) allows scope for creative insulation solutions from the cellar and the walls through to the ceilings and the roof. It is ideal in the lightweight, low-energy or zero-energy building approach (Passivhaus).

Insulation Boards

Thanks to their excellent mechanical strength, insulation boards made of rigid polyurethane foam (PUR/PIR) are highly resistant; they can be combined with other materials and are easy to install on the building site.

Metal Faced Sandwich Panels

Sandwich panels have a rigid polyurethane foam (PUR/PIR) core with profiled and in most cases metal facings on both the upper and lower surfaces. Sandwich panels are particularly suited for roofing and wall applications, for the various support structures in halls and industrial buildings, as well as for refrigeration and cold-storage units. The lightweight panels are easy to process and can be installed in all weather conditions. PUR/PIR sandwich panels are to a high degree pre-fabricated, giving them structural and constructional design properties that offer a high level of security, both in the processing stages and in the finished building.

Blocks

Polyurethane (PUR/PIR) block foam can be cut to shape for the insulating building equipment and industrial installations.

In-situ Foams

In addition to factory made polyurethane rigid foams (PUR/PIR), in-situ foams are also used in building. They are produced with state-of-the-art equipment "in situ" on the building site itself. In-situ foams are mainly used for technical insulation applications. The in-situ foam is sprayed onto the desired surface or poured into moulds, producing a seamless structure.

2 Technical and physical properties of rigid polyurethane foam (PUR/PIR)

The properties of the insulation materials depend on their structure, the raw materials used and the manufacturing process. In the selection of a suitable thermal insulation material, the required thermal properties are of prime importance. For the functionality and safety of the building, other important criteria in the choice of insulation are mechanical strength, resistance to ageing, sound insulation properties, and resistance to moisture and fire.

Rigid polyurethane foam (PUR/PIR) insulation materials display excellent insulation characteristics. They have extremely low thermal conductivity values and can achieve optimal energy savings. The excellent mechanical strength values and exceptional durability of rigid polyurethane foam (PUR/PIR) fulfil all the requirements made of insulation materials used in the building industry.

2.1 Thermal conductivity

The most important property of an insulation material is its insulation performance. The yardstick for such insulation performance is low thermal conductivity or high thermal resistance.

2.1.1 Thermal conductivity and thermal resistance of insulation materials

Thermal conductivity (λ) is a specific material property. It represents the heat flow in watts (W) through a 1 m² surface and 1 m thick flat layer of a material when the temperature difference between the two surfaces in the direction of heat flow amounts to 1 Kelvin (K). The unit of measurement for thermal conductivity (λ) is W/(m·K).

The thermal resistance (R) describes the thermal insulation effect of a constructional layer. It is obtained by dividing the thickness (d) by the design thermal conductivity value of a building component: $R = d/\lambda$ (in accordance with EN ISO 6946). The unit of thermal resistance (R) is (m²·K)/W. In building components comprising several layers, the thermal resistances of the individual layers are added together.

The thermal transmittance (U) is the heat flow in watts (W) through 1 m² of a building component when the temperature difference between the surfaces in the direction of heat flow is 1K. U-value can be calculated from $U = 1/R$ for a given construction, and is generally represented in W/(m^2.K).

The thermal conductivity and thermal resistance of rigid polyurethane foam (PUR/PIR) insulation materials are to be determined in accordance with Annex A and Annex C of EN 13165.

2.1.2 Thermal conductivity of rigid polyurethane foam (PUR/PIR)

The thermal conductivity of rigid polyurethane foam (PUR/PIR) is dependent on:

- the cell gas used
- density
- temperature
- behaviour in the presence of water and moisture
- time of measurement

2.1.2.1 Influence of the cell gas

The exceptional insulation properties of rigid polyurethane foam (PUR/PIR) are achieved through the use of blowing agents. The thermal conductivity of the blowing agent at a reference temperature of 10° C is considerably lower than that of air [(λ_{air} = 0.024 W/(m·K)]. The most commonly used blowing agent is the hydrocarbon pentane, either a pure isomer or as mixes of the isomers normal, iso or cyclo pentane, with a thermal conductivity between 0.012 and 0.013 W/(m·K). [1] For special purposes, fluorohydrocarbons such as HFC-365 mfc or HFC-245 fa are employed.

Owing to the high closed-cell content of rigid polyurethane foam (PUR/PIR) (proportion of closed cells > 90 %), the blowing agents remain in the insulation material over the long term. Gas diffusion-tight facings reduce the cell-gas exchange with the surrounding air.

The thermal conductivity levels specified by the manufacturer are long-term values. These are based on an insulation material lifetime of at least 25 years, in practice the lifetime is expected to be greater than 60 years. The thermal conductivity levels allow for possible ageing effects. Annex C of the product standard EN 13165 describes the procedures for determining the effects of ageing on rigid polyurethane foam (PUR/PIR).

The initial values of thermal conductivity are determined within the framework of third-party monitoring in accordance with EN 13165 one to eight days after the manufacture of the insulation boards by a test institute approved by the building authorities.

2.1.2.2 Influence of density

The amount of structural material increases as the density rises. This increases the share of heat conducted over the structural material. The increase in thermal conductivity, however, does not increase in proportion to the increase in density; the thermal conductivity of rigid polyurethane foam (PUR/PIR) changes little in the density range 30 to 100 kg/m³ relevant for building.

2.1.2.3 Influence of temperature

The thermal conductivity of insulation materials decreases as the temperature falls. Temperature increases on the other hand result in a minimal increase in thermal conductivity.

Thermal conductivity measurements are made under standardised conditions. That is why the measured values are converted to a mean temperature of 10°C. The minimal deviations in thermal conductivity for the building applications compared with the reference temperature of 10 °C are taken into account in the design value of thermal conductivity.

2.1.2.4 Influence of water absorption after immersion in water for 28 days

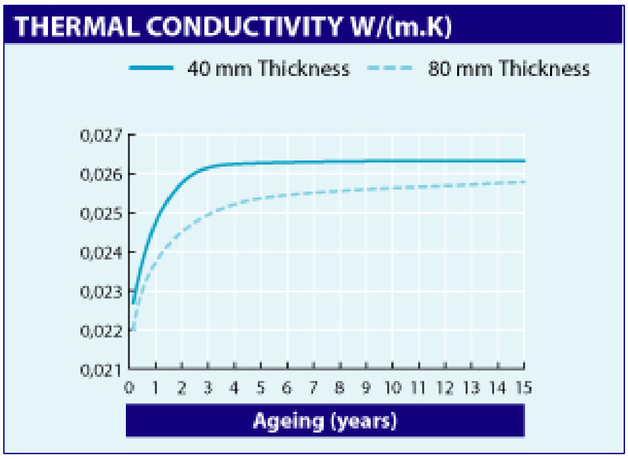
At a reference temperature of 25 °C, the thermal conductivity of water is λ = 0.58 W/(m·K). As the thermal conductivity of most common insulation materials ranges between 0.020 W/(m·K) and 0.050 W/(m·K), water absorption due to immersion in water leads to an increase in thermal conductivity. However, water absorption has only a small impact on the thermal conductivity of rigid polyurethane foam (PUR/PIR). Studies undertaken by the Forschungsinstitut für Wärmeschutz e. V. Munich have shown that the increase in thermal conductivity of rigid polyurethane foam (PUR/PIR) expanded with pentane after 28-day immersion in water is negligible, amounting to around 0.0018 W/(m·K) [2]

2.1.3 Declared value of thermal conductivity

The declared value of thermal conductivity (λ_D) is derived from measured values determined under the conditions and rules set out in EN 13165. The declared value is determined from the initial measured values, taking account of the statistical scatter, and the ageing increment. It is reported in steps of 0.001 W/(m·K).

2.1.4 Long-term thermal conductivity of rigid polyurethane foam (PUR/PIR) insulation materials

The Forschungsinstitut für Wärmeschutz e. V. Munich conducted long-term tests on rigid polyurethane foam (PUR/PIR) insulation boards over a period of 15 years. The thermal conductivity and cell gas composition were determined periodically. Picture 3 shows the change in thermal conductivity of rigid polyurethane foam (PUR/PIR) boards blown with pentane over a storage period of 15 years at room temperature.



Picture 3: Increase in thermal conductivity of rigid polyurethane foam (PUR/PIR) insulation materials in the first 15 years after manufacture

In addition to the thermal conductivity of the solid material structure and the heat radiation in the foam cells, the thermal conductivity of rigid polyurethane foam (PUR/PIR) depends for the most part on heat transfer through the cell gas. The relatively sharp increase in thermal conductivity at the beginning of the study is due to the gas exchange between CO_2 (thermal conductivity c. 0.016 W/(m·K)) and air (thermal conductivity c. 0.024 W/(m·K).

After approximately 3 years, the cell gas composition reaches a stable equilibrium, and the thermal conductivity changes only minimally thereafter. In general, insulation materials of greater thicknesses achieve lower long-term thermal conductivity values.

The time curves show that the ‘fixed increments’ in accordance with EN 13165 for pentane have been accurately dimensioned:

- 5.8 mW/(m·K) at thicknesses < 80 mm
- 4.8 mW/(m·K) at thicknesses > 80 mm and < 120 m

Users can be sure that the declared values of thermal conductivity (λ_D) will not be exceeded even over very long periods. [2 and 3]

2.2 Density

The density of rigid polyurethane foam (PUR/PIR) used for thermal insulation in buildings normally ranges between 30 kg/m³ and 45 kg/m³. However, it can reach 100 kg/m³ for some applications.

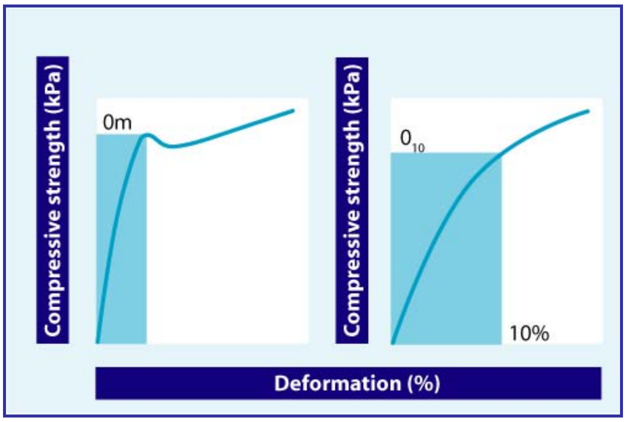
For special applications that are subject to extreme mechanical loads, the density of the rigid polyurethane foam (PUR/PIR) can be increased to 700 kg/m³.

Picture 4: Cell structure of rigid polyurethane foam (PUR/PIR)

Only a small portion of the rigid polyurethane foam volume consists of solid material. At a density of 30 kg/m³ usual in building applications, the solid plastic material makes up only 3% of the volume. This material forms a grid of cell struts and cell walls that can withstand mechanical loads due to its rigidity and anti-buckling properties.

2.3 Compressive strength σ_m or compressive stress at 10% deformation σ_{10}

The strength behaviour of rigid polyurethane foam (PUR/PIR) is primarily a function of its density. When looking at material behaviour under pressure loading we differentiate between compressive stress and compressive strength. Compressive stress is generally determined at 10% deformation. Compressive strength is defined as the maximum stress up to the breaking strength.



Picture 5: Compressive strength and compressive stress at 10% deformation (compressive strength: the foam material suddenly collapses under the increasing pressure loading. The value at the maximum point on the curve is the compressive strength σ_m. Compressive stress: there is no clear break. The value at 10% deformation of the sample is the compressive stress σ_{10})

The compressive strength or compressive stress at 10% deformation of rigid polyurethane foam (PUR/PIR) insulation materials are measured in accordance with EN 826 within a timeframe of only few minutes. This is known as short-term behaviour. These measured values can be employed to compare various insulation materials. For reliable statistical measurements, it is necessary to have values for the long-term continuous compressive stress (compressive creep).

For many rigid polyurethane foam (PUR/PIR) applications, a compressive strength σ_m or compressive stress σ_{10} value of 100 kPa is sufficient.

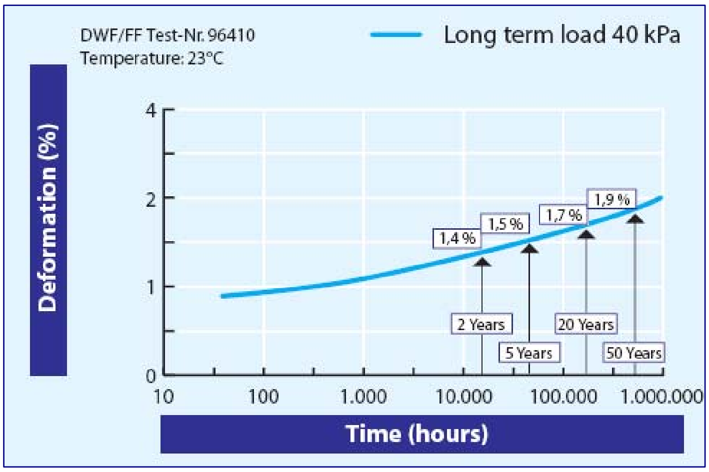
In some insulation applications, for example in flat roofing, flooring, ceilings or perimeter insulation, higher pressure loadings can occur.

2.4 Continuous compressive stress σ_c (compressive creep)

Building structures are generally subject to static loads over long periods. The loads must be transferred safely without impairing the overall construction. With its excellent compressive stress values combined with elasticity, rigid polyurethane foam (PUR/PIR) has proved itself an exceptional thermal insulation material in such pressure-loaded applications over many decades.

In certain applications – mostly in flooring – rigid polyurethane foam (PUR/PIR) is exposed to continuous static loads, for example by machines or stored materials. Here, the deformation under continuous stress is the essential factor in the static calculation. To ensure safe dimensioning in such constructions, the maximum deformation of the insulation material must not significantly exceed 2% over a load period of 20 and 50 years respectively. Long-term tests on rigid polyurethane foam (PUR/PIR) have confirmed reliable compliance with these values.

The long-term behaviour of rigid polyurethane foam (PUR/PIR) insulation materials under continuous compressive stress (compressive creep) is determined in accordance with EN 1606.



Picture 6: Long-term pressure curves of rigid polyurethane foam (PUR/PIR) insulation board, 33 kg/m³ with aluminium foil facing, long-term load 40 kPa, measured values after 2 and 5-year load period and extrapolation to 20 and 50 years [4]

Long-term pressure tests in accordance with EN 1606 on rigid polyurethane foam (PUR/PIR) with aluminium facings and a density of 33 kg/m³ have shown that this thermal insulation material produces excellent results in pressure-loaded applications over periods of several decades. Subject to a continuous load of 40 kPa over a two-year period, deformation measurements of 1.4% were obtained. In the five-year continuous load test, deformation was measured at 1.5%.

Using the Findley extrapolation procedure, deformation values of 1.7% and 1.9% were obtained for periods of continuous compressive stress of 20 years and 50 years respectively.

2.5 Tensile strength perpendicular to faces σ_{mt}, shear strength and bending strength σ_b

Insulation materials made from rigid polyurethane foam (PUR/PIR) are often used in combination with other building materials (for example in external thermal insulation composite systems (ETICS)) for large industrial and agricultural buildings. In such applications, they are exposed to tensile, shear and bending stresses. Thanks to their stability and exceptional insulation properties, composite elements with a rigid polyurethane foam (PUR/PIR) core have a proven performance record going back decades – even in the case of extremely thin elements too.

If rigid polyurethane foam (PUR/PIR) is used for thermal insulation in flat roofs, interior finishing or in the external thermal insulation composite system (ETICS), it is important to ensure that the composite structure remains intact with no breaks in the insulation layer. Tensile stress and shear strength are important in this respect. Tensile stress perpendicular to the faces is determined in accordance with EN 1607.

Depending on the density, the values for PUR/PIR lie between 40 und 900 kPa. Depending on density, rigid polyurethane foam (PUR/PIR) insulation materials exhibit shear strengths in accordance with EN 12090 of between 120 and 450 kPa.

The bending strength determined in accordance with EN 12089 describes the behaviour under bending stress in certain application areas, such as plaster supports in wooden structures or bridging large open spans between the top chords in roofing constructions. The bending strength of composite elements with a rigid polyurethane foam (PUR/PIR) core depends on the foam density and the facings used; the values lie between 250 and 1300 kPa.

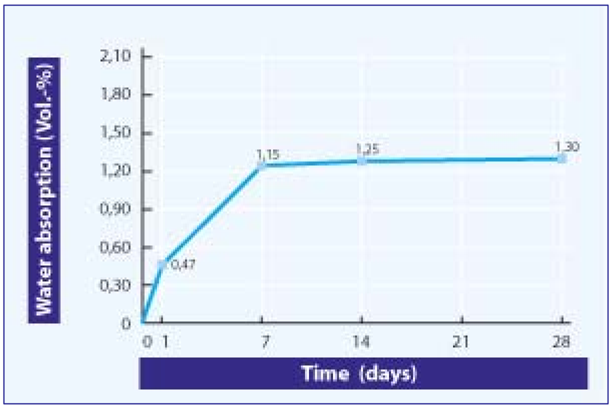
2.6 Behaviour in the presence of water and moisture

The functional efficiency of building components in terms of resistance to moisture is largely dependent on the behaviour of the insulation materials vis-à-vis building and ground moisture, as well as to precipitation during transport, storage and assembly. Condensation moisture on the surface of the building component and condensation in the cross-section of building components due to vapour diffusion also play a role.

Insulation materials made of rigid polyurethane foam (PUR/PIR) do not absorb moisture from the air. Due to their closed cell structure, they do not absorb or transport water, i.e. there is no capillary action. For this reason, normal moisture in buildings does not lead to an increase in thermal conductivity. Water vapour diffusion cannot cause increased moisture levels in rigid polyurethane foam (PUR/PIR) insulation boards unless these have not been properly installed from a structural point of view, for example where vapour barriers are lacking, or due to air pockets or faulty seals in flat roofs.

2.6.1 Water absorption after immersion in water for 28 days

In laboratory tests, in which rigid polyurethane foam (PUR/PIR) insulation boards are permanently surrounded by water, absorption of water can result through diffusion and condensation. In the 28-day immersion test in accordance with EN 12087, the absorption level measured in a 60 mm thick PUR/PIR insulation board (with mineral fleece facing, density 35 kg/m³) is typically around 1.3 percent by volume.



Picture 7: Water absorption of rigid polyurethane foam (PUR/PIR) after 28-day immersion in water [2]

When rigid polyurethane foam (PUR/PIR) insulation boards are used as perimeter insulation, they may be constantly exposed to wetting.

2.6.2 Moisture behaviour under the effects of diffusion and condensation and in alternating frost-thaw conditions

When rigid polyurethane foam (PUR/PIR) is used as perimeter insulation, the insulation boards are constantly in direct contact with the ground, and there is therefore increased exposure to the effects of moisture and frost.

The maximum moisture absorption of rigid polyurethane foam (PUR/PIR) insulation boards due to diffusion and condensation measured in accordance with EN 12088 amounts to about 6 percent by volume.

Tests carried out at the Forschungsinstitut für Wärmeschutz e.V. Munich into the moisture behaviour of rigid polyurethane foam (PUR/PIR) exposed to alternating frost-thaw conditions yielded values of between 2 percent by volume and 7 percent by volume - on insulation boards without facings.

2.6.3 Water vapour diffusion resistance factor μ

The water vapour diffusion resistance factor (μ) is a prime parameter in determining the moisture-related behaviour of building components. The μ-value specifies by how much the water vapour diffusion resistance of a building component layer is greater than the same thickness of air ($\mu_{air} = 1$).

The water vapour diffusion resistance factor of rigid polyurethane foam (PUR/PIR) is determined in accordance with EN 12086. It is dependent on the density and method of manufacture. If the materials have coatings or facings, the declared level for water vapour diffusion resistance (symbol Z) must be specified.

For moisture-related calculations of building components in specific applications, the less favourable value is to be assumed.

2.6.4 Diffusion-equivalent thickness of the air layer s_d

The diffusion-equivalent thickness of the air layer (s_d) is the product of the layer thickness(es) in metres and the diffusion resistance factor (μ).

$s_d = \mu \cdot s$

Example:
Depending on their application in the construction, 120 mm thick rigid polyurethane foam (PUR/PIR) insulation boards with mineral fleece facings have an s_d value of between 40 x 0.12 = 4.8 m and 200 x 0.12 = 24 m.

2.7 Thermal expansion

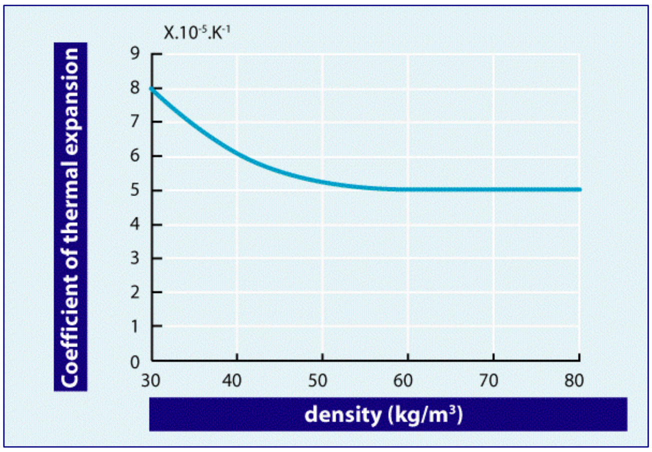
All materials expand under the effects of heat. The coefficient of thermal expansion expresses the material-specific thermal expansion per 1 Kelvin increase in temperature. In closed-cell foamed plastics, the gas pressure in the cell structure also influences expansion.

The coefficient of thermal expansion of rigid polyurethane foam (PUR/PIR) depends inter alia on

- density
- facing
- attachment, if any, of the insulation material to a building component layer
- the selected temperature range

Measurements taken on rigid polyurethane foam (PUR/PIR) insulation boards with flexible facings and densities of between 30 and 35 kg/m³ yielded coefficients of thermal expansion of between 3 and 7 x $10^{-5} \cdot K^{-1}$.

For rigid polyurethane foam (PUR/PIR) insulation boards without facings and with densities of between 30 and 60 kg/m³ the linear coefficient of thermal expansion lies between 5 and 8 x $10^{-5} \cdot K^{-1}$. The coefficient of thermal expansion of insulation boards of higher density without facings is around 5 x $10^{-5} \cdot K^{-1}$. These values apply to boards or cut sections/mouldings that are not attached to a substrate or are not tautly mounted.



Picture 8: Thermal expansion of rigid polyurethane foam (PUR/PIR) without facings. (Thermal expansion of rigid polyurethane foam (PUR/PIR) without facings in the temperature range -60°C to +20°C, measured in relation to density)

2.8 Specific heat capacity and heat storage capacity

2.8.1 Specific heat capacity c_p

The specific heat capacity c_p states how much heat energy is required to increase the temperature of 1 kg mass of a material by 1 K. Specific heat capacity c_p is measured in J/(kg·K).

More heat energy is required to raise the temperature by 1 K of a material with a greater heat capacity. And inversely, less energy is required to produce a 1 K increase in temperature in materials with lower heat capacities.

Table 1: Calculated values of specific heat capacity c_p of various materials

Material	Specific heat capacity c_p = J/(kg·K)
Rigid polyurethane foam (PUR/PIR)	1400 – 1500
Wood-fibre insulation boards	1400
Mineral wool	1030
Wood and wood-based materials	1600
Plasterboard	1000
Aluminium	880
Other metals	380 – 460
Air (ρ=1.25 kg/m³)	1000
Water	4190

In accordance with EN 12524, these calculated values are to be used in special calculations of heat conduction in building components with unsteady boundary conditions.

2.8.2 Heat storage capacity C

The heat storage capacity of building components is influenced by the specific heat capacity of the individual building materials they contain.

Table 2: Example of the heat storage capacity of various building component layers in an inclined roof

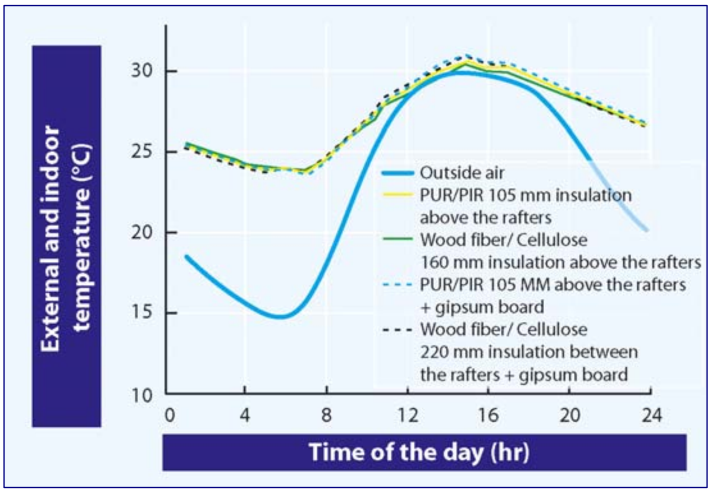
Material	Thick-ness	Thermal conductivity	Density	Specific heat capacity	Heat storage capacity
	mm	W/(m·K)	kg/m³	kJ/(kg·K)	kJ/(m²·K)
Case 1: Inclined roof with rigid polyurethane foam (PUR/PIR) insulation					
Rigid polyurethane foam (PUR/PIR) insulation	105	0.025	30	1.5	4.73
timber shell	28	0.13	600	1.6	26.88
bitumen strip	2	0.17	1200	1.0	2.40
plasterboard	12.5	0.21	900	1.0	11.25
Case 2: Inclined roof with wood-fibre insulation					
wood-fibre board	180	0.040	120	1.4	30.24
timber shell	28	0.13	600	1.6	26.88
bitumen strip	2	0.17	1200	1.0	2.40
plasterboard	12.5	0.21	900	1.0	11.25

The heat storage capacity C in J/(m²·K) specifies how much heat a homogeneous building material with a surface area of 1 m² and thickness (s) can store when the temperature rises by 1 K.

Heat storage capacity C in J/(m²·K) = specific heat capacity (c) x density (r) x thickness of the layer (d)

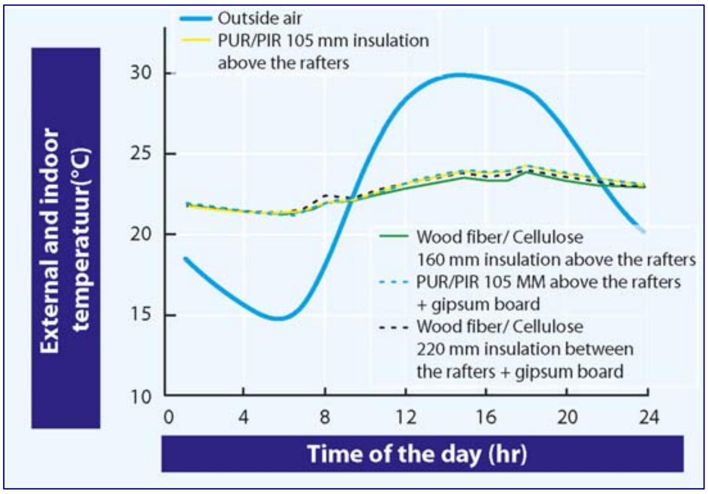
Table 2 shows that the heat storage capacity of wood-fibre boards is many times that of rigid polyurethane foam (PUR/PIR) insulation boards. In indoor climatic conditions in summer, these differences are negligible.

Using computer-aided thermal simulations, the Forschungsinstitut für Wärmeschutz e. V. Munich examined the influence of insulation type in various inclined roofing constructions on the indoor climate. [5]



With no sun protection, the interior temperature reached 31° C in the afternoon. The temperatures measured in the room show that the heat storage capacity of the various insulation materials is of no relevance. The indoor temperatures differed at most by 0.6 K.

Picture 9: External and indoor temperatures on the hottest day in a hot week in summer – without sun protection



When the window in the roof is protected from the sun, the interior temperature in the afternoon is clearly lower than the temperature outside; the room temperature remains below 25° C at all times. Here too, the type of insulation material has no significant influence on the indoor temperature.

Picture 10: External and indoor temperatures on the hottest day in a hot week in summer – with sun protection

The results of the computer simulation show that:

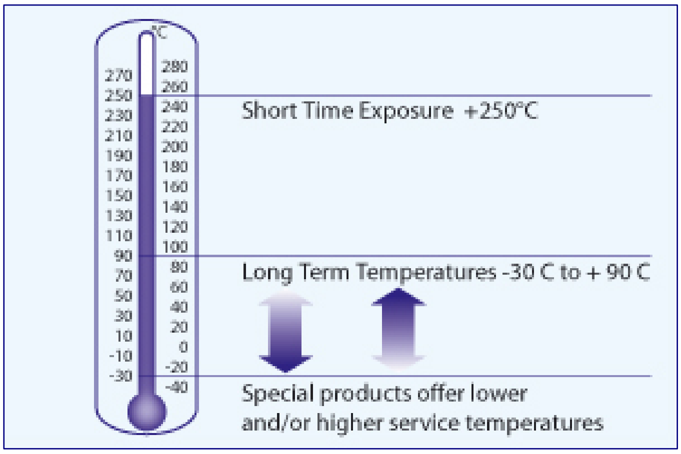
- solar radiation is the major influencing factor on the interior climate in summer, and therefore effective sun protection at the windows creates pleasant conditions indoors;
- the heat storage capacity of the various insulation materials has very little effect on the indoor climate in summer.

Good thermal insulation improves indoor climatic conditions in summer too. Thickness for thickness, insulation materials with lower thermal conductivities reduce the heat inflow through the external building components.

2.9 Temperature stability

In addition to the stability characteristics of insulation materials under increased temperatures, the maximum and minimum temperature limits are also important for certain fields of application. The duration of a specific temperature influence is especially important here. The temperature limit for the application of the material can become apparent through various effects, for example changes in dimensions, loss of form and stability, through to thermal decomposition.

Insulation materials made of rigid polyurethane foam (PUR/PIR) have a high level of thermal resistance and good dimensional stability properties. Depending on the density and facings, rigid polyurethane foam (PUR/PIR) insulation materials for building applications can be used long-term over a temperature range of –30°C to +90°C. Rigid polyurethane foam (PUR/PIR) insulation materials can withstand temperatures of up to 250°C for short periods with no adverse effects. Rigid polyurethane foam (PUR/PIR) with mineral fleece facings or without coatings is resistant to hot bitumen and can be used in flat roofing sealed with bituminous roof covering. Rigid polyurethane foam (PUR/PIR) is a thermosetting plastic and does not melt under the effects of fire.



Picture 11: Durability of rigid polyurethane foam (PUR/PIR) insulation boards under the effects of heat

Furthermore, a number of special polyurethane products can be installed as insulation under poured-asphalt floor screed and withstand temperatures of +200°C without additional heat protection, or can be used for cold-temperature applications down to –180°C.

2.10 Chemical and biological stability

Contact with chemicals can affect the properties of insulation materials. However, insulation boards made of rigid polyurethane foam (PUR/PIR) are for the most part resistant to the common chemical substances used in building.

This includes for instance most solvents as used in adhesives, bituminous materials, wood protection products or sealing compounds. In addition, the insulation material is not susceptible to the effects of plasticizers used in sealing films, or to fuels, mineral oils, diluted acids and alkalis, exhaust gases or aggressive industrial atmospheres.

Rigid polyurethane foam (PUR/PIR) does not rot; it resists mould and decay and is odour-neutral.

UV radiation causes discolouring in rigid polyurethane foam (PUR/PIR) insulation boards without facings or at the cut faces, and over time leads to a low-level sanding effect on the surface. However, this is not a technical drawback. The surface sanding can be removed in subsequent work steps.

Table 3: Chemical resistance of rigid polyurethane foam (PUR/PIR)

Building materials / chemical substances	Behaviour of rigid polyurethane foam (PUR/PIR)
Lime, gypsum (plaster), cement	+
Bitumen	+
Cold bitumen and bituminous cements on water basis	+
Cold bituminous adhesive	+/-
Hot bitumen	+/-
Cold bitumen and bituminous cements with solvents	+/-
Silicon oil	+
Soaps	+
Sea water	+
Hydrochloric acid, sulphuric acid, nitric acid Caustic soda (10% resp.)	+
Ammonium hydroxide (conc.)	+
Ammonia water	+
Normal petrol / diesel fuel / mixed	+
Toluene / chlorobenzene	+/-
Monostyrene	+/-
Ethyl alcohol	+/-
Acetone / Ethyl acetate	+/-

Key: + resistant +/- partly resistant

The resistance of rigid polyurethane foam (PUR/PIR) (without facings) to building materials and chemical substances was determined at a test temperature of 20°C

2.11 Fire performance of rigid polyurethane foam (PUR/PIR)

2.11.1 Reaction to fire of insulation products according to European standards

The European test standards describe the test equipment and test arrangement, and how the test is to be conducted and evaluated. The central test method for products in classes A2 to D, excluding floorings, is the Single Burning Item (SBI) test in accordance with EN 13823. The SBI test is carried out with a gas burner whose fire load corresponds to that of a burning wastepaper basket. The following parameters are determined: fire growth rate, total heat release, lateral flame spread on the surface, smoke development and burning droplets. The SBI test replaces previously used national tests.

An additional small burner test conducted in accordance with EN ISO 11925-2 is required for classes B, C and D (duration of flaming: 30 seconds).

Euroclass E is tested exclusively in accordance with EN ISO 11925-2 (duration of flaming: 15 seconds).

Classification standards are available to facilitate the assessment or evaluation of the test results. Construction products are assigned to 'Euroclasses' in accordance with EN 13501-1 "Fire classification of construction products and building elements – Part 1: Classification using test data from reaction to fire tests". Currently 4 different fire classifications have been decided: for construction products excluding floorings, for floorings, for pipe insulation and for cables.

Under the harmonised European standards, construction products are divided into 7 Euroclasses: A1, A2, B, C, D, E and F.

The European classification system also takes account of other, secondary reaction to fire related behaviour characteristics, such as smoke development and burning droplets/particles. For building materials, three classes have been established for smoke development (s1 to s3) and for burning droplets/particles (d0 to d2). These must always be declared together with the reaction to fire classes for the classes A2 to D. For products classified class E, burning droplets have to be declared if ignition of the filter paper occurs in the small flame test, leading to E, d2.

Rigid polyurethane foam (PUR/PIR) is a thermosetting plastic and does not melt or produce burning droplets under the effects of fire.

2.11.2 Resistance to fire of building elements containing rigid polyurethane foam (PUR/PIR) insulation

Building elements are classified in accordance with EN 13501 "Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services".

The building supervisory authorities in the individual EU Member States are currently reviewing their national requirements in order to determine which European classes will be necessary in the future in terms of the resistance to fire of building elements. This is relatively easy in the case of the fire resistance tests and the resulting resistance to fire classes for building materials, as the national tests deviate only minimally from the new European test standards.

2.11.3 Reaction to fire classification of rigid polyurethane foam (PUR/PIR) based products

According to the formulation and type of facings, the most common PUR/PIR boards will have a classification from C, s2, d0 till F.

For PUR/PIR pipe insulation, depending on the formulation and type of facing, a classification from B_L, s1, d0 till F would be possible.

Metal faced sandwich panels based on PUR/PIR can reach B, s2, d0.

3 Sustainable Development with rigid polyurethane foam (PUR/PIR)

Since the UN Earth Summit in Rio de Janeiro in 1992, the term "sustainability" has been on everyone's lips. But to explain sustainability simply in terms of "ecology" is not enough. Implementing the sustainability principle means taking into account environmental, economic and social aspects to an equal extent. The emphasis must be on a holistic approach that takes equal account of environmental protection, social needs and sustainable business practices.

Energy conservation will be a prime demand and with the world's population already exceeding 6 billion the preservation of food will be equally important.

Sustainable Construction is not just about evaluating the environmental aspects of individual building materials. The sustainability concept calls for a more complex approach that encompasses the whole lifetime of a building structure and the materials used. The following aspects must be considered:

- environmental goals, such as resource conservation, energy saving, CO_2 reductions and recycling
- economic goals, such as reducing building and running costs by using building products with the corresponding performance profile
- sociocultural aspects, health and comfort, i.e. buildings in which people live and work must correspond to user needs and guarantee a high level of well-being

In this report we focused on the PUR/PIR contribution to the environmental aspects of Sustainable Development.

3.1 Reducing energy consumption and emissions

Buildings account for more than 40% of total energy consumption in the EU. Our sources of energy, however, are not infinite. Increases in energy efficiency, i.e. energy savings and the optimal use of energy, are the prerequisite for closing the gap between finite resources and increasing demand.

There is a close link between greenhouse gas emissions and energy consumption. Fossil fuels provide energy for heating and cooling buildings, for transport and industrial processes. The rise in the earth's mean surface temperature can be attributed to the rapid increase in the burning of fossil fuels. Carbon dioxide (CO_2) accounts for more than 80% of all greenhouse gas emissions. These emissions exacerbate the greenhouse effect and so contribute to the earth's warming. In the Kyoto Protocol to the UN Framework Convention on Climate Change, the EU Member States made a commitment to reduce their overall greenhouse gas emissions by 8% between 2008 and 2012, based on the figures for 1990. These goals could be achieved through improved energy efficiency in buildings.

3.2 Hygiene and Food Preservation

With a doubling of the world population in 50 years and an expected 8 billion inhabitants by the year 2030, the world has an ever increasing number of inhabitants to shelter and especially to feed.

The insulation efficiency of rigid polyurethane foam (PUR/PIR) is a key property for the low temperature preservation of food during processing, storage and distribution to the consumer and can save as much as fifty percent of valuable food that would otherwise rot before it is consumed.

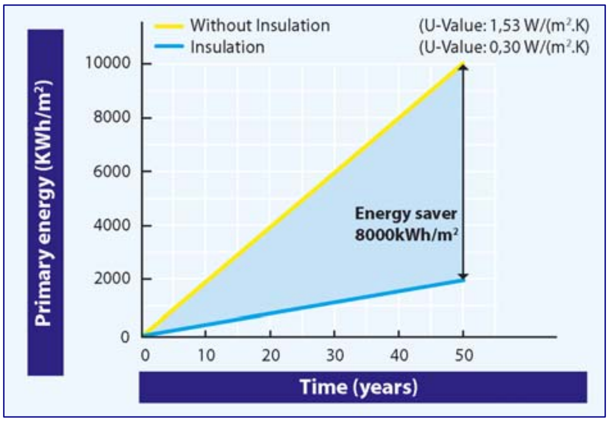
Hygiene is an important consideration where food is processed. Rigid polyurethane foam (PUR/PIR) core sandwich panels constructions eliminate cold bridges which ensure that both surface and interstitial condensation will not occur, as this could lead to the formation of bacteria and mould growth. They are supplied with easy to clean foodsafe liners especially designed to comply with the regulations.

In refrigerated transport, the thickness of the insulation is constrained by the maximum width of truck and a minimum internal dimension dictated by the size of standardized pallets. Studies have demonstrated the key role of rigid polyurethane foam (PUR/PIR) core panels on CO_2 saving.

Hygiene is equally important for other processes that require a clean environment, such as electronic and pharmaceutical industries. These are no negligible areas of activities when we see the trend to higher technology industries and the increasing life expectancy depending on proper and adapted medication.

3.3 Life-cycle analysis of rigid polyurethane foam (PUR/PIR) and energy balance

In addition to good structural properties, environmental criteria are playing an increasingly important role in the selection of insulation materials. In terms of the ecological balance, it is important to draw on comprehensive data to evaluate the whole lifetime of thermal insulation products. This includes data on energy, raw materials and processing inputs, and on the impact of emissions and waste on the air, water and soil. In the evaluation, long periods of use and material lifetimes are crucial factors, as these decisively improve the overall ecological balance.



Picture 12: Energy savings with rigid polyurethane foam (PUR/PIR) insulation over a period of 50 years

The energy balance is an important component of the lifecycle analysis. This compares the production inputs in the manufacture of the product with the energy it saves over its lifetime. Studies show that, over a useful lifetime of more than 50 years, thermal insulation products made of rigid polyurethane foam (PUR/PIR) save many times the energy that is consumed during their production. The energy inputs for the manufacture of rigid polyurethane foam (PUR/PIR) are recovered as a rule after the first heating period. 100 kW·h of energy is consumed in the manufacture of an 80 mm-thick rigid polyurethane foam (PUR/PIR) board with a surface area of 1 m² and with aluminium facings. When rigid polyurethane foam (PUR/PIR) insulation boards with a thickness of 80 mm and aluminium facings are used to improve the thermal insulation of an inclined roof in an old building, it is possible to save 160 kW·h of energy per square metre of roof each year, making a total of 8,000 kW·h over the 50 years of the product's useful lifetime. [6 and 7]

3.4 Rigid polyurethane foam (PUR/PIR) - material recycling and energy recovery

Thermal insulation products made of rigid polyurethane foam (PUR/PIR) are extremely stable and durable; they generally last for the useful lifetime of the building. After dismantling/demolishing the building, rigid polyurethane foam (PUR/PIR) insulation materials can be re-used.

Clean and undamaged rigid polyurethane foam (PUR/PIR) insulation boards can be used again to insulate top floors/attic spaces.

Clean rigid polyurethane foam (PUR/PIR) waste can be crushed and made into pressed boards made of recycled polyurethane, similar to chipboard. These are used in special purpose applications, for example floor constructions, requiring additional moisture resistance.

Particles from grinded rigid polyurethane foam (PUR/PIR) thermal insulation can also be used as oil binders or in combination with cement as insulating mortar.

If the composition of the waste material is known and there are no impurities, one raw material component can be recovered via glycolysis.

Rigid polyurethane foam (PUR/PIR) waste with impurities, or with the remains of other building materials still attached, can be burned together with other household waste in incineration plants with heat recovery systems without any additional negative environmental impacts. In the process, the energy in the insulation material is transformed into primary energy.

Table 4: Rigid polyurethane foam (PUR/PIR) waste - material recycling and energy recovery

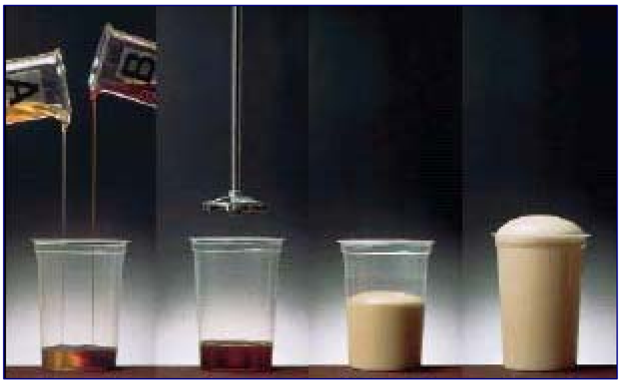
Production waste	Building waste	Building waste during dismantling / demolition	
clean	clean	clean	impure
Material recycling			**Energy recovery**
glycolysis	pressed board particles	recycled	waste incineration plant with heat recovery system
raw material	chipboard oil binder insulation mortar	e.g. insulation board for top floors/ attic spaces	energy recovery

With rigid polyurethane foam (PUR/PIR) there is a dual saving: when retrofitting rigid polyurethane foam (PUR/PIR) insulation, you save up to 30% on the heating costs over a period of at least 50 years. After its useful life as an insulant, rigid polyurethane foam (PUR/PIR) can generate further savings by being fed into waste incineration plants with heat recovery systems and thus reducing the need for burning new energy sources (oil or gas). This is beneficial for the environment, for people, and for plants and animals.

4 Manufacture of thermal insulation materials made of rigid polyurethane foam (PUR/PIR)

Rigid polyurethane foam (PUR/PIR) are produced through a chemical reaction between two base components in liquid form and a low-boiling point blowing agent such as pentane or CO_2.

The base materials react directly on mixing and build a polymer matrix: polyurethane. The heat released in this reaction causes the blowing agent to evaporate and foam the polymer matrix.



Picture 13: Four phases in the expansion of rigid polyurethane foam (PUR/PIR) in a measuring beaker

The expanded foam volume and thus the density of the foam are controlled through the quantity of blowing agent added. The foam material formulations can be modified by using various additives in order to produce the required properties. [8]

The surface of the reaction mixture retains its adhesive capacity for a certain period after the foaming process, enabling facings to be solidly and permanently attached.

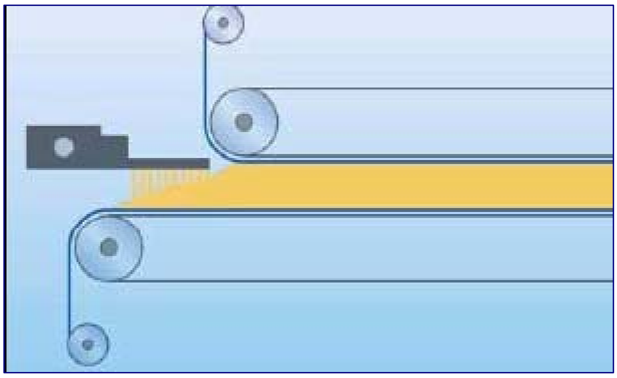
In industrial manufacture, the foaming process is fine-tuned through the use of catalysts, which facilitates the efficient time management of the production cycle.

Rigid polyurethane foam (PUR/PIR) insulation materials are produced in the factory as:

- insulation boards with flexible facings
- block foam, which is cut to form insulation boards or sections
- sandwich panels with rigid facings

4.1 Manufacture of rigid polyurethane foam (PUR/PIR) insulation boards with flexible facings

Rigid polyurethane foam (PUR/PIR) insulation boards with flexible facings are manufactured in a continuous process on a continuous laminator. In this manufacturing process, the reaction mixture is poured through a mixing head onto the lower facing made of a flexible material that is drawn into the laminator. The mixture expands and then bonds within the pressure zone of the laminator to the upper facing that is fed in from above. The laminate after passing through the laminator is hardened sufficiently to allow it to be cut to the desired dimensions. The boards can be manufactured in various thicknesses up to 200 mm.



Picture 14: Continuous manufacture of rigid polyurethane foam (PUR/PIR) insulation boards with flexible facings

Picture 15: Insulation boards made of rigid polyurethane foam (PUR/PIR) with aluminium foil and other facings

The flexible facings are generally made of

- mineral fleece
- glass fleece
- aluminium foil
- composite film

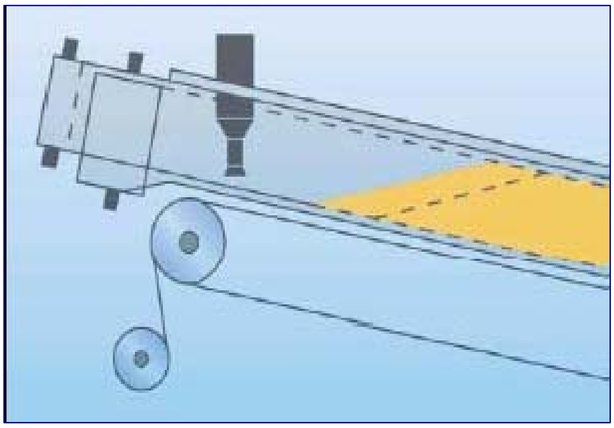
Different facings are chosen to suit the intended application of the insulation boards. The facings can serve as vapour barrier, moisture lock, optical surface or protection against mechanical damage. The insulation boards are offered with various edge profiles, for example tongue-and-groove, stepped profile or flat.

Rigid polyurethane foam (PUR/PIR) insulation boards with flexible facings are also manufactured in conjunction with rigid facings as composite thermal insulation panels. Here, chipboard or mineral materials for wall applications, such as plasterboard, are glued to the insulation boards.

4.2 Manufacture of rigid polyurethane foam (PUR/PIR) blocks

Rigid polyurethane foam (PUR/PIR) blocks can be manufactured in either continuous or discontinuous processes.

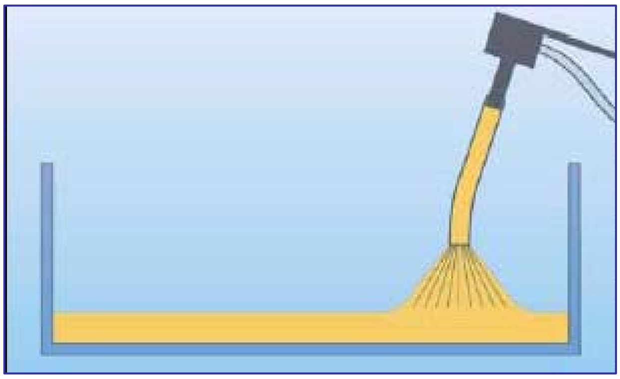
4.2.1 Continuous manufacture of block foam



In the continuous manufacture of block foam, the reaction mixture is applied to a U-shaped paper strip that is supported at the sides and transported on a conveyor belt. At the end of the conveyor belt, the expanded block can be cut to the desired length.

Picture 16: Continuous manufacture of block foam

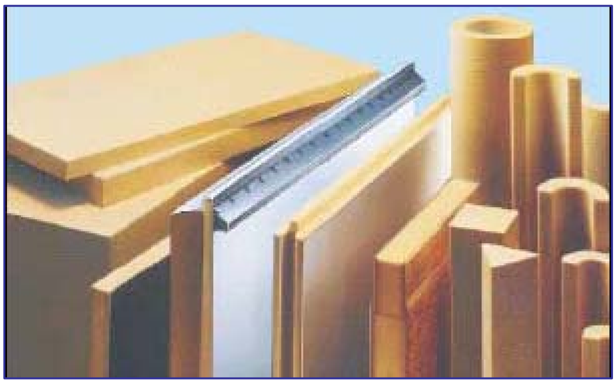
4.2.2 Discontinuous manufacture of block foam



The base components are mixed in an agitator before being poured into a box mould. The reaction mixture expands and forms a rigid foam block.

Picture 17: Discontinuous manufacture of block foam

After they have reached their final rigidity, the blocks produced in the continuous and discontinuous processes are cut into boards (for example insulation boards for either flat or inclined roofs) or sections (for example attic/garret wedges or pipe insulation).



Appropriate facings can be glued to the cut boards to make laminates of various kinds for diverse applications.

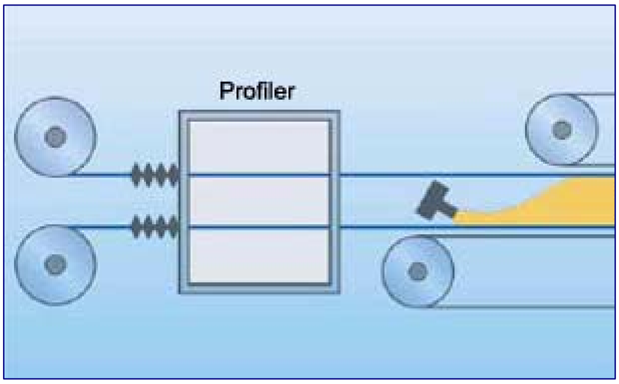
Picture 18: Block foam insulation boards, attic wedges and pipe insulation made of polyurethane (PUR/PIR)

4.3 Manufacture of rigid polyurethane foam (PUR/PIR) sandwich panels with rigid facings

Polyurethane (PUR/PIR) sandwich panels can be manufactured in continuous or discontinuous processes.

4.3.1 Continuous manufacture of metal faced sandwich panels

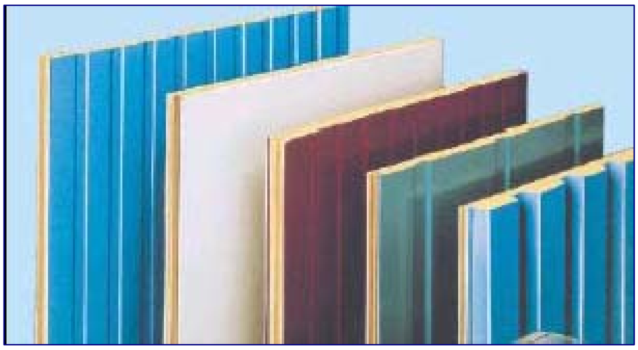
Polyurethane (PUR/PIR) sandwich panels are manufactured on continuous laminators. The reaction mixture is applied to a steel or aluminium sheet being fed in on the bottom laminator belt. In order to increase rigidity, the metal facings are generally profiled prior to foaming. Inside the laminator the expanding mass adheres to a steel or aluminium sheet fed in on the upper belt. After running though the laminator, the sandwich panels are cut to the desired length. The long edges of the sandwich panels are generally given a tongue-and-groove profile to facilitate rapid and easy installation of the pre-fabricated elements. These panels are often factory-manufactured with seals, making them air-tight.



Picture 19: Continuous manufacture of sandwich panels with profiled metal facings in the laminator

Polyurethane (PUR/PIR) sandwich panels are manufactured as self-supporting pre-fabricated construction elements with steel, aluminium or other rigid facings. They are supplied in widths from 800 mm to 1250 mm and up to 24 m in length. These building components have relatively low overall weight, but nevertheless display great strength and stability. They are easy to transport and can be installed with minimal labour.

4.3.2 Discontinuous manufacture of sandwich panels

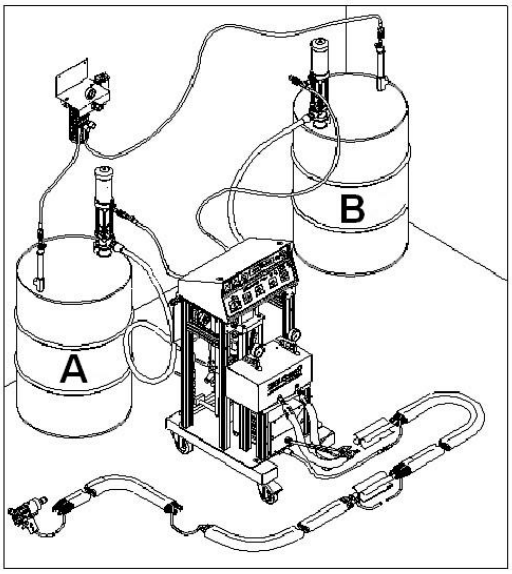


Picture 20: Polyurethane (PUR/PIR) sandwich panels

In the discontinuous manufacture of sandwich elements, the facings are fixed in a support mould on a frame and the resulting cavity is filled with the polyurethane reaction mixture. In suitable support moulds, several sandwich panels can be produced simultaneously in this process.

4.4. Manufacture of in situ rigid polyurethane foam (PUR/PIR)

The manufacture of in situ rigid polyurethane foam (PUR/PIR) consists of the two components passing through a dosed machine fixed to a transport media.

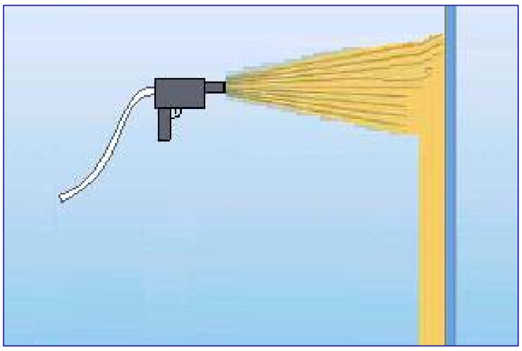


Picture 21: Spray machine scheme. Courtesy of Gusmer

Each component is conditioned in the machine at a determined temperature and pressure, and then both components pass separately through a heated hose which connects the machine to the spray gun. Once both components reach the gun, they are mixed proportionally and are then propelled in a shape or a fan over the substrate, where the foam is formed.

The in situ rigid polyurethane foam (PUR/PIR) can be formed by spraying or by dispensing.

4.4.1 In situ sprayed rigid polyurethane foam (PUR/PIR).



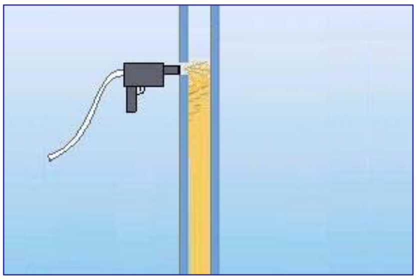
Picture 22: In situ sprayed rigid polyurethane foam (PUR/PIR)

In this case, the substrate must be dry, clean and firm. The surfaces will be impregnated with the mix in successive passes to obtain the desired foam thickness. This application method assures that the insulation foam will be totally adhered to the substrate and without joints.

Picture 23: Spraying over a masonry wall

4.4.2 In situ dispensed rigid polyurethane foam (PUR/PIR)

In this case, the foam will fill in the space between the external surfaces.



Picture 24: In situ dispensed rigid polyurethane foam (PUR/PIR)

Picture 25: Example of dispensed foam to insulate a pipe in situ. Courtesy of SPA Contracts

4.5. Summary

Applications and manufacturing methods of rigid polyurethane foam (PUR/PIR) thermal insulation materials are presented in Table 5.

Table 5: Applications and manufacturing methods of rigid polyurethane foam (PUR/PIR) thermal insulation materials

Applications	**Insulation boards, factory made**		**Block foam, factory made**	On the building site **in-situ foam manufactured on site, sprayed/poured**
	Insulation boards with flexible facings	Insulation boards with rigid facings/ steel-faced sandwich panels	Insulation boards, cut sections/ mouldings, composite panels	In-situ foam
Building envelope	EN 13165	EN 14509	EN 13165	DIN 18159-1
Building services Insulation	prEN 14308	-	prEN 14308	DIN 18159-1

5 European harmonisation of insulation materials – marking rigid polyurethane foam (PUR/PIR) thermal insulation products

The aim of the European regulations in the building sector is to create a common single market and guarantee the free flow of goods in order to increase the competitiveness of European industry. The harmonisation of the technical provisions for building products and the dismantling of trade barriers are cornerstones of the common single market.

5.1 Regulations in the European Construction Products Directive

The European Construction Products Directive contains authoritative provisions for harmonisation in the building sector. The Directive sets out conditions under which building products can be introduced and sold on the market. The products must demonstrate certain characteristics to ensure that the building in which they are to be installed fulfils the following essential requirements, under the assumption that building work has been properly planned and executed:

- mechanical resistance and stability
- safety in case of fire
- hygiene, health and the environment
- safety in use
- protection against noise
- energy economy and heat retention

The building products and their properties are described in the harmonised European standards (hEN) and the European Technical Approvals (ETA). The European Committee for Standardisation (CEN) draws up the harmonised standards on behalf of the European Commission on the basis of the Construction Products Directive (CPD). Conformity of a building product with a harmonised European standard or a European Technical Approval is confirmed by the CE marking.

5.2 CE Marking

The CE marking is the sole evidence of conformity required by law. The CE marking displays the following information:

- the CE marking symbol (consisting of the letters CE)
- details of the manufacturer (address) and manufacture (year of manufacture)
- coded information on certain product properties
- declaration of conformity by the manufacturer

The CE marking is a kind of ‘technical passport’. Insulation products bearing the CE marking can be traded within the European common market. The insulation product fulfils certain minimum requirements concerning its general suitability for use as “thermal insulation in buildings”. The manufacturer is responsible for affixing the CE marking.

October 2006

6 Annexes

6.1 Pictures index

6.2 Tables index

6.3 References

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