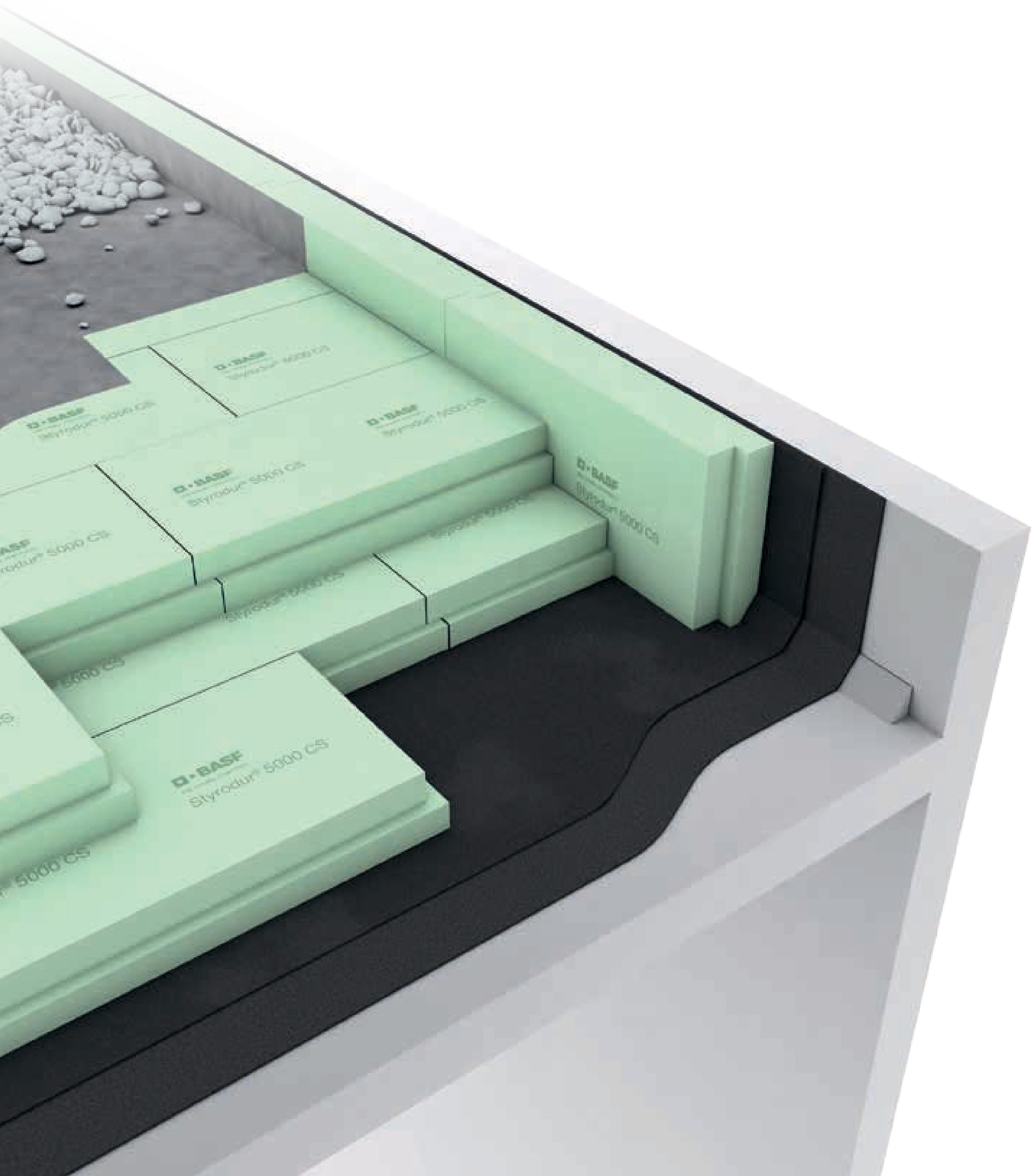
Flat Roof Insulation

Inverted Roof

www.styrodur.com



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1. Long-standing Trust in Styrodur®

With Styrodur®, BASF can draw on decades of experience in the XPS market: since 1964, the company has been producing the green insulation material, which is set apart by its high quality, versatile applications, and robustness. Styrodur stands for technology “made in Germany” and for unique, constantly evolving work on approvals.

This is why Styrodur has convinced generations of architects, craftsmen, builders, and building material suppliers of these benefits:

Environmental advantages:
- Environmentally friendly due to CO_2 production process with air as cell gas
- Reduction of carbon dioxide emissions (CO_2) thanks to excellent insulation performance
- Free from harmful blowing agents
- Polymer flame retardant

Quality and safety advantages:
- Technology “made in Germany”
- Most technical approvals on the market
- Proven since 1964
- Protects the building construction from external forces such as heat, cold, and humidity
- Comprehensive production control and quality monitoring, documented by CE marking, KEYMARK and Q-sign
- Long-lasting: if correctly installed, Styrodur outlasts the life expectancy of the building construction

Structural-physical advantages:
- Excellent insulation properties
- High compressive strength
- Low water absorption
- Resistance to aging and decay
- Fulfils all structural-physical and building construction requirements in Europe’s various climate conditions

Processing advantages:
- Low dead weight
- Simple and practical processing with appropriate saws or hot-wire cutting equipment
- Can be installed in all weather conditions
- No dust hazardous to health during mechanical processing
- Extensive product range
- Very wide variety of potential applications

Economic advantages:
- Strong market presence
- Fast availability and reliable partnerships thanks to Europe-wide logistics with professional customer service via local distributors
- Reduction of energy costs for heating and cooling
- Quick amortisation of the insulation investment with rising energy costs
- Increases the lifespan of the building and raises the value of the structure

2. Flat Roofs According to ZVDH Guidelines

Although the style and materials chosen for covering and sealing inclined and flat roof constructions have a high architectural significance, it is not solely the creative aspects that shape the characteristics of a building. Apart from the building's functionality, economic aspects as well as structural design play a big part in choosing the right style, shape, and material for the roof. Regardless of any specific requirements, flat roofs are as capable of meeting the structural-physical and building construction requirements as pitched roofs.

The structural design of inclined roofs as well as slightly sloped roofs with varying inclinations, or even zero-degree roofs, meets the current standards and regulations for thermal insulation and provides long-term, reliable protection against the effects of the weather. Thus, the functionality of a roof does not depend on how steeply the water-bearing layer is inclined, but rather on the design and execution of the roof structure. The technical guidance for sealing (flat roof guidelines) of the German Roofing Contractors Association (ZVDH) applies to the design and construction of sealed roof structures and to any layers necessary for the proper functioning of the roof structure and building elements.

Inverted roofs with Styrodur®

In contrast to the conventional non-insulated roof with its waterproofing above the thermal insulation, special insulation materials such as BASF's Styrodur may also be laid "inverted" on a flat roof. An increasing number of planners prefer the inverted roof, and BASF's Styrodur is an ideal insulation material for this system.

This brochure contains important planning and installation instructions for inverted roofs and explains the advantages of inverted roofs with Styrodur.

The thermal insulation material used in inverted roofs is subject to high compressive stress caused by rainwater, the plant substrate used for green roofs, and the traffic load on patio and parking roofs. Therefore, it must be highly resistant to moisture and decay. The material must exhibit high compressive strength as it will be walked on or crossed with light equipment (wheelbarrows) during installation and is placed directly below the pavement or green roof. Good, durable thermal insulation properties are also important to ensure its proper function in inverted roofs **(Fig. 1)**.

Fig. 1: Thanks to its compressive strength, low water absorption, and low thermal conductivity, Styrodur® is perfectly suited for inverted roof structures, such as plus roofs for flat roof renovations.

Application guidelines and technical data

Styrodur is a robust, easy-to-process building material that meets all of the above requirements. During the extrusion process of the thermal insulation boards, a smooth compressed foam membrane forms on the surface of the board, thus allowing for its installation in all weather conditions. The edges of the board feature a circumferential shiplap, which prevents the formation of thermal bridges when the boards are joined.

As its versatile properties make Styrodur suitable for very diverse applications, BASF keeps a broad range ready for delivery. The Technical Data brochure (see download area of www.styrodur.com) lists the main distinguishing features and the available shapes of Styrodur grades suitable for inverted roof constructions. Most significantly, these properties include compressive strength and thermal conductivity.

For inverted roof constructions in accordance with DIN 4108-2, the λ value in line with DIN 4108-4 is to be taken from the Technical Data brochure (see download area of www.styrodur.com).

If the roof is designed as a green roof, parking roof, or a water-draining and vapour-permeable separation layer covered with gravel, then the respective approvals must be observed. These can be found on www.styrodur.com. Confirmation of the thermal insulation performance based on the thickness of insulation must be documented using rated values of thermal conductivity as per DIBt approval.

2.1 Types of Flat Roofs/Definitions

According to the guidelines of the German Roofing Contractors Association (ZVDH), flat roofs are categorised by their structural design as ventilated or non-ventilated roofs. With non-ventilated flat roofs, all functional layers are arranged directly on top of each other. If these layers are glued together, the construction is known as a compact roof. Flat roofs are divided into "underutilised roof surfaces", "utilised roof surfaces", "earth-covered ceiling surfaces", and "frequented roof and ceiling surfaces made from reinforced concrete", depending on their type of use.

Roof surfaces that are only frequented for care and maintenance purposes and may be extensively planted but are not intended to be accessed by persons or crossed by traffic are classified as underutilised roof surfaces.

Utilised surfaces are surfaces intended to be accessed by persons, surfaces designed for the installation of equipment, or intensively planted surfaces (e.g. a roof with solar system, patio, balcony, pergola, or loggia).

According to the flat roof guidelines, the sealing bed should be designed with a surface incline of at least 2% in order to allow drainage of rainwater. Surfaces with lower or non-existent inclines may only be designed and installed in exceptional circumstances.

The drainage of inverted roofs with Styrodur® should be designed and implemented such that long-term flooding of the thermal insulation is prevented if the roof is regularly maintained. Short-term flooding is harmless. Provided that these conditions are met, the use of Styrodur means inverted roofs can be designed and installed with inclines of less than 2% or with zero-degree slopes.

The flat roof guidelines call for pressure-resistant, rigid polystyrene foam boards to be used for underutilised flat roofs, and enhanced pressure-resistant, rigid foam boards for utilised roof surfaces. All Styrodur grades suitable for inverted roofs meet these requirements.

The application requirements for thermal insulation are specified in DIN 4108-10 "Thermal insulation and energy economy in buildings—application-related requirements for thermal insulation materials". The inverted roof construction is classified as "DUK" in DIN 4108-10, Table 5.

The minimum requirements are thickness tolerances, maximum deformation under specified pressure and thermal load, creep behaviour, water absorption in a diffusion test, and resistance to the frost-thaw cycle. The compressive strength or the compressive stress at 10% deformation is listed in three categories: dh for high compressive strength (at least 300 kPa), ds for very high compressive strength (at least 500 kPa), and dx for extremely high compressive strength (at least 700 kPa).

A single-layer, non-ventilated flat roof is classified as either a "non-insulated roof" or an "inverted roof", corresponding to the position of the insulation layer. Both roof variants are suitable for either utilised or underutilised flat roofs. **Fig. 2** shows the basic arrangement of flat roof structures.

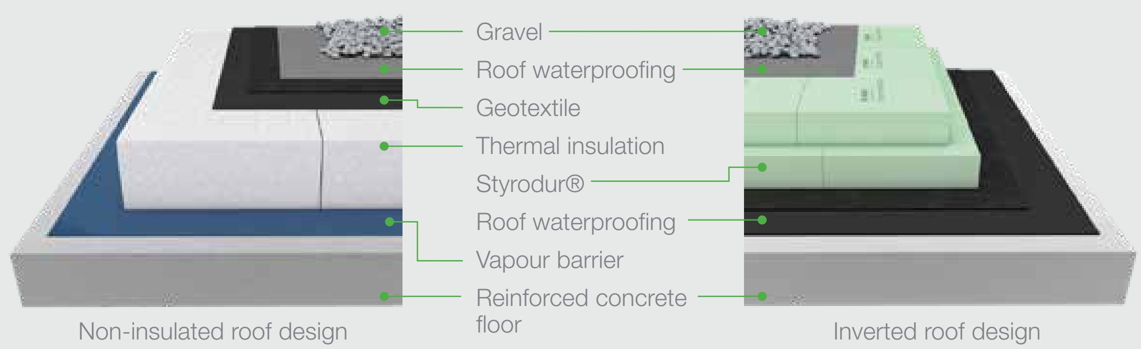


Fig. 2: Comparison of non-insulated and inverted roof designs.

The non-insulated roof is a single-layer, non-ventilated roof with weather-resistant waterproofing on top of the thermal insulation.

However, there are four different types of inverted roofs:

Single-layer inverted roof

The "standard" inverted roof is the most commonly used, in which the thermal insulation consists of a layer of extruded rigid polystyrene foam (XPS) arranged above the roof waterproofing.

Double-layer inverted roof

The German Institute for Building Technology (DIBt) approved the double-layer installation in gravelled inverted roofs (Z-23.4-222) for the first time in 2011. Samplings and long-term studies of existing double-layer inverted roofs in Germany and Austria illustrate that Styrodur maintains its mechanical and physical properties over a very long period of time with virtually no variations.

Added values DU for inverted roofs

In calculating the thermal transmission coefficient (U-value) of inverted roofs, the calculated U-value is increased by the value ΔU. According to DIN 4108-2, this value is a function of the percentage of the thermal resistance below the sealing barrier of the total thermal resistance as given in **Table 1**. For substructures with a mass per unit area of less than 250 kg/m², the thermal resistance below the sealing barrier must be at least 0.15 m² K/W.

Table 1: Added values for inverted roofs (DIN 4108-2)

Room-side thermal resistance of sealing barrier as a percentage of total thermal resistance %	Added value ΔU W/(m²·K)
under 10	0.05
from 10 bis 50	0.03
over 50	0

According to the respective approvals for Styrodur 3000 CS (60 mm – 160 mm), the added value ΔU is not required for inverted roof designs with a water-draining and vapour-permeable separation layer covered with gravel, when used above single- or double-layer Styrodur boards.

Fig. 3: Inverted roof insulation with Styrodur® for 250 housing units in Hamburg.

Duo roof

In the case of the so-called "duo roof", an additional Styrodur insulation layer is installed above the waterproofing layer of a conventional non-insulated roof with XPS boards. With this design, which is used if the installation of double-layer insulation in line with the approval is not possible, the vapour barrier can often be omitted, depending on weather conditions.

Plus roof

The so-called "plus roof" is a design solution for the energy-efficient renovation of flat roofs with insufficient thermal insulation. It is also used to combine the advantages of a non-insulated roof with those of an inverted roof. In order to protect the roof and extend its lifespan, an inverted roof with XPS is installed on top of a non-insulated roof structure with, for example, EPS or mineral wool. In this case, a thermal insulation layer of Styrodur is laid on top of the existing non-insulated roof structure. The existing roof waterproofing must first be checked for functional reliability.

Single-layer inverted roofs, duo roofs, and plus roofs may optionally be used for gravel, patio, green, or parking roofs. The inverted roof principle always remains the same, only the construction design is adapted. Inverted roof structures for gravel or patio roof designs are standardised in accordance with DIN 4108-2. The configurations as green and parking roofs are regulated by the respective approvals (see download area of www.styrodur.com).

The green and gravelled inverted roof construction for single-layer Styrodur 3000 CS (60 mm – 160 mm) is regulated by DIBt approval Z-23.31-2079.

3. Advantages of the Inverted Roof System

An inverted roof consists of the following layers (from top to bottom):

- Functional or protective layer (e.g. gravel)
- Water-draining and vapour-permeable separation layer; the added value ΔU is not required in accordance with DIBt approvals Z-23.4-222, Z-23.31-2079 and Z-23.31-2083
- One or two layers of Styrodur® insulation (depending on the respective approval)
- Roof waterproofing (and vapour barrier)
- Inclined levelling course, if necessary
- Roof structure, e.g. reinforced concrete floor

Note:
Functional or protective layers, such as gravel, traffic, or terrace layers, green roofs, etc., also function as security against wind suction and provide protection against flying sparks or radiant heat.

The inverted roof is easier and faster to erect than the conventional non-insulated roof as it consists of fewer layers requiring installation and gluing.

In the case of inverted roofs, the most important layer—roof waterproofing—lies on a solid, sturdy, and joint-free base, with the exception of plus roofs and duo roofs. If the sealing membrane is mechanically stressed, then it can directly transfer the resulting loads. However, if an insulation layer is used as the substrate, small gaps may form between the individual insulation boards and the waterproofing layer can "sag" into these joints, which in turn can lead to cracks.

If the roof waterproofing layer is glued over the expanse of the solid concrete ceiling, leaks can be located easily in the event of damage. Water appears on the inner surface, precisely at the place where the roof waterproofing is damaged. This is not the case with conventional non-insulated roofs: if water trickles through the sealing barrier, visible water damage often appears far from the actual location of the leak in the waterproofing layer.

In the case of non-insulated roofs, it is also important that no moisture is trapped between the vapour barrier and the waterproofing layer—something that is often difficult to achieve in practice. When constructing a non-insulated roof, thermal insulation materials on the site must be protected from moisture, and installed insulation boards must be covered.

As a rule, insulation boards should not be installed if it is raining or foggy, otherwise the moisture trapped under the roof waterproofing will lead to vapour bubbles. In contrast, the thermal insulation layer of inverted roofs can even be installed in the rain. Stagnant rainwater on the roof waterproofing can permeate through the Styrodur thermal insulation layer or evaporate through the insulation board joints to the outside air.

The waterproofing of inverted roofs should have a water vapour diffusion-equivalent air layer thickness s_d of at least 100 m. This significantly reduces the water vapour diffusion flow from the inside to the outside through the roof construction and also prevents permeation of moisture into the interior of the building during the hot summer months when the direction of diffusion is reversed.

As the waterproofing layer in inverted roofs is below the thermal insulation layer and the functional layers (e.g. gravel layer or pavement), it is permanently protected from UV rays.

Depending on the further design of conventional non-insulated roofs, waterproofing may be directly exposed to the sun's UV radiation, which can lead to damage to bituminous seals and plastic waterproofing layers alike.

The temperature fluctuations in terms of waterproofing are also significantly lower with inverted roofs. With conventional non-insulated roofs, the temperature fluctuation on the roof membrane over the course of one year can reach up to 110 K. In contrast, the temperature fluctuation with inverted roofs over the course of a year is approximately 12 K if the room air temperature under the roof is 20°C

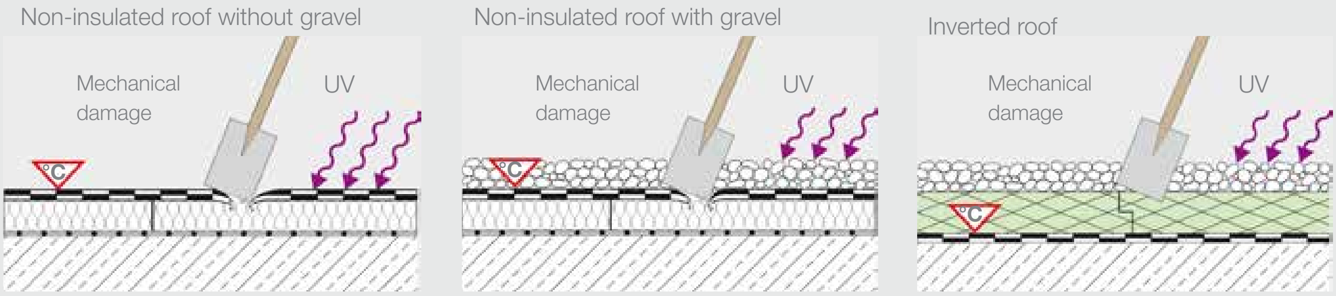


Fig. 4: An advantage of the inverted roof system is that the insulation material on top of the roof waterproofing protects it from high temperature fluctuations, thermal shocks, mechanical damage, and the sun's UV radiation.

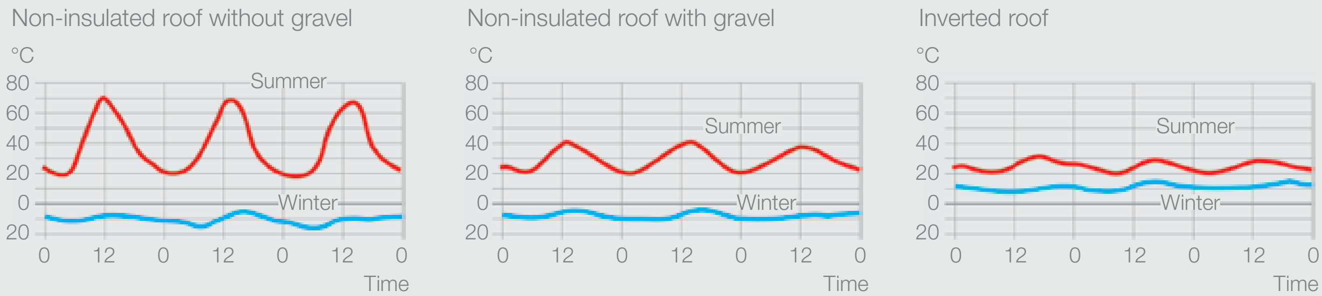


Fig. 5: Thermal load of waterproofing in a non-insulated roof and an inverted roof.

Fig. 4 and Fig. 5 show the daily thermal load for the waterproofing of a conventional non-insulated roof with and without gravel compared with that of an inverted roof. In non-insulated roofs, temperatures in waterproofing layers can peak at 90°C in summer, whereas the temperature remains almost constant when the waterproofing layer is protected by a thermal insulation layer, as is the case with inverted roofs. Thermal shocks, caused by hail storms in summer, for example, do not damage the waterproofing of inverted roofs.

The waterproofing of conventional non-insulated roofs is permanently exposed to mechanical strains. In many cases, damage already occurs during the construction phase due to work on the roof, storage of building materials, falling items, and many other reasons. By contrast, the inverted roof's waterproofing is protected from mechanical damage thanks to the resilient, elastic thermal insulation layer. At the same time, the insulation acts as a protective layer in order to meet the requirements for sealing barriers as laid out in DIN 18195-10.

3.1 Advantages of Styrodur® in Inverted Roofs

Styrodur has been used in inverted roofs since the late 1970s and has been technically approved since 1978. Samples taken from functional inverted roofs have demonstrated that Styrodur maintains its mechanical and physical properties over a very long period of time with virtually no variations **(Fig. 6)**.

Fig. 6: Image shows a green inverted roof that is more than 30 years old

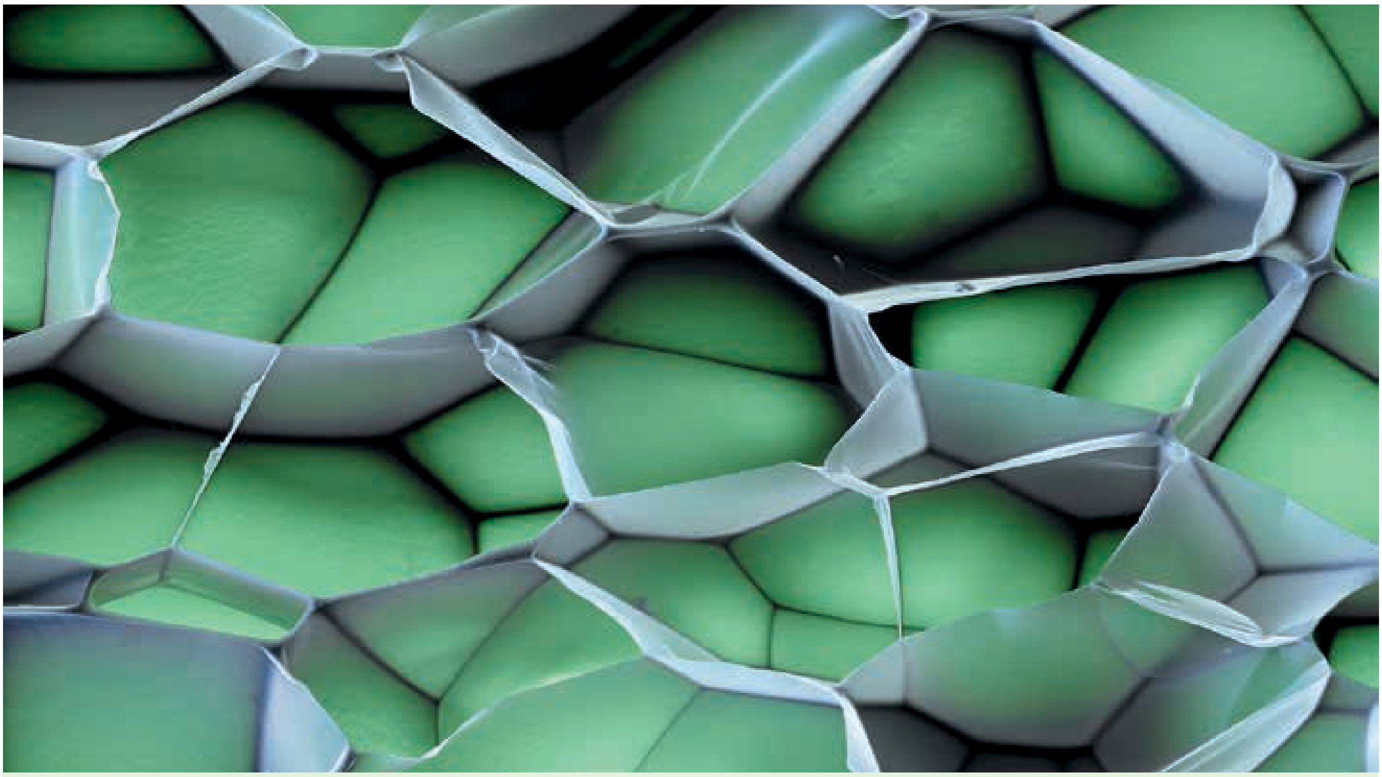


Fig. 7: Water absorption of Styrodur® is extremely low due to its closed-cell foam structure.

Resistance to water

Water absorption by the boards is exceptionally low due to the closed-cell foam structure **(Fig. 7)** and the foam membrane on both sides. The moisture content of Styrodur® boards that had been installed in gravel roofs for many years was approximately 0.1% by vol. and had no effect on the thermal insulation properties of the material.

High strength

The strength properties of Styrodur make it the ideal insulation material for inverted roofs. The Styrodur 4000 CS and Styrodur 5000 CS compression-proof rigid polystyrene foam boards are recommended for applications with particularly heavy loads, such as parking roofs.

Dimensional stability

The extrusion process and controlled storage conditions prior to delivery ensure high dimensional stability. Styrodur boards are dimensionally stable at the loads and temperatures defined in DIN EN 13164.

Fire protection classification

Inverted roof constructions with Styrodur generally meet the requirements of DIN 4120-4 with regard to protection against flying sparks and radiant heat (hard roofing).

Thermal bridges

No significant structural-physical thermal bridges are formed when installing Styrodur boards with shiplap edges.

Processing

Appropriate saws or hot-wire cutting equipment are used to process Styrodur. Connections or penetrations can be easily made with clean-cut edges. The machine manufacturer's operating and safety instructions must be observed.

The flat roof design constructed according to the inverted roof principle essentially arises from the need to protect waterproofing from static, dynamic, and thermal influences. This is also a mandatory requirement according to DIN 18195-10. The standard also specifies that protective layers may also be functional layers of the building structure. In inverted roofs, the functional "thermal insulation" layer doubles as the protective layer for waterproofing.

Styrodur

- can take over static functions and uniformly embed the arising loads due to its modulus of compressive elasticity.
- can dynamically decouple the superstructure and the wearing surface from the substructure with the supporting structure and the roof waterproofing due to its resilient and elastic yet solid construction.
- saves heating and cooling energy and protects the building from severe climatic conditions.

The properties of Styrodur enable the planner to use the inverted roof principle for highly stressed, utilised flat roof constructions.

4. Application Notes

4.1 Substructure

The inverted roof thermal insulation system can be implemented for single-layer (non-ventilated) flat roofs, both for heavy and light substructures provided that the following conditions are met:

- Heavy substructures, such as solid ceilings, must have an area-related mass of 250 kg/m². Light substructures with an area-related mass of less than 250 kg/m² must exhibit a thermal resistance of $R \geq 0.15$ m²·K/W under the sealing barrier.
- he high area-related mass and the prescribed minimum thermal resistance of the substructure are intended to prevent the underside of the ceiling from cooling to the point of condensation formation during cold rain showers.

The surfaces upon which the roof waterproofing is to be laid must be clean and free of foreign objects. Concrete ceilings, including any sloping layers, must be sufficiently hardened and their surface must be dry. The dimensional tolerances of DIN 18202 "Tolerances in building construction" and the applicable flat roof guidelines must be complied with. If the incline is lower than 2%, a special contractual agreement is necessary.

Inverted roofs with Styrodur® do not require an incline. Although some water remains on the zero-degree surfaces after the rain, this does not affect the functionality of the inverted roof, provided the insulation boards are not permanently flooded.

4.2 Roof Waterproofing

All common roof waterproofing materials are suitable for inverted roofs with an incline of more than 2%:

- Polymer-bitumen membranes
- High-polymer membranes

Inverted roofs with an incline of less than 2% require special precautions to reduce risks associated with stagnant water. That is why two polymer-bitumen membrane layers are to be used in the case of bituminous seals. If the roof waterproofing layer consists of plastic membranes, then thicker membranes are to be used. It is recommended to always reference the manufacturer's processing specifications and the applicable flat roof guidelines.

Note:
Tar-based or solvent-based sealing barriers are not suitable for inverted roofs with Styrodur.

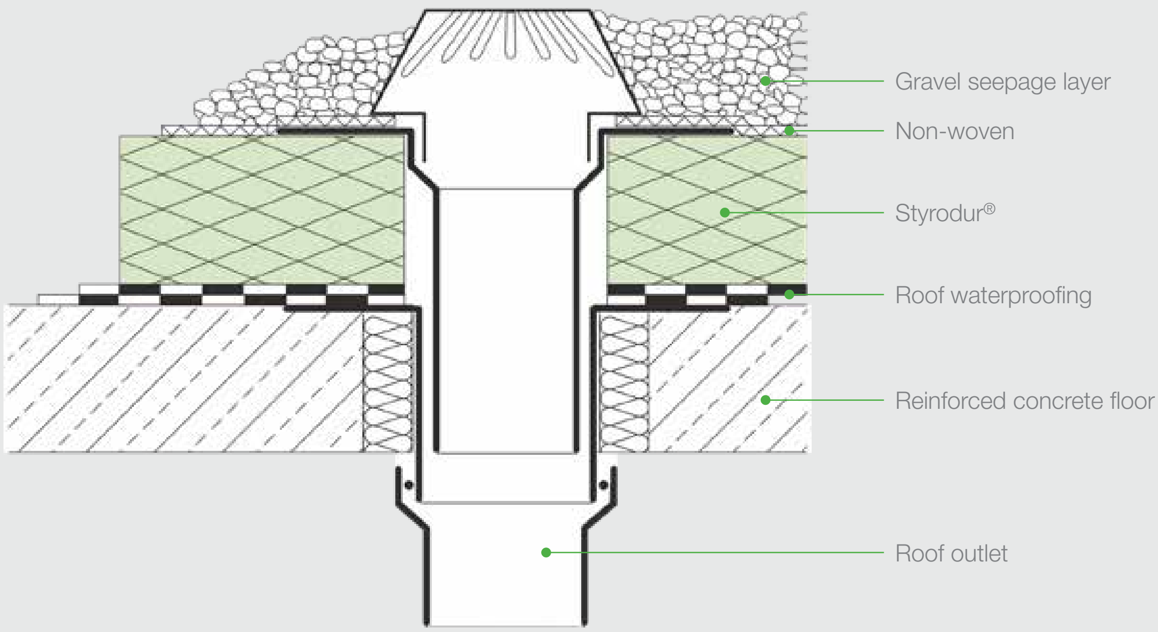


Fig. 8: Roof outlet with two drainage levels for draining the roof above and below the insulation layer.

4.3 Roof Drainage

The drainage system of an inverted roof (see DIN EN 752, DIN EN 12056, and DIN 1986-100) is to be designed such that long-term flooding of the Styrodur boards is prevented. Short-term flooding during severe precipitation is harmless.

Roof outlets

As the inverted roof system requires the roof membrane to be installed under the insulation layer, water drainage must take place both above and below the insulation boards. It is therefore necessary to provide a roof outlet with two drainage levels **(Fig. 8)**. The prerequisites for the professional installation of roof outlets must be verified during the planning stage.

In order to prevent the Styrodur® boards from being permanently submerged due to the roof outlets being too high, the arrangement and sizing of the required roof outlets and the corresponding down pipes are regulated by DIN 1986 and DIN EN 12056-3.

4.4 Thermal Insulation Layer

In order to avoid thermal bridges, inverted roof designs require Styrodur boards with shiplap. The boards are joined in one or two layers, butted tightly with staggered transverse joints (avoid cross joints). In the case of parapet walls or rising brickwork with bituminous seals, the Styrodur boards have to be aligned with the insulation wedge, as this enables the installation of the insulation material without thermal bridges. Since the insulation boards lie loosely on the roof waterproofing layer, they have no effect on each other in the event of thermal expansion.

So far, inverted roofs have only been insulated with a single layer. BASF has demonstrated a secure double-layer application of Styrodur based on the respective technical approval.

As described in section 5.2, gravelled inverted roofs with Styrodur boards can be laid as a double layer, provided that an approval-compliant water-draining and vapour-permeable separation layer is placed between the Styrodur boards and the gravel layer. However, this only applies to Styrodur 3035 CS, 4000 CS, and 5000 CS.

- Isover AquaDefense UKD
- Bachl LiquiStopp LS

In this case, the added value ΔU is not necessary (see page 6, Added values ΔU for inverted roofs, and download area of www.styrodur.com).

The Styrodur insulation layer is suitable for foot and vehicle traffic. To carry items over the insulated surface, use wheelbarrows with pneumatic tyres.

Styrodur insulation boards are not resistant against substances containing solvents.

4.5 Protective Layer

As previously described, the Styrodur thermal insulation of inverted roofs always lies on top of the waterproofing layer. As a consequence, the insulation material is exposed to the elements all year round. The closed-cell, rigid-foam polymer chains are not permanently resistant to UV rays. For this reason, it is always necessary to apply a protective layer over the insulation material of inverted roofs **(Fig. 9)**. The protective layer performs four functions:

- Protection of the insulation boards against direct UV radiation
- Protection of the roof layers against lifting due to wind suction
- Protection against flying sparks and radiant heat (hard roofing)
- Securing the insulation boards against floating

Generally, the protective layer consists of gravel. However, it can also be a functional layer as in the case of green roofs, terrace tiles, or parking roofs. The protective layer is made up of different materials depending on the intended use.

Fig. 9: Inverted roof with separation layer and gravel.

4.6 Protection Against Floating

To prevent the insulation layer of inverted roofs from floating, a suitable load must be applied, e.g. a layer of gravel. A layer of washed, round gravel (16/32 mm diameter) can provide the necessary load and act as a protective layer at the same time. If required, the gravel can be coated with a sealer. However, it must not form a closed film over the Styrodur® boards. The protective layer over the Styrodur boards must be permanently vapour-permeable.

When used without a non-woven and with a minimum insulation layer thickness of 50 mm, the thickness of the gravel layer is always equal to that of the insulation layer. If a non-woven is used, the gravel layer can be reduced to 50 mm **(Table 2)**.

Table 2: Securing the Styrodur® boards against floating

Thickness of insulation layer	Gravel layer	
single layer	without non-woven	with non-woven
30–50 mm	50 mm	50 mm
60–200 mm	equal to insulation layer thickness	50 mm
double layer	water-draining non-woven	
220–400 mm	50 mm	

4.7 Protection Against Wind Suction

Protection of the Styrodur boards against wind suction is to be implemented in accordance with DIN EN 1991-1-4 or the respective technical approvals. The required load can be provided by a layer of gravel with a grain diameter of 16/32 mm and a bulk density of ≥ 1.800 kg/m³, or by using concrete slabs with a raw density of ≥ 2.000 kg/m³. The gravel layer must be secured against the wind.

Flat roofs and other roof types with an incline of up to five degrees are subdivided into roof groups F to I (groups A to E apply to vertical building elements such as walls; hipped roofs are subdivided into groups F to N) according to the wind load standard DIN 1991-1-4. Furthermore, the building height, location, and site (wind zone/wind profile) as well as the velocity pressures for buildings (kN/m²) are taken into account.

For the roof groups H and I (interior), the required load of approximately 0.75 kN/m² is to be met, for example by using a minimum gravel layer of 50 mm with a grain diameter of 16/32 mm.

Buildings in geographically exposed locations, such as on mountain ridges or hillsides with extreme wind movements or with high buildings in the vicinity, may require significantly higher loads.

Appendix 1 to technical approvals Z-23.4-222, Z-23.31-2079 and Z-23.31-2083 contains notes and values corresponding to the following tables for securing inverted roofs with a water-draining and vapour-permeable separation layer covered with gravel or with concrete slabs against wind suction (see download area of www.styrodur.com).

- Table 1: Maximum height of roof edge h above ground
- Table 2: Required load in kN/m² for securing roof groups F and G against wind suction in accordance with DIN EN 1991-1-4, image 7.6
- Table 3: Reduction factor K as a function of the width of edge and corner groups F and G in accordance with DIN 1991-1-4, image 7.6
- Table 4: Maximum building heights above ground at a sole load of gravel with a grain diameter of 16/32 for roof groups F and G in accordance with DIN 1991-1-4, image 7.6
- Table 5: Thickness t of concrete slabs in mm
- Table 6: Examples of loads to secure against wind suction

5. Configurations

5.1 Gravelled Inverted Roof—Single-layer

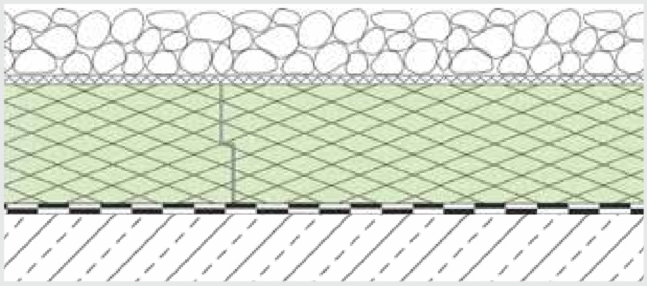


Fig. 10: Single-layer, gravelled inverted roof.

Depending on the requirements, Styrodur® 3000 CS, 3000 BMB CS, 3035 CS, 4000 CS, and 5000 CS insulation boards can be used for single-layer, gravelled inverted roofs in accordance with DIN 4108-2.

The extruded foam boards must also have an overall edge profiling, e.g. shiplap.

As trickle protection between the insulation layer and gravel protective layer, a non-woven resistant to decay and vapour-permeable with an area-related mass of approx. 140 g/m² protects the roof waterproofing from damage by fine, penetrating gravel particles **(Fig. 10)**. Together with the non-woven, a gravel layer prevents the individual Styrodur boards from shifting and tilting caused by floating or wind suction. Plastic sealing membranes or PE films should never be installed as trickle protection because they act as a vapour barrier, which would cause the insulation layer underneath to absorb more and more water.

After each rainfall, small amounts of water remain on the roof waterproofing, which must always have a chance to evaporate in the outside air. This is usually achieved through the grooves of the Styrodur board joints and by directly diffusing through the insulation material. This also explains one of the fundamental rules of inverted roof systems: a vapour-permeable layer must always be installed on top of the insulation material. Roof surfaces exposed to regular traffic for maintenance work should be fitted with pavement flags.

Note: According to approvals Z-23.31-2079, Z-23.4-222 and Z-23.31-2083, the added value ΔU is not required for inverted roof designs with a water-draining and vapour-permeable separation layer covered with gravel, above single- or double-layer Styrodur boards. Single-layer insulated inverted roofs can also be renovated to the current insulation standards by installing a second layer of Styrodur.

5.2 Gravelled Inverted Roof—Single- or Double-layer with Water-draining, Vapour-permeable Separation Layer

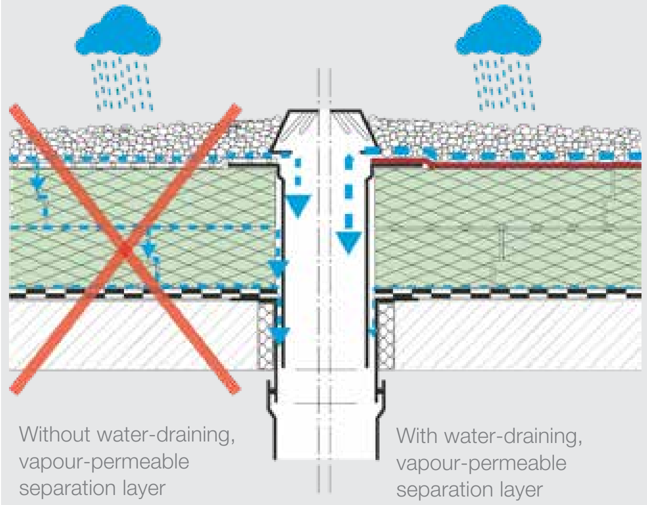


Fig. 11: Double-layer, gravelled inverted roof configuration.

The structure of single- and double-layer gravelled inverted roofs featuring a water-draining, vapour-permeable separation layer is also defined in respective the technical approvals. The following XPS insulation materials from BASF are approved for installation:

- Styrodur 3000 BMB CS* min. 60 mm, max. 160 mm*
- Styrodur 3000 CS min. 60 mm, max. 160 mm*
- Styrodur 3000 SQ min. 160 mm, max. 240 mm*
- Styrodur 3035 CS min. 50 mm, max. 200 mm
- Styrodur 4000 CS min. 60 mm, max. 160 mm
- Styrodur 4000 SQ min. 160 mm, max. 240 mm*
- Styrodur 5000 CS min. 60 mm, max. 120 mm
- Styrodur 5000 SQ min. 160 mm, max. 240 mm*

  * single-layer only

As a result of the water-draining and vapour-permeable separation layer (Isover AquaDefense UKD, Bachl LiquiStopp LS) being laid above the insulation layers, most rainwater is safely conveyed to the surface and the formation of a permanent water film between the board layers is largely prevented **(Fig. 11)**. There is thus no risk from structural-physical reasons of excessive moisture accumulation in the lower board layer, which could lead to a reduction of thermal insulation efficiency.

The inverted roof construction with two insulation layers allows the cost-effective use of Styrodur standard boards. The boards with standard thicknesses of up to 200 mm and shiplap are readily available and can be combined so as to achieve insulation thicknesses from 220 to 400 mm. The bottom layer should have a minimum thickness of 120 mm, while the top layer of Styrodur boards can be installed with a minimum thickness of 100 mm. The requirements of the German Building Energy Act (Gebäudeenergiegesetz, GEG) from November 1st, 2020 can be met thanks to double-layer insulation with Styrodur. The energy-efficient renovation of single-layer inverted roofs up to the passive house standard is even possible.

Fig. 12: Installation of Styrodur® for a duo roof.

Fig. 13: Parapet insulation with Styrodur®.

5.3 Duo Roof

The duo roof is an inverted roof variant used when the requirements concerning the thermal transmission coefficient (U-value) are particularly high and installing the double-layer variant in accordance with approval Z-23.4-222 is not possible, e.g. for green roofs or parking roofs. For this purpose, an additional insulation layer of Styrodur® with a thickness of up to 200 mm is applied above the sealing barrier on a standard, non-insulated roof structure with Styrodur. For Styrodur 3000 CS, a thickness range of 60 mm–160 mm applies. For Styrodur 3000 SQ, 3000 BMB SQ, 4000 SQ and 5000 SQ, a thickness range of 160 mm - 240 mm applies.

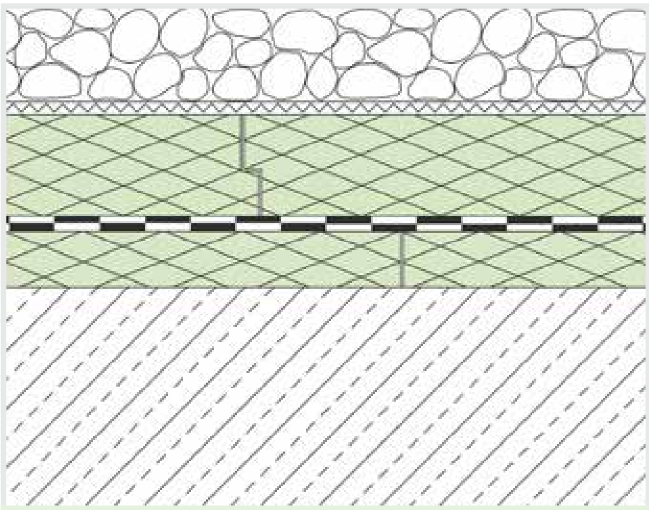


Fig. 14: Duo roof configuration with gravel.

Condensation protection in accordance with DIN 4108-3 should be documented in each case if less than 1/3 of the overall thermal resistance below the roof waterproofing is expected.

A separation layer on top of the reinforced concrete floor is not necessary. Depending on the climatic conditions, a vapour barrier may also often not be required.

In accordance with the approval and DIN 4108-2, the added value ΔU may be omitted with duo roofs if more than 50% of thermal resistance is assured below the waterproofing layer.

5.4 Plus Roof—Renovation

The plus roof design is the perfect choice when reconstructing existing, insufficiently insulated non-insulated roofs in order to meet today's thermal insulation standards **(Fig. 16)**. The plus roof can be constructed as a single- or double-layer inverted roof to renovate an existing non-insulated roof if the conditions, such as incline and so forth, comply with the approval guidelines.

The following steps are required in order to convert an existing non-insulated, gravelled roof into a plus roof with Styrodur®:

- The existing layer of gravel is removed in sections and stored on the roof, taking into account the static requirements.

Fig. 15: Installation of Styrodur® on top of the roof waterproofing.

Fig. 16: Renovated inverted roof as a plus roof.

- The existing roof waterproofing is to be examined for leaks. Damages and defects are to be repaired professionally.
- Connections to rising brickwork, skylights, ventilation plugs, and roof gutters should be checked and raised, if required.
- Connections to rising building elements must be positioned at least 15 cm above the top edge of the gravel layer or the finished plus roof. This requirement reduces to a minimum of 10 cm for roof gutters. When appropriate, connections should be raised.
- The Styrodur boards are then installed and covered with geotextile. In configurations with a gravel layer and a water-draining, vapour-permeable separation layer in accordance with section 4.4.2 of approval Z-23.4-222, the Styrodur boards may be installed in a single or double layer. For Styrodur 3000 CS, 3000 BMB CS and 3000 SQ, a single-layer installation in accordance with approvals Z-23.31-2079 and Z-23.31-2083 applies.
- The gravel that was temporarily stored can be distributed on the insulation layer in sections **(Fig. 17)** until the energy-efficient restoration of the entire roof surface has been completed.

If the substructure provides the necessary load-bearing capacity, renovated non-insulated roofs may also be converted into green inverted roofs. The existing roof waterproofing is to be examined for its resistance to roots. If necessary, an additional root-barrier membrane is to be applied

5.5 Plus Roof—New Construction

Plus roofs are suitable if a regular incline is required. In this case, the lower insulation layer can be constructed, for example, as a gradient roof with insulation boards made of Neopor®.

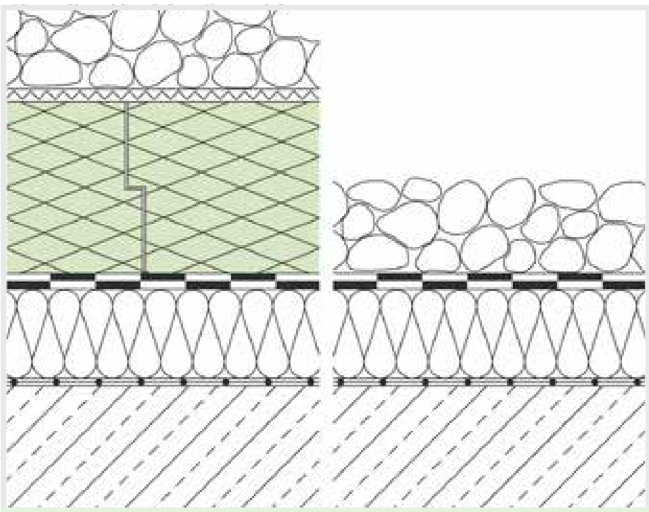


Fig. 17: New plus roof on the left; old non-insulated roof on the right.

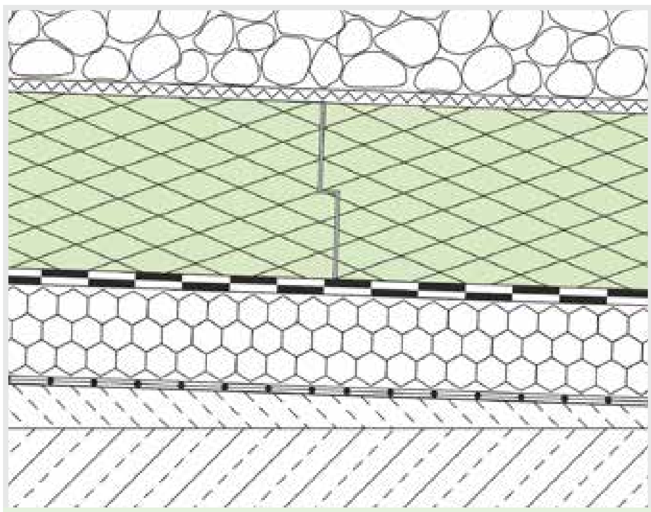


Fig. 18: Renovated plus roof with gradient insulation in an old existing building.

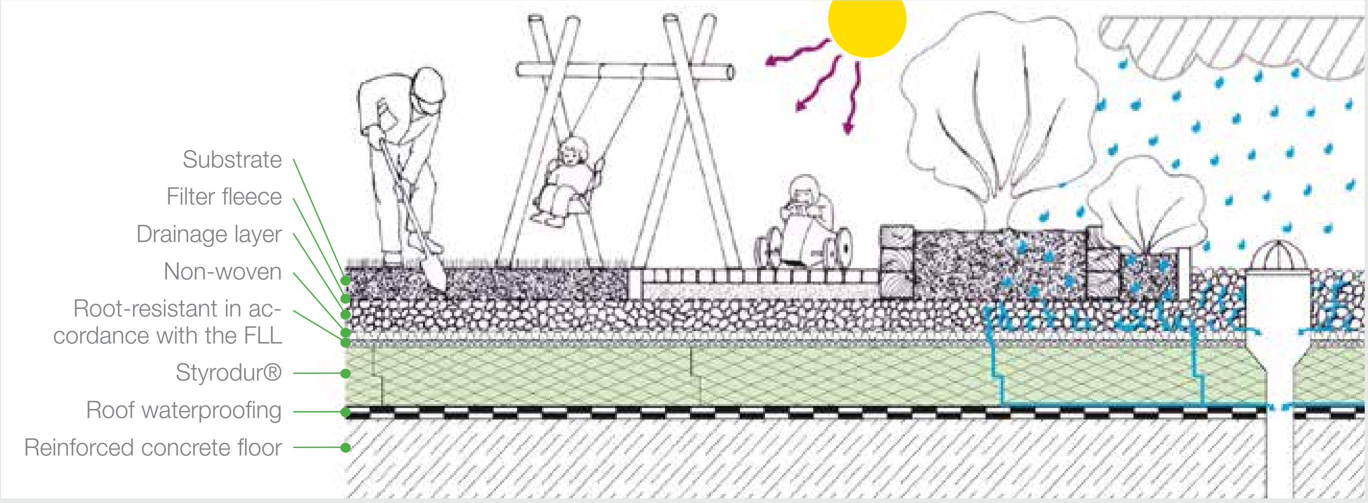


Fig. 19: Green roof loads.

5.6 Green Roof

Extensive or intensive green roofs with water features, paths, and paved areas can be created on any functional inverted roof construction **(Fig. 19)**. The substructure is to be checked for static load-bearing capacity. A vapour-permeable layer must be installed on top of the thermal insulation layer of Styrodur® boards. The notes in the respective technical approvals must be complied with (download area of www.styrodur.com).

The green inverted roof design holds many advantages compared with the non-insulated roof:

- The thermal insulation protects the root-resistant sealing barrier from thermal stresses **(Fig. 21)**.
- During the construction phase, the insulation package provides reliable protection against mechanical strains.
- Once the green roof is in use, the insulation layer protects the underlying waterproofing against rakes or other garden appliances used for maintenance **(Fig. 20)**.
- In the construction of inverted green roofs, there is a clear separation between the trades. The roofer takes care of sealing and thermal insulation while the roof gardener is responsible for the substrate layer and greening. This simplifies the final acceptance and warranty.
- Companies frequently offer green roofs as a complete system.

In the case of inverted roofs, insulation materials made of extruded foam boards may not be permanently flooded with rainwater. To satisfy the structural-physical principle of inverted roofs, a vapour-permeable layer has to be applied between the water storage level and the Styrodur boards. This may consist of Styropor compact boards, for example **(Fig. 22)**. The egg-carton design collects the rainwater on the upper surface and drains off excess water along the cavities on the underside.

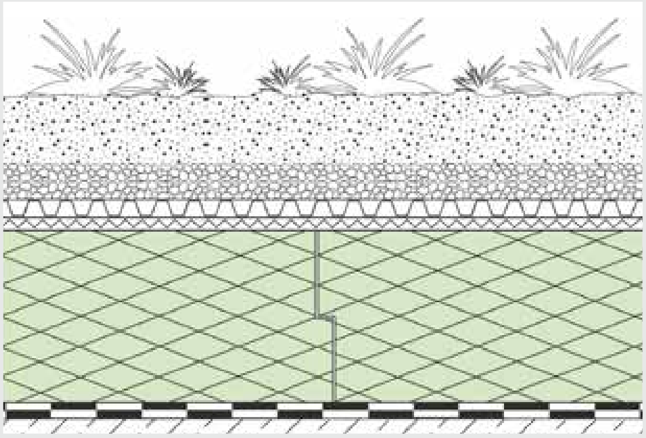


Fig. 20: Green roof configuration.

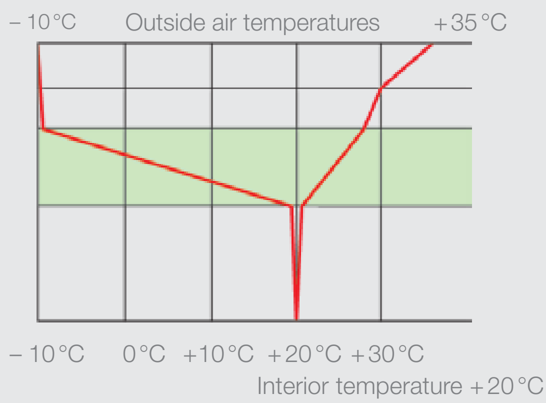


Fig. 21: Temperature profile of an inverted green roof.

Another alternative is the green, walkable roof terrace **(Figs. 23 and 24).** Part of this design is a non-woven positioned between the Styrodur® thermal insulation layer and the drainage layer. This layer drains the excess rainwater and offers vapour-permeable coverage for the extruded foam boards on top. Above the gravel drainage layer, the structure can consist of virtually any variety of materials. Part of the roof may be covered with a pond system using welded membranes. Other parts may be converted into a terrace with bedding sand and filter fleece, or filter fleece and a plant substrate to create a green roof.

The planner must always take into consideration both the roof's load-bearing capacity for the substrate **(Table 3)** and the possible weight gain of the plants. The Styrodur 3000 CS, 3000 BMB CS, 3000 SQ, 3035 CS, 4000 CS, or 5000 CS boards used for inverted roofs in accordance with the respective approvals exhibit the permissible compressive load properties of 130, 180, or 250 kPa, depending on the material type. This corresponds to loads ranging from 13, 18, or 25 tonnes per square metre.

Table 3: Load assumptions of vegetation types (FLL green roof guideline 2008)

Vegetation type	Load assumption	
Extensive greening	kN/m²	kg/m²
Moss sedum greening	0.10	10
Sedum moss herb greening		
Sedum herb grass greening		
Grass herb greening (dry lawn)		
Simple intensive greening		
Grass herb greening (grass roof, poor grassland)	0.15	15
Wild shrubs grove greening	0.10	10
Grove shrubs greening	0.15	15
Grove greening up to 1.5 m in height	0.20	20
Intensive greening		
Lawn	0.05	5
Low shrubs and grove	0.10	10
Shrubs and bushes up to 1.5 m in height	0.20	20
Bushes up to 3 m in height	0.30	30
Large bushes up to 6 m in height[1)]	0.40	40
Small trees up to 10 m in height[1)]	0.60	60
Trees up to 15 m in height[1)]	1.50	150

[1)] Information in relation to the surface of the canopy drip.

Fig. 22: Styropor compact boards for the retention and drainage of water on a green inverted roof with Styrodur®.

Fig. 23: Green and walkable roof terrace with pond irrigation system on an inverted roof with full gravel drainage layer.

Fig. 24: Vibrant urban landscapes can be achieved with a green roof on Styrodur®.

Note:
More information on the configuration of green roof surfaces can be obtained in the document "Guideline for the planning, execution, and maintenance of green roofs—green roof guideline" (2018 edition) from German landscaping society Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. (FLL). www.fll.de

Extensive green roof

Extensive green roofs **(Fig. 26)** require little maintenance—possibly one or two inspections a year.

Irrigation and the application of nutrients are mostly covered by natural processes.

The plants only need additional irrigation during the establishment phase. For the most part, extensive greening comprises drought-resistant plants that are ideally suited to extreme conditions and regenerate quickly, i.e. short plants (max. 15 cm in height) that provide extensive coverage. The substrate thickness generally measures between 6 and 16 cm.

The substrate layer of extensive green roofs is drained by the drainage layer beneath. A filter fleece should be positioned between the two layers. Various green roof contractors also offer substrate layers that act both as a growth medium for the plants and, due to their grain structure, as a drainage layer for any excess rainwater. In many cases, such bifunctional substrate layers consist of expanded clay or shale. In general, the planner must match the properties of the substrate mixtures to the designated plant types and their appearance in the planning phase.

Fig. 25: Installation of Styrodur® boards under an extensive green roof.

Intensive green roof

Intensive green roofs **(Fig. 27)** can be divided into simple and high-maintenance intensive green roofs. Simple intensive green roofs require a limited amount of maintenance. For their use and design, plants with modest demands on the layered structure as well as on the supply of water and nutrients must be considered. These include grasses, shrubs, and groves.

High-maintenance intensive green roofs, however, have to be planned thoroughly and need the continuous care of a gardener. They require irrigation, fertilisation, mowing, and weeding.

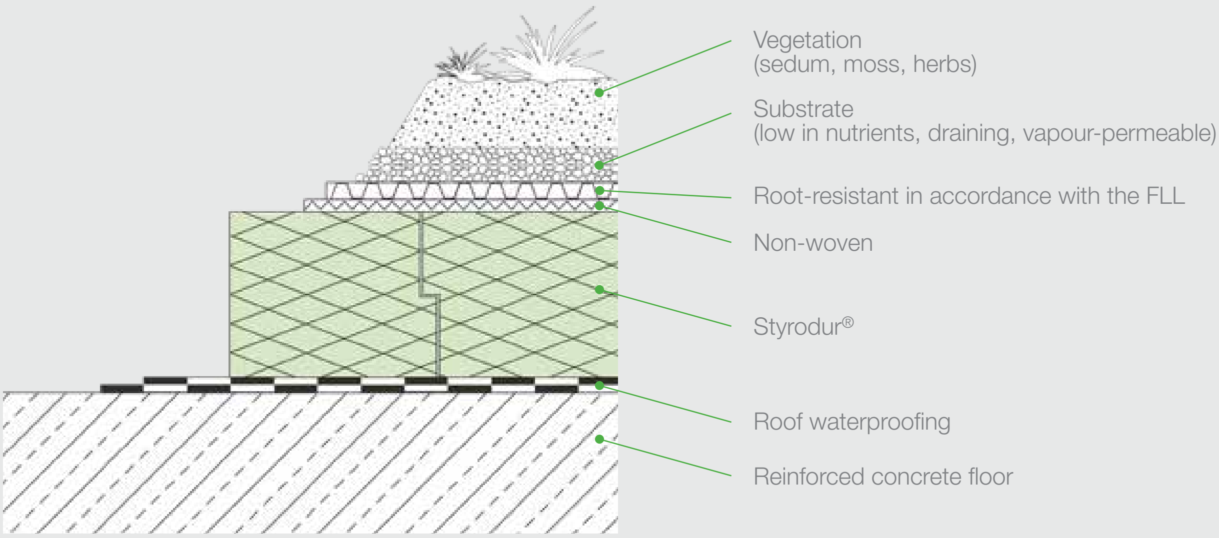


Fig. 26: Profile of an extensive green inverted roof.

Fig. 27: Intensive green inverted roof.

As a rule, the substrate thickness measures between 10 and 60 cm, depending on the intended use. The height of the plants should be between 1 and 3 metres. The possibilities regarding use and design of such roofs are virtually unlimited.

Most suitable are plants used for extensive and simple intensive green roofs, ornamental lawns, high-maintenance shrubs and bushes between 3 and 6 metres in height, as well as short and tall trees. In order to maintain green inverted roofs—with either extensive or intensive planting—in the long term, certain factors must be taken into account for each functional layer.

Root-barrier membrane of roof waterproofing

On green roofs, the roots of the plants advance as far as the sealing barrier, following the course of the water. To protect the waterproofing layer from damage caused by penetrating roots, only root-resistant sealing membranes should be used. The Fachvereinigung Bauwerksbegrünung e. V. (FBB, German professional association for constructional greening) provides a list of all membranes and sheets (WBB) exhibiting such properties according to FLL testing. The current product and manufacturer's specifications can be requested from the FBB (www.fbb.de).

Filter and drainage layer

The vegetation layer of green roofs should be capable of storing as much water as possible so that the plants have enough water available to survive potential periods of drought. Excess water, on the other hand, must be disposed of through the seepage layer to the drainage pipe or roof outlet. The seepage layer is thus part of the drainage layer. Since small particles of the plant substrate may damage the seepage layer, a filter fleece should be installed between the substrate and seepage layers. The most common choice is a synthetic non-woven made of polypropylene or polyester fibre with an area-related mass of approx. 140 g/m². Fibreglass non-wovens are not suitable because the alkalinity of the ground and water will damage them.

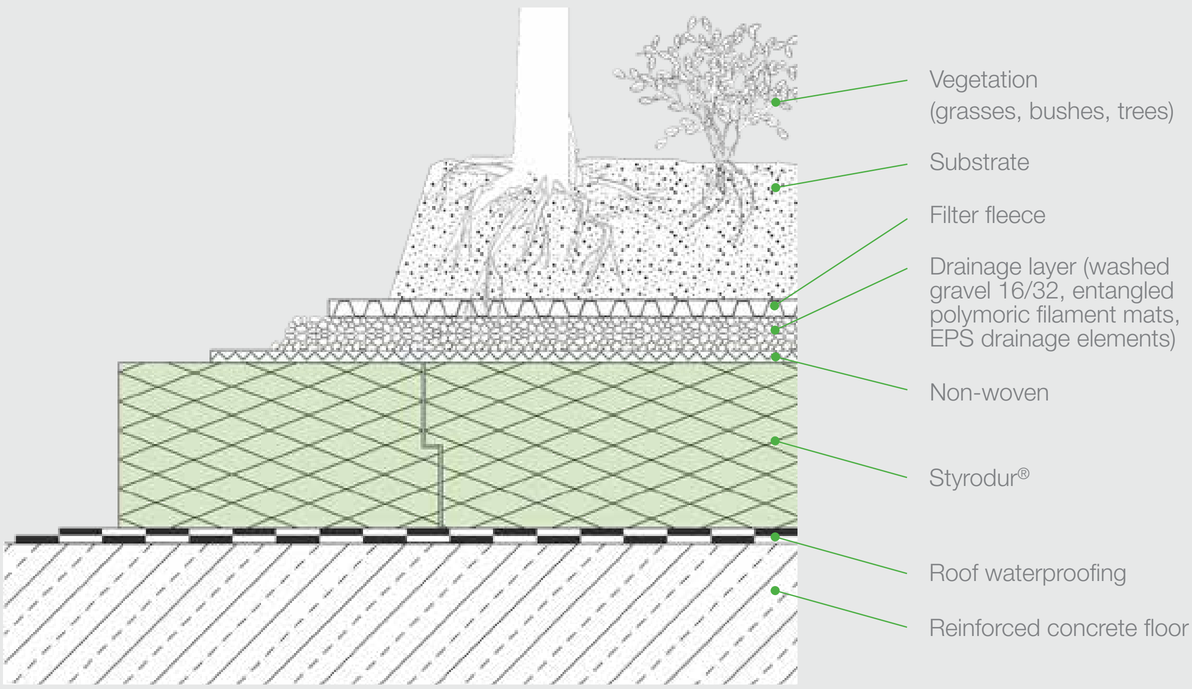


Fig. 28: Profile of an intensive green inverted roof.

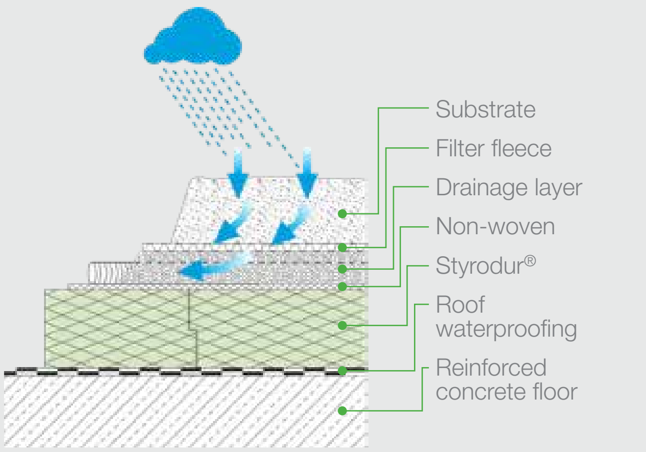


Fig. 29: Structure of a green inverted roof with drainage layer for surface water absorption and alternatively with drainage pipe.

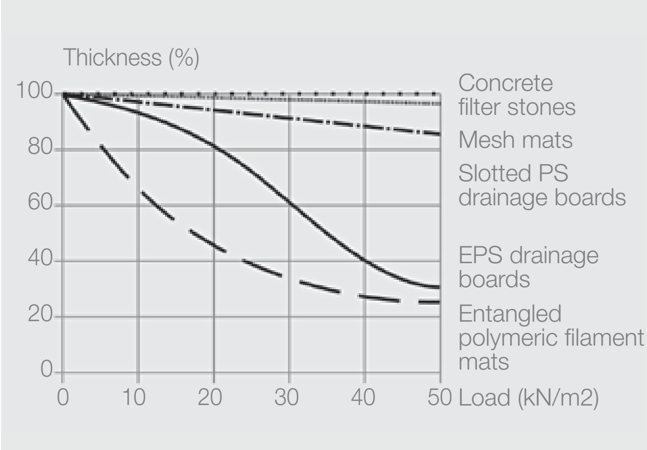


Fig. 30: Creep behaviour of various drainage elements after 50 years. Thickness change as a function of the load.

Functions of the seepage layer in inverted roofs

The drainage layer absorbs excess water that cannot be retained by the vegetation layer and leads it along the roof incline to a drainage pipe or roof outlet **(Fig. 29)**.

The seepage layer of inverted roofs must not only drain rainwater but also guarantee the vapour permeability of the insulation material. The water vapour must diffuse through the thermal insulation layer and pass into the seepage layer where it condenses. Under certain climatic conditions, the condensation water in the layers of green roofs can benefit the substrate layer and in turn the plants. If the substrate is saturated and cannot retain any more condensation water, it flows towards the roof outlet or settles on the waterproofing layer. From there it enters the diffusion cycle once again.

The drainage layer must be able to bear the load of the plant substrate on top, the other superstructures, as well as the traffic load, as in the case of walkable green roofs. It should be as light as possible in order to protect the substructure from unnecessary strain. In addition, it must be frost- and rot-proof. The following materials are suitable as seepage layers:

Seepage layer consisting of concrete drainage stones

The use of concrete drainage stones is only appropriate in combination with thicker plant substrate layers. In general, they are not as suitable for green roofs because they can cause structural damages. Constant exposure to water washes the lime out of the concrete drainage stone, which may settle as lime hydrate inside the roof outlets and down pipes. This can lead to sintering and even complete clogging of the outlets.

Drainage layer of loose materials (e.g. gravel, expanded clay or lava)

Particularly in the case of extensive greening with very thin substrate layers, gravel seepage layers are often the only choice to achieve the mandatory load of 100 kg/m². By contrast, for intensive greening with very thick substrate layers, seepage layers of expanded clay or lava are preferred due to their comparatively light weight.

Seepage layers made of foam plastics, such as EPS drainage boards or entangled polymeric filament mats (e.g. made from polypropylene), are especially light. Recycled products, such as foam and plastic shavings mats, are also suitable.

Technically speaking, these seepage layers can also be considered complete drainage layers. The entangled polymeric filament mat has a tight non-woven on both surfaces, which makes it a drainage element in the form of a mat. EPS drainage boards usually do not need a non-woven layer because their foam structure is already filter-stable. Consequently, they already meet the requirements for both seepage and filter layers.

When using plastic drainage elements, it should be noted that the constant load from the vegetation layer as well as the traffic load may cause a reduction or deformation of the material. When employing deformable drainage elements, the assumed thickness of the elements after 50 years must be taken into account to ensure lasting water drainage. For example, at a load of 10 kN/m², only 60–80% of the original outlet cross section is generally to be calculated **(Fig. 30)**. Manufacturers can provide the relevant information for prefabricated drainage elements.

Roof drainage and roof outlets

The drainage layer must cover the entire roof surface up to any adjacent building elements, such as parapets or rising walls. In the case of roof outlets with a cross section of 100 mm or more, partial areas of up to 150 m^2 may be combined as one drainage unit.

If roof outlets are spaced too far apart, excess water might accumulate in the drainage layer. Drainage pipes should be considered in this case. In order to guarantee proper installation, all roof outlets should be placed at least one metre away from rising building elements. For inverted roofs, only roof outlets with at least two drainage levels are permissible. Both the water from above the roof waterproofing and the excess water from the drainage layer must be allowed to flow freely into the roof outlet. The same applies to the rainwater falling on frozen ground.

The number and dimension of required roof outlets is determined in accordance with DIN EN 12056-3 and DIN 1986-100 “Drainage systems on private ground”. Irrespective of the roof size, at least two outlets must be installed. Gravel drainage layers extend directly to the roof outlet **(Fig. 31 and Fig. 32)**. In the substrate layer, a separation barrier of gravel measuring 50 cm in width is laid around the roof outlet and prevents the plants from overgrowing and thereby hindering inspection.

For intensive green roofs with thicker substrate layers, it is necessary to install a roof outlet with an inspection shaft. Inspection shafts made of concrete or plastic components are easily connected to the drainage pipes. They are thus readily accessible for inspection or cleaning **(Fig. 33)**.

When a green roof borders on rising facades, gutters should be installed at the base of the respective facade. Gutters ensure a direct and quick drainage flow of the rainwater accumulating at the facades without additionally flooding the green roof construction. Facade gutters in front of windows and terrace doors additionally dispose of excess water before it can penetrate through the joints **(Fig. 34)**.

Plant substrate

Selecting and combining plants for the plant substrate—also known as the vegetation layer—of green roofs is a very difficult and complex task, which should be left to a specialist such as a garden planner, landscape designer, or roof gardener.

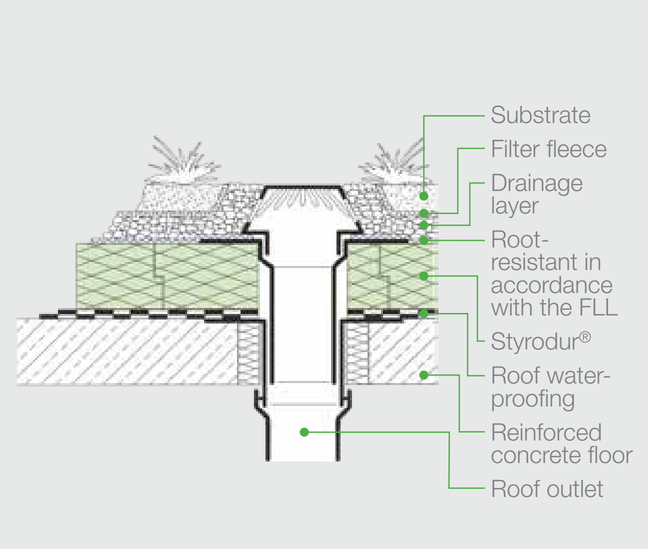


Fig. 32: Roof outlet of an inverted green roof with gravel seepage layer.

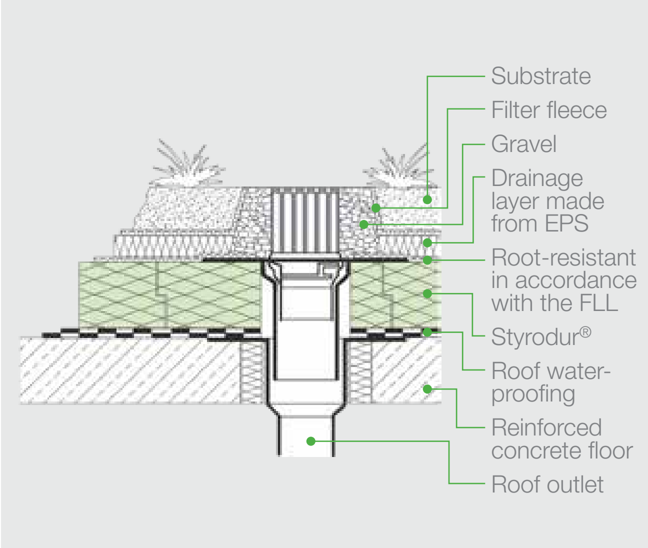


Fig. 31: Roof outlet of an inverted green roof with EPS drainage boards.

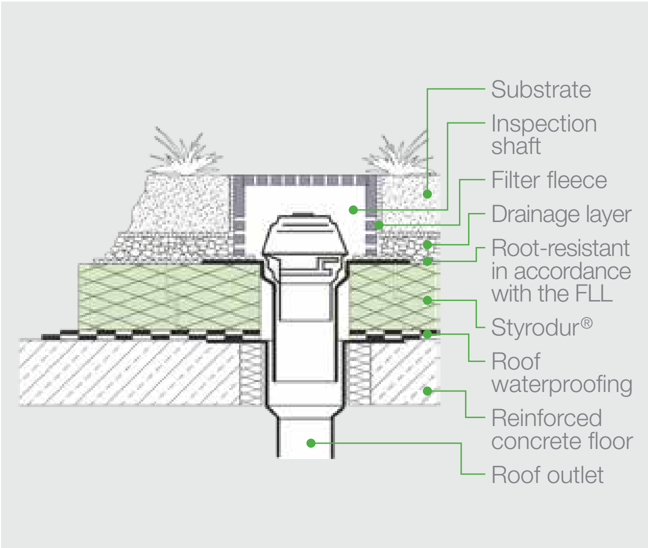


Fig. 33: Roof outlet with inspection shaft on an intensive inverted green roof with expanded clay seepage layer.

The intended purpose as well as the type and form of vegetation must be planned ahead just as thoroughly as the aforementioned structural requirements. Furthermore, consideration must be given to the long-term functionality of the green roof as well as to the cost of its development and maintenance.

As soon as the builder and the planner have settled these basic conditions, they must select the physical, chemical, and biological properties, as well as the vegetation layer's materials and dimensions conducive to the growth of vegetation. The easily root-permeable and solid substrate layer must be able to store enough seeping water and incorporate enough air for all vegetation types.

Protection against wind suction and erosion

In extensive and intensive green roofs, the vegetation assumes the protective function against wind suction. Often, the weight of vegetation alone is not sufficient to protect the vulnerable edges and corners of the roof against wind suction forces. For this purpose, an additional gravel load/concrete slabs or a combination of load and mechanical fixing will be necessary.

Wind loads are determined in DIN 1055-4, DIN EN 1991-1-4, and the "Notes on the determination of loads" from the German Roofing Contractors Association (ZVDH). The required load to secure the boards against wind suction has to be implemented in accordance with the respective technical approvals. Moreover, a separation barrier of gravel along the parapet will provide fire protection and prevent plants from growing over the roof edge. **Table 4** specifies the standard layer thicknesses and distributed loads for the various forms of vegetation (FLL guideline, see note on page 17). These values may differ greatly depending on the project. During the installation and establishment phase, wind can cause the erosion of various green roof layers. This can be prevented by means of stable vegetation layers and a higher load assumption.

In addition, rock gravel can improve the stability of fine-textured vegetation substrates. The easiest way to reduce the erosion risk is to use plants and vegetation with fast coverage and that are suitable for green roofs. Particularly in areas "severely exposed to wind", hydroseeding and pre-cultivated vegetation mats can further lower the risk of erosion.

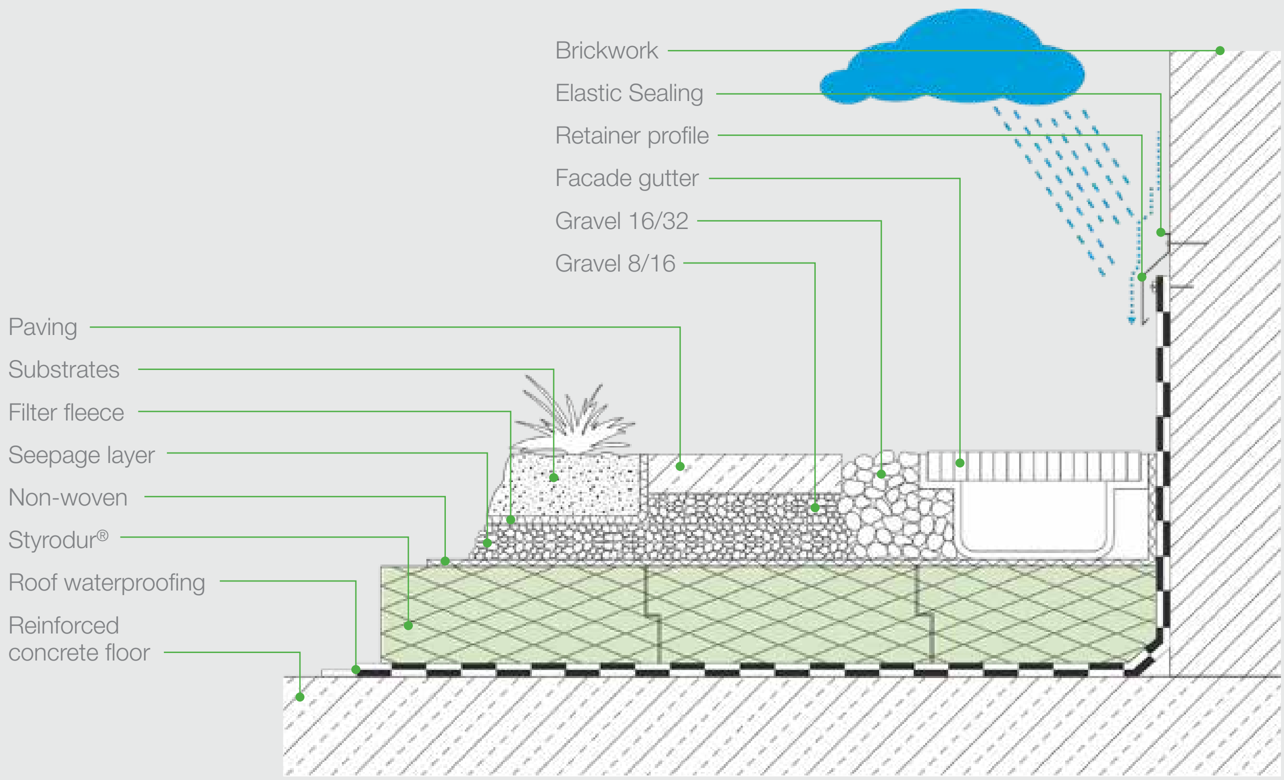


Fig. 34: Inverted green roof connection to a rising wall with facade gutter.

Table 4: Standard layer thicknesses and distributed loads for various types of vegetation

Vegetation types	Thickness of vegetation layer in cm	Total thickness of green roof construction in cm		Load assumption	
		With 2 cm drainage mat	With 4 cm loose material*	kg/m²	kN/m²
Extensive greening, low maintenance, no additional irrigation					
Moss sedum greening	2–5	4–7	6–9	10	0.10
Sedum moss herb greening	5–8	7–10	9–12	10	0.10
Sedum grass herb greening	8–12	10–14	12–16	10	0.10
Grass herb greening (dry lawn)	≥ 15	≥ 17	≥ 19	10	0.10
Simple extensive greening, medium maintenance, periodic irrigation					
Grass herb greening (grass roof, poor grassland)	≥ 8	≥ 10	≥ 12	15	0.15
Wild shrubs grove greening	≥ 8	≥ 10	≥ 12	10	0.10
Grove shrubs greening	≥ 10	≥ 12	≥ 14	15	0.15
Grove greening	≥ 15	≥ 17	≥ 19	20	0.20
Extensive intensive greening, high maintenance, regular irrigation		**Thickness of drainage layer in cm**	**Total thickness of structure in cm**		
Lawn	≥ 8	≥ 2	≥ 10	5	0.05
Low shrubs grove greening	≥ 8	≥ 2	≥ 10	10	0.10
Medium shrubs grove greening	≥ 15	≥ 10	≥ 25	20	0.20
Tall shrubs grove greening	≥ 25	≥ 10	≥ 35	30	0.30
Bush greening	≥ 35	≥ 15	≥ 50	40	0.40
Tree greening	≥ 65	≥ 35	≥ 100	≥ 60	≥ 0.60

* With a 2–3% roof incline; above 3%, the layer thickness can be reduced to 3 cm.

Fire protection

The IS-ARGEBAU (German Conference of the Ministers of Building) has passed fire protection requirements for green roofs as an amendment to pre-existing regional building regulations. Accordingly, intensive green roofs are classified as "hard roofing".

Extensive green roofs are considered sufficiently resistant if the mineral vegetation layer has a minimum thickness of 3 cm, the type of vegetation only constitutes a low fire load, and the plants are at least 50 cm away from all roof penetrations and rising building elements. The spacer strips must consist of either solid concrete slabs or 16/32 mm coarse gravel **(Fig. 35)**.

Fig. 35: Gravel strip along the roof edge and roof penetrations.

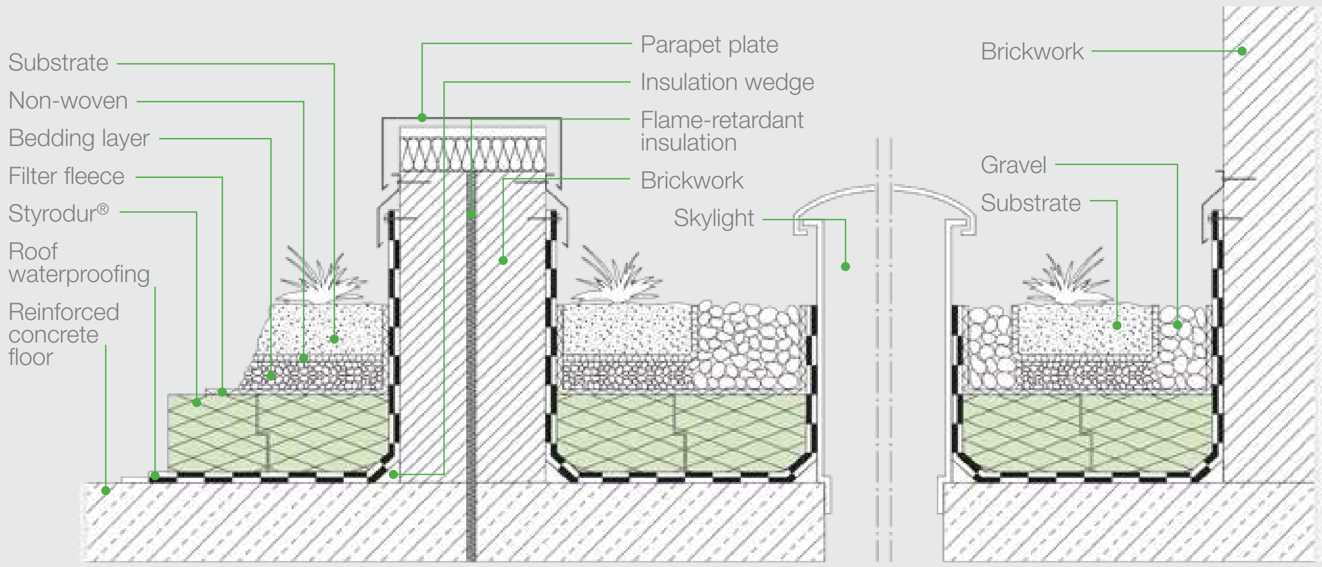


Fig. 36: Fire section of a flat roof with extensive greening.

In all buildings — including terraced houses — the building's outer walls, firewalls, or those walls approved to substitute firewalls must be no more than 40 m apart from each other and positioned at least 30 cm above the top edge of the substrate **(Fig. 36)**.

5.7 Patio Roof

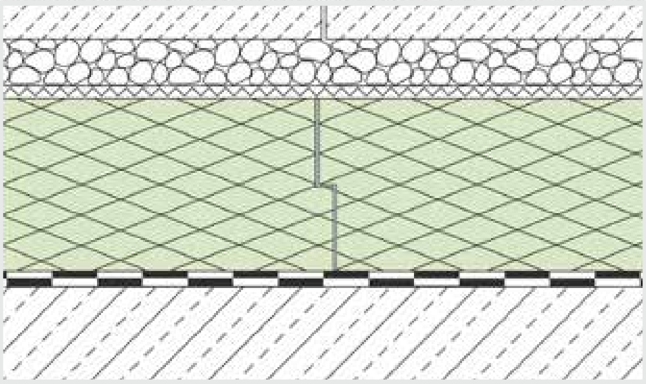


Fig. 37: Patio roof configuration.

According to DIN 4108-2, waterproofing and thermal insulation of patio roofs are installed in the same way as on gravelled or green inverted roofs. The top layer can be a stable, walkable pavement made of washed concrete slabs, prefabricated ceramic slabs, paving stones, or grid constructions, laid either on gravel or pavement slab supports. This constitutes a vapour-permeable release layer between the thermal insulation and the pavement, which guarantees the unproblematic diffusion of water vapour through the insulation material.

Should the pavement be laid on a gravel bed, the Styrodur® insulation boards have to be protected with a trickle protection non-woven so as to prevent gravel/chippings from slipping between the joints or underneath the boards. The geotextile is made of either polypropylene or polyester fibre. Most suitable for inverted roofs are vapour-permeable and filter-stable fleece materials with an area-related mass of approx. 140 g/m².

PE films are not vapour permeable and therefore not suitable. The geotextile is topped with approx. 3 cm of frost-resistant grit or fine gravel (3–8 mm), above which the pavement is then laid **(Fig. 37 and Fig. 38)**.

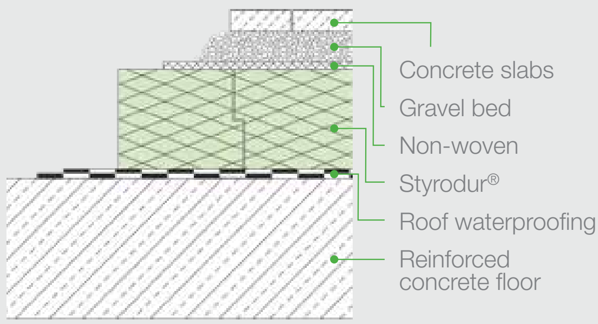


Fig. 38: Profile of an inverted patio roof with concrete slabs on a gravel bed.

5.8 Parking Roof

The roofs of public buildings, department stores, and warehouses, as well as traversable cellar ceilings, are increasingly used as parking decks. To minimise the heat loss from the heated areas below, these parking roofs are insulated with Styrodur® following the principle of inverted roof constructions **(Fig. 39)**. In accordance with the respective technical approval (download area of www.styrodur.com), the following configurations are possible:

- Prefabricated concrete slabs on supports
- Composite stone pavement laid on gravel
- In-situ concrete slabs on an incline

Thanks to their high compressive strength, Styrodur boards 4000 CS and 5000 CS can handle the strain of parking and moving cars if the following building guidelines are applied.

Fig. 40, left, shows the structure of a conventional parking roof with thermal insulation. In this design, the roof membrane near the concrete slab joints is particularly at risk due to the dynamic load of the moving wheels. In the case of an inverted roof construction **(Fig. 40, right),** the waterproofing layer is protected from such dynamic loads by the insulation layer.

A second possible configuration involves the use of pavement slab supports **(Fig. 41)** made of aging- and weather-resistant plastic. The pavement slab supports are located at the intersection of the slab joints. Spacers ensure a consistent joint design. Water is conveyed on the insulation material underneath the paving.

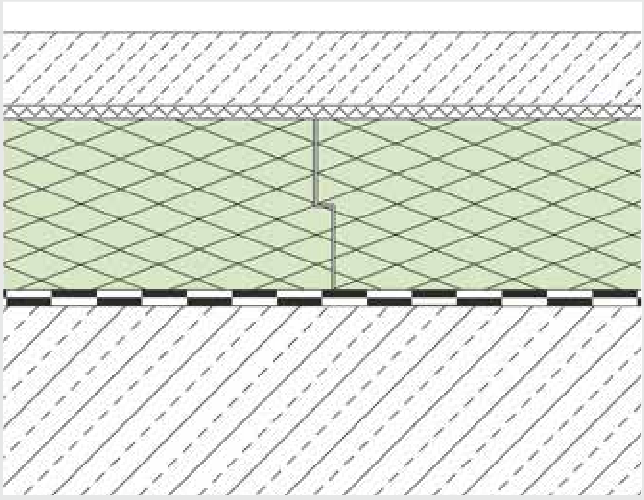
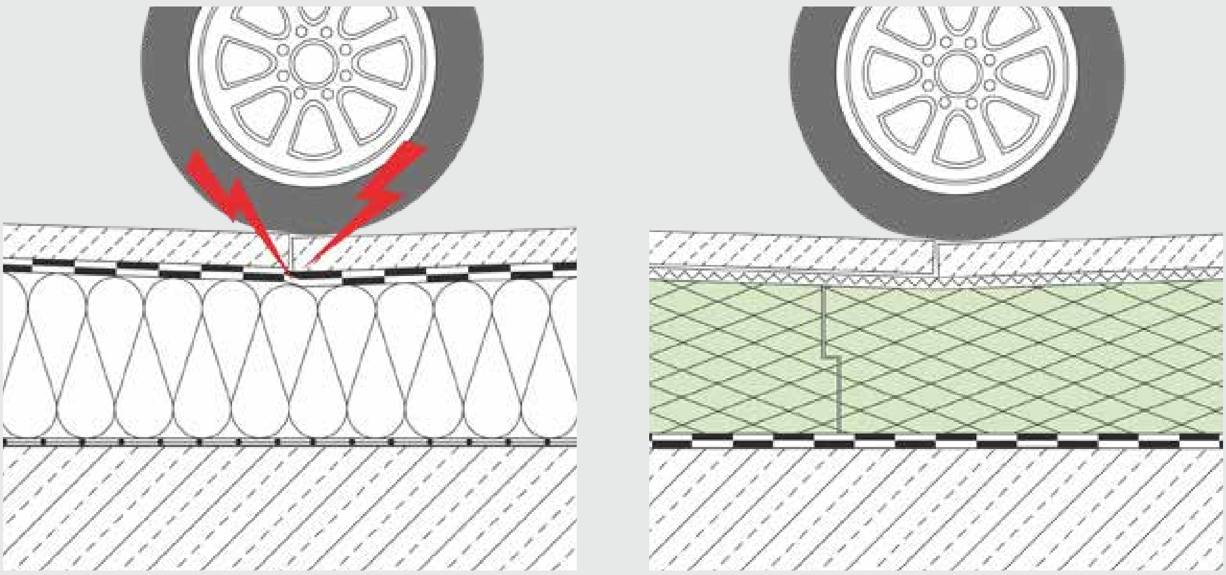


Fig. 39: Parking roof configuration.

The surface water flowing through the open joints leads to some self-cleaning between the thermal insulation boards and the pavement. Nevertheless, at least once a year, a few of the pavement slabs should be lifted and the spaces between them should be cleared of any accumulated dirt with a pressure hose.



The sealing barrier of conventional non-insulated roofs is under particular stress at the joints of the driving surface.

By contrast, the insulation layer on top protects the waterproofing of inverted roofs.

Fig. 40: Parking roof as a conventional non-insulated roof and as an inverted roof. While the waterproofing layer of the non-insulated roof is at risk, it lies safely protected in the inverted roof design.

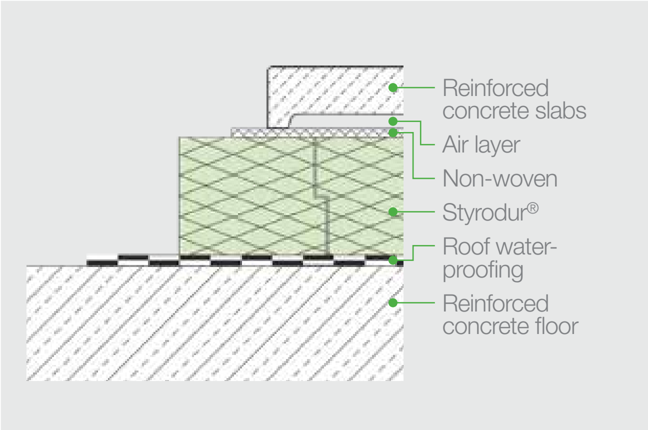


Fig. 41: Parking roof with large-size reinforced concrete slabs on pavement slab supports.

Fig. 42: Parking roof with concrete slabs laid on an inverted roof with Styrodur®.

Configuration 1a: Large-size concrete slabs on pavement slab supports

Reinforced precast concrete slabs (1.500 x 2.000 x 80 mm) are laid on top of the Styrodur® boards, which are covered with vapour-permeable polymer fleece. However, the boards are approx. 100 mm thick around the edges. This leads to an air space of 20 mm between the concrete slabs and the thermal insulation boards, which enables the atmospheric moisture to diffuse **(Fig. 41)**. In order to keep the reinforced concrete slabs from shifting under the traffic load, the edges should be fitted with rubber buffers that distribute the horizontal forces between the slabs.

As the weight of parking cars is only transmitted onto the insulation boards via the edges of the concrete slabs (point load), it is necessary to use Styrodur 5000 CS boards with high compressive strength. Since levelling is not possible when installing such large-size slabs, it is crucial that the planner and builder ensure that the reinforced concrete floor—including sealing barrier—does not show any warping and the insulation boards are laid on a fully even surface. Any unevenness can be levelled out using suitable measures.

Configuration 1b: Small-size concrete slabs on pavement slab supports

The pavement of a parking roof can also be constructed with small-size concrete slabs (600 x 600 x 80 mm) laid on pavement slab supports in order to guarantee adequate structural-physical air spaces between the top surface of the insulation material and the driving surface **(Fig. 42)**. The slab supports can be made of special plastic discs or rubber granulate plates, for example.

With the plastic disks or rubber granulate adjusted to the covering, the height of the driving surface slabs can be changed during construction as well as during operation. As with configuration 1, joint spacers or rubber buffers around the edges prevent the concrete slabs from shifting.

The prefabricated concrete slabs, which are produced following strict production guidelines, are resistant to weather and de-icing salt. High-quality concrete and system solutions with certified and field-tested cone-like spreading elements guarantee a horizontally braced driving surface that is weather-resistant and can be installed in a very short time **(Fig. 43)**.

Fig. 43: Parking roof with concrete slabs laid on an inverted roof with Styrodur®.

Configuration 2: Parking roof with composite stone pavement

Apart from the vapour-permeable polymer fleece, this structure is identical to the aforementioned configurations. Frost-resistant, graded gravel (grain size 2/5 mm) is recommended for the bedding layer of composite stone pavement. After compaction, the bedding layer should have a thickness of approx. 5 cm. The required incline of > 2.5% should be pre-determined by the reinforced concrete floor.

All additional layers are equal in thickness, running parallel to the reinforced concrete floor.

Suitable pavement types include pre-cast concrete blocks, bricks, or natural stones. A composite stone pavement should preferably have a thickness of at least 10 cm **(Fig. 44)**. The shape of the composite pavement stones is of particular importance for the stability of the driving surface. The stones should be interlocking at the edges in order to avoid possible opening of the staggered joints parallel to the centreline and pitch axis of the composite pavement **(Fig. 46)**. The joints between the stones should be filled with jointing sand (grain size 0/2 mm). The paving blocks should be resanded up to final consolidation. Natural stone crusher dust has proved favourable for this purpose.

Fig. 46: Stone shapes for stable pavement.

Only Styrodur® 5000 CS is suitable for parking roofs with composite stone pavement, as only these insulation boards provide the sufficient compressive strength for the expected traffic loads and the necessary stiffness to avoid excessive sagging. Larger elastic deformations would cause vertical movements of the driving surface and thus compromise the stability of the structure as a whole.

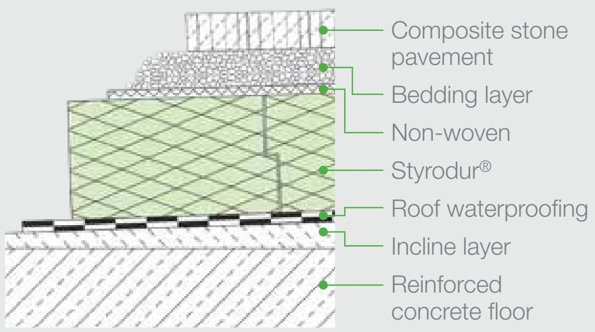


Fig. 44: Parking roof design with composite stone pavement on a bedding layer.

Fig. 47: Concrete pavement on Styrodur® boards.

Fig. 45: Composite stone pavement with grass joints for a parking roof on top of a gymnasium.

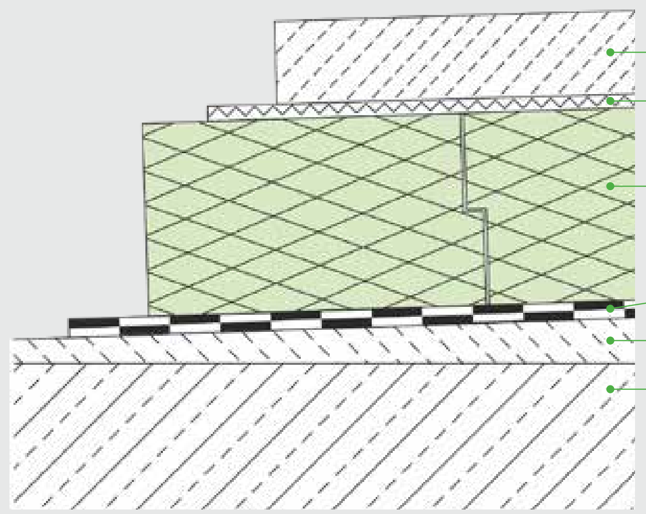


Fig. 48: Basic outline of a parking roof with in-situ concrete driving surface on an inverted roof construction with Styrodur®.

Configuration 3: Parking roof with in-situ concrete driving surface

The construction of parking roofs with in-situ concrete driving surfaces on inverted roofs is recommended for highly frequented parking areas. This construction requires thorough planning and execution.

The basic structure of a parking roof with in-situ concrete driving surface is illustrated in **Fig. 48 and Fig. 49**. A separation layer and the in-situ concrete driving surface are installed on top of the load-bearing ceiling structure, the roof waterproofing, and the thermal insulation layer of Styrodur®.

This configuration is described in approval Z-23.4-222 as a design for frequented inverted roof constructions.

The planner and the builder must work with a high degree of precision so as to ensure that rainwater is always completely drained over the in-situ concrete driving surface.

Moreover, there are some basic guidelines pertaining to construction and design that have to be followed in order to guarantee the long-term, reliable operation of parking roofs with in-situ concrete. However, this information does not guarantee completeness or general validity. It is therefore vital that each case be treated individually by a specialised engineer.

Fig. 49: Parking roof with in-situ concrete driving surface.

Fig. 50: In-situ concrete driving surface slab, cut open for the scientific examination of its long-term behaviour.

Roof construction:

- The incline of the load-bearing reinforced concrete floor must be at least 2%.
- The roof waterproofing must be laid in direct contact with the reinforced concrete floor so that, in the event of a leak, no rainwater may seep below the sealing barrier. This makes it easier to locate any damage below the driving surface.
- The slope of the roof waterproofing and the in-situ concrete driving surface must be at least 2% and parallel to each other.

Roof drainage:

- Roof drainage outlets have to be installed at the lowest points (taking into account sagging roof areas).
- Roof outlets with two drainage levels must be installed so that, even in the case of damage, both the driving surface and the sealing layer can be drained without a backflow of water.
- The outlets must be inspected and cleaned on a regular basis.
- The concrete or cement mixture must be composed of appropriate ingredients in order to keep the drainage system from sintering as a consequence of lime hydrate flushing out of the weathered in-situ concrete driving surface.

In-situ concrete driving surface:

- The in-situ concrete driving surface must have a minimum thickness of 12 cm.
- The quality and processing of the concrete must ensure resistance to long-term frost, weathering, and wear damages. Concrete with high resistance to water penetration is specified in accordance with DIN EN 206-1 and DIN 1045-2.
- The concrete surface must be abrasion-resistant and slip-proof for driving.
- If necessary, the in-situ concrete slabs are to be anchored according to the planner's specifications for the bearing structure. The measurement of plate reinforcement must be calculated according to the elastic bedding theory.

Joint formation:

- The joints between the in-situ concrete slabs have to be protected against water penetration.
- The spaces between the joints should be between 2.5 and 5 m.
- The planning and implementation of permanent elastic and sealed joints (with joint backfill) is to be executed by specialists and with suitable products.

The durability of parking roofs with in-situ concrete pavement largely depends on the choice, installation, and quality of the joint waterproofing.

6. Information and General Technical Guidelines

- Styrodur® should not be exposed to solar radiation for extended periods, particularly during summer months.
- If Styrodur is used under covers such as roofing sheets, films, or building protection mats, excessive heating could possibly occur during summer temperatures due to the absorption of sunlight, which might cause deformation of the Styrodur boards. It is therefore essential to immediately apply the appropriate protective layer in accordance with the flat roof guidelines.
- Styrodur insulation boards must be permanently protected against UV radiation.
- Styrodur is not resistant to all substances (see "Chemical Resistance" brochure in the download area of www.styrodur.com). The instructions of the adhesive manufacturer must be observed when selecting the adhesive.
- Values for the applicable constant compressive stresses at 2% deformation should be taken from the Technical Data brochure (application recommendations, dimensioning aids).

7. Application Recommendations for Styrodur®

	Application type according to DIN 4108-10 or general construction type approval (CTA)/ETA	General	Product properties according to DIN EN 13164 and DIN 4108-10					
			2800 C/Q	3000 CS/SQ	3035 CS	4000 CS/SQ	5000 CS/SQ	Hybrid
			CS(10\Y)	CS(10\Y)	CS(10\Y)	CS(10\Y)	CS(10\Y)	
			200 *(20–60 mm)* 300 *(80–200 mm)*	300	300	500	700	300
Perimeter[1] floor	*PB*	*wd*		dh	dh	ds	dx	
Perimeter[1] wall	*PW*	*wd*		dh	dh	ds	dx	dh
Perimeter[1] foundation slab	*See CTA*	*wd*		dh	dh	ds	dx	
Perimeter[1] groundwater	*See CTA*	*wd*		dh	dh	ds	dx	dh
Living area floor	*DEO*		dm	dh	dh			
Industrial and refrigerated warehouse floor	*DEO*		dm	dh	dh	ds	dx	
Cavity insulation	*WZ*	*tf*	dm	dh	dh			
Interior insulation	*WI*	*tf*	dm					
Permanent formwork	*WAP*	*tf*	dm					dh
Thermal bridges	*WAS*	*tf*	dm	dm	dm			
Base insulation	*WAS*	*wf*	dm	dm	dm			
Plaster base	*WAP*	*wf*	dm					
Inverted roof	*DUK*	*wd*		dh	dh	ds	dx	
Duo and plus roof	*DUK*	*wd*		dh	dh	ds	dx	
Patio roof	*DUK*	*wd*		dh	dh	ds	dx	
Green roof	*See CTA*	*wd*		dh	dh	ds	dx	
Parking roof	*See CTA*	*wd*				ds[2]	dx	
Conventional flat roof[3]	*DAA*	*wf*		dh	dh	ds	dx	
Parapets/rising building elements	*DAA*	*wf*	dm	dh	dh			
Basement ceiling/ underground garage ceiling	*DI*	*tf*	dm	dh				
Attic floor	*DEO*	*tf*	dm	dh	dh			
Pitched roof	*DAD*	*wf*	dm	dh				

[1] Insulation with ground contact
[2] Not under composite stone pavement
[3] With protective layer over sealing barrier

dm = 200 kPa, dh = 300 kPa, ds = 500 kPa, dx = 700 kPa

BASF
We create chemistry

Safe. Strong.
Styrodur®

Styrodur® – A Strong Product Line

With the Styrodur® product line, BASF offers the ideal insulation solution for almost every application.

Styrodur® 2800 C/Q
The thermal insulation board with an embossed honeycomb pattern on both sides and smooth edges for applications in combination with concrete, plaster, and other top coats.

Styrodur® 3000 CS/SQ
The innovative multipurpose thermal insulation board with smooth surfaces and shiplap for almost all applications in structural and civil engineering and with uniform thermal conductivity across all board thicknesses.

Styrodur® 4000/5000 CS/SQ
The extremely compression-proof thermal insulation board with smooth surfaces and shiplap for applications that require maximum compressive strength.

Styrodur® 3000 BMB
The multipurpose thermal insulation board produced using renewable instead of fossil raw materials with the same technical properties as conventional Styrodur CS/SQ, which helps to save resources and reduce CO_2 emissions.

Styrodur® Hybrid
The thermal insulation board with longitudinal grooves on one side and a shiplap for use as perimeter insulation for concrete pouring with waterproof concrete exterior basement walls.

Up-to-date technical information is available on our website: **www.styrodur.com**

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E-CPB/FM 2401 BE Styrodur® Flat Roof Insulation

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The information submitted in this publication is based on our current knowledge and experience and refers only to our product and its properties at the time of going to print. It does not imply any warranty or any legally binding assurance about the condition of our product. Attention must be paid to the requirements of specific applications, especially the physical and technological aspects of construction and building regulations. All mechanical drawings are basic outlines and have to be adapted to each application.

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