Flat Roof Insulation
Inverted Roof
# Table of Contents

1. **Long-standing Trust in Styrodur®** 3
2. **The Flat Roof** 4
   2.1 Types of Flat Roofs and Definitions 5
3. **Advantages of the Inverted Roof System** 7
   3.1 Advantages of Styrodur® in Inverted Roofs 8
4. **Application Notes** 10
   4.1 Substructure 10
   4.2 Roof Waterproofing 10
   4.3 Roof Drainage 10
   4.4 Thermal Insulation Layer 11
   4.5 Protective Layer 11
   4.6 Protection Against Floating 12
   4.7 Protection Against Wind Suction 12
5. **Configurations** 13
   5.1 Gravelled Inverted Roof—Single-layer 13
   5.2 Gravelled Inverted Roof—Single- or Double-layer with Water-draining, Vapour-permeable Separation Layer 13
   5.3 Duo Roof 14
   5.4 Plus Roof 15
   5.5 Green Roof 16
   5.6 Patio Roof 24
   5.7 Parking Roof 25
6. **General Technical Guidelines** 30
7. **Application Recommendations for Styrodur®** 31
1. Long-standing Trust in Styrodur®

With Styrodur®, BASF can draw on over 50 years 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 CO₂ production process with air as cell gas
- Reduction of carbon dioxide (CO₂) emissions thanks to excellent insulation performance

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 and Ü-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 suitable saws or hot-wire cutting equipment
- Can be installed in all weather conditions
- No dust hazardous to health during mechanical processing
- Extensive product range
- Most diverse 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 life span of the building and raises the value of the structure
2. The Flat Roof

Although the style and materials chosen for covering and waterproofing 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 for inclined roofs as well as slightly sloped roofs with varying inclinations, or even zero-degree roofs, meet the current standards and regulations for thermal insulation and provide long-term, reliable protection against the effects of the weather. How “secure” a roof is does not depend on how steep the water-bearing layer incline is, rather on how well the planner and builder are informed of the specifics of the construction in question and how well they implement the requirements in the design and execution.

Inverted roofs with Styrodur®

In contrast with 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 of inverted roofs is subject to high compressive stress caused by rainwater, soil used for green roofs, and the traffic load on patio and parking roofs. Therefore, it must exhibit a high resistance 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 soil. Good, durable thermal insulation properties are also important to ensure its proper function in inverted roofs (Fig. 1).

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 is formed on the surface of the board, thus preventing 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.de) lists the main distinguishing features and the available shapes of Styrodur® types suitable for inverted roof constructions, the most important being 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.de).

If the roof is designed as a green roof, parking roof, or a water-draining and vapour-permeable separation layer covered with gravel, then DIBt approval Z-23.4-222 must be observed. 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 (German Institute for Building Technology).
2.1 Types of Flat Roofs and Definitions

Depending on the intended use, DIN 18531-1 classifies roof waterproofing in categories K1 (standard version) and K2 (high-end versions).

- **K1—standard version**
  Roof waterproofing satisfying the common requirements and roofs that are designed with a waterproofing layer incline of at least 2%.

- **K2—high-end versions**
  Roof waterproofing that needs to meet more stringent requirements, such as more intensive use of the building, high-rise buildings, or roofs with difficult access. In this case, the waterproofing layer must have an incline of at least 2% and at least 1% in channels.

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” and “utilised roof surfaces”, depending on their type of use.

Underutilised roof surfaces are only accessed for servicing and general maintenance purposes. DIN 18531-1 “Waterproofing of roofs” applies to the design of underutilised roof surfaces.

Utilised roof surfaces are intended to be accessed by persons, crossed by traffic, or to provide surfaces for extensive and intensive green roofs.

The flat roof guidelines differentiate accordingly between:
- **Patio roofs**
- **Utilised roof surfaces (parking roofs)**
- **Green roofs**

The design of utilised roof surfaces is executed in accordance with DIN 18195-5 “Waterproofing of buildings”. 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® boards suitable for inverted roofs meet the applicable requirements.

Application requirements for thermal insulation are specified in DIN V 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 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.
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 layer consists 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 gravel 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 ∆U for inverted roofs**
  In calculating the thermal transmission coefficient (U-value) of inverted roofs, the calculated U-value is increased by the value ∆U. According to DIN 4108-2, this value is a function of the percentage of the thermal resistance below the waterproofing layer of the total thermal resistance as given in Table 1. For substructures with an area-related mass of less than 250 kg/m², the thermal resistance below the waterproofing layer must be at least 0.15 m² K/W.

<table>
<thead>
<tr>
<th>Room-side thermal resistance of waterproofing as a percentage of total thermal resistance in %</th>
<th>Added value ∆U W/(m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>under 10</td>
<td>0.05</td>
</tr>
<tr>
<td>from 10 to 50</td>
<td>0.03</td>
</tr>
<tr>
<td>over 50</td>
<td>0</td>
</tr>
</tbody>
</table>

According to approval Z-23.4-222, the added value ∆U is not required for inverted roof designs with a water-draining and vapour-permeable separation layer covered with gravel, above single or double Styrodur® boards.

- **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 two-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 energetic 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 life span, an inverted roof with XPS is installed on top of a non-insulated roof construction 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.

In accordance with the above-mentioned national technical approval, the double-layer inverted roof is only intended for use in connection with gravel inverted roofs.

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Fig. 3: Inverted roof insulation with Styrodur® for 250 housing units in Hamburg.
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)
- Geotextile (polyester or polypropylene non-woven), for single-layer insulation, added value ∆U must be observed
- Alternatively, water-draining and vapour-permeable separation layer, in accordance with DIBt approval Z-23.4-222, added value ∆U not required
- One or two layers of Styrodur®
- 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 that require laying and gluing.

In the case of inverted roofs, the most important layer—roof waterproofing—lies on a solid, massive, 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 between the individual insulation boards may form and the waterproofing layer could “sag” into these joints, which in turn can lead to cracks.

If the roof waterproofing layer is glued over the expanse of the concrete ceiling, leaks can be easily located in the event of damage. Water appears on the inner side directly at the location where the roof waterproofing is damaged. This is not the case with conventional non-insulated roofs: if water trickles through the waterproofing, 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, which is often difficult to achieve in practice. When constructing a non-insulated roof, thermal insulation materials on site must be protected from moisture, and installed insulation boards must be covered.

As a rule, insulation boards may 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 be installed even during 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 of both bituminous and plastic waterproofing layers.

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.
Advantages of the Inverted Roof System

Figures 4 and 5 show the daily thermal load for the waterproofing of a conventional non-insulated roof with and without gravel compared to 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 the thermal insulation layer, as is the case with inverted roofs. Thermal shocks, e.g. caused by hail storms in summer, do not damage the waterproofing of inverted roofs.

The waterproofing of conventional non-insulated roofs is permanently exposed to mechanical strain. 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 waterproofing layers 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. 5).

Fig. 6: Samples taken from a ten-year-old green inverted roof.
Resistance to water
Water absorption of the boards is exceptionally low due to the closed-cell foam structure (Fig. 7) and the foam skin 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 practically no effect on the thermal insulation properties of the material.

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

High strength
The strength properties of Styrodur® make it the ideal insulation material for inverted roofs. The Styrodur® 4000 CS and Styrodur® 5000 CS pressure-resistant 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 loads and temperatures defined in DIN EN 13164.

Fire protection classification
Styrodur® boards are classified as Euroclass E (normally flammable) in accordance with DIN EN 13501-1 “Fire classification of construction products and building elements” and as B1 (flame-retardant) in accordance with DIN 4102-1 “Fire behaviour of building materials and building components”.

Thermal bridges
No significant 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 basically 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 structure; and
- 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 $R \geq 0.15 \text{ m}^2\cdot\text{k}/\text{W}$ under the waterproofing.

- The high area-related mass and the prescribed minimum thermal resistance of the substructure are to prevent the underside of the ceiling from cooling to the point of condensation formation, for instance 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.

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%:

- Bitumen roof membranes
- Polymer-modified bitumen membranes
- Plastic membranes
- High-polymer membranes

Inverted roofs with an incline of less than 2% are considered special constructions under the flat roof guideline and require special precautions to reduce risks associated with stagnant water. That is why in the case of bituminous waterproofing under a top layer of polymer-bitumen membranes, either a further polymer-bitumen membrane or two layers of bitumen membranes are to be used. 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.

Caution:
Tar-based or solvent-based waterproofing is not suitable for inverted roofs with Styrodur®.

4.3 Roof Drainage

The drainage system of inverted roofs (see DIN EN 752, DIN EN 12056, and DIN 1986-10) is to be designed such that long-term flooding of the Styrodur® boards is prevented. Short-term flooding during severe rain is harmless.

Roof outlets

As the inverted roof system requires the roof membrane to be installed under the insulation layer, water drainage must occur both from 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.

![Fig. 8: Roof outlet with two drainage levels for draining the roof above and below the insulation layer.](image)

Table 2: Diameter of the roof outlets depending on the type of application and surface of the flat roof.

<table>
<thead>
<tr>
<th>Pipe diameter (ID in mm)</th>
<th>Roof area in m² for roof types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flat roof &lt; 15°</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>100</td>
<td>187</td>
</tr>
<tr>
<td>125</td>
<td>337</td>
</tr>
</tbody>
</table>
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. Depending on the application, the number of roof outlets required per m² for inverted roofs is specified in Table 2.

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 waterproofing, 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 national technical approval Z-23.4-222 by the German Institute for Building Technology (DIBt).

As described in section 5.2, gravelled inverted roofs with Styrodur® boards can now 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.

- 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.de).

In special cases, the Styrodur® boards can be spot-glued to the waterproofing layer. With bituminous waterproofing, for example, this method can be used with blown bitumen B85/25 or cold bitumen adhesive.

The Styrodur® insulation layer is suitable for foot and vehicle traffic. For transport over the insulated surface, use wheelbarrows with pneumatic tires.

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. It can also be a functional layer such as 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 boards 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 3).

<table>
<thead>
<tr>
<th>Thickness of insulation layer</th>
<th>Gravel layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>single-layer</td>
<td>without non-woven</td>
</tr>
<tr>
<td>30–50 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>60–200 mm</td>
<td>equal to insulation layer thickness</td>
</tr>
<tr>
<td>double-layer</td>
<td>water-draining, vapour-permeable separation layer</td>
</tr>
<tr>
<td>220–400 mm</td>
<td>50 mm</td>
</tr>
</tbody>
</table>

4.7 Protection Against Wind Suction

Protection of the Styrodur® boards against wind suction is to be implemented in accordance with DIN 1055-4 or DIBt approval Z-23.4-222. The required load can be provided by a layer of gravel with a grain diameter of 16/32 mm and a bulk density of ≥ 1,600 kg/m³, or by using concrete slabs with a 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 structures such as walls; hipped roofs are subdivided into groups F to N) according to the wind load standard DIN 1055-4. 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 hillside with extreme wind movements or with high buildings in the vicinity, may require significantly higher loads.

Appendix 1 to DIBt approval Z-23.4-222 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 and or concrete slabs against wind suction (see download area of www.styrodur.de).

- 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 dependent on 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

Depending on the requirements, Styrodur® 3000 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 polymer fleece 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 synthetic fleece, 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 a 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 have a chance to evaporate at all times. It usually does so through the grooves of the Styrodur® board joints and by directly diffusing through the insulation material. This 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 equipped with pavement flags.

**Note:** According to approval Z-23.4-222, the added value $\Delta U$ 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

The structure of single- and double-layer gravelled inverted roofs with water-draining, vapour-permeable separation layer is also defined in the technical approval Z-23.4-222. The following XPS insulation materials from BASF are approved for installation:

- Styrodur® 3035 CS min. 40 mm, max. 200 mm
- Styrodur® 4000 CS min. 40 mm, max. 160 mm
- Styrodur® 5000 CS min. 40 mm, max. 120 mm

As a result of the water-draining and vapour-permeable separation layer (Isover AquaDefense UKD, Bachl LiquiStopp LS) being laid above the insulation layers, the majority of rainwater is safely conveyed to the surface and largely prevents the formation of a permanent water film between the board layers (Fig. 11). There is thus no risk 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 economic 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 German Energy Saving Ordinance (EnEV) from 2014 as well as future requirements can be met thanks to the double-layer insulation with Styrodur®. The energy-efficient renovation of single-layer inverted roofs up to the passive house standard is even possible.
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 waterproofing on a standard, non-insulated roof structure with Styrodur®.

Condensation protection in accordance with DIN 4108-3 should be documented in each case if less than one third 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 is also often not 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.

**Fig. 12:** Duo roof configuration with gravel.

**Fig. 13:** Installation of Styrodur® for a duo roof.

**Fig. 14:** Parapet insulation with Styrodur®.

**Fig. 15:** Installation of Styrodur® on top of the roof waterproofing.
The plus roof design is the perfect choice to reconstruct existing, insufficiently insulated non-insulated roofs in order to meet today’s thermal insulation standards (Fig. 16, left). The plus roof can be executed 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 roof with gravel 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.
- The existing roof waterproofing is to be examined for leaks and repaired, if necessary. 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.
- Furthermore, connections to rising building elements must be positioned at a minimum of 15 cm above the top edge of the gravel layer or the finished plus roof. This requirement is reduced to a minimum of 10 cm for roof gutters. When appropriate, connections should be raised (Fig. 18).
- 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.

The temporarily stored gravel can be distributed on the insulation layer in sections (Fig. 17) until the energetic 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 Green Roof

Extensive or intensive green roofs with water features, paths, and plazas 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 national technical approval Z-23.4-222 have to be complied with (download area of www.styrodur.de).

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

- The thermal insulation protects the root-resistant waterproofing from thermal stresses (Fig. 20).

- 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. 21).

- During the construction period of inverted green roofs, there is a clear separation between the trades. The roofer takes care of waterproofing 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.

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**Fig. 19:** Green roof configuration.

**Fig. 20:** Temperature profile of an inverted green roof.

**Fig. 21:** Green roof loads.
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 variation 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 4) and the possible weight gain of the plants. The Styrodur® 3035 CS, 4000 CS, or 5000 CS boards used for inverted roofs in accordance with approval Z-23.4-222 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 metric t/m².

Table 4: Load assumptions of vegetation types (FLL green roof guideline 2008).

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Load assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive greening</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Moss sedum greening</td>
<td>0.10</td>
</tr>
<tr>
<td>Sedum moss herb greening</td>
<td>0.10</td>
</tr>
<tr>
<td>Sedum herb grass greening</td>
<td>0.15</td>
</tr>
<tr>
<td>Grass herb greening (dry lawn)</td>
<td>0.20</td>
</tr>
<tr>
<td>Simple intensive greening</td>
<td></td>
</tr>
<tr>
<td>Grass herb greening (grass roof, poor grassland)</td>
<td>0.15</td>
</tr>
<tr>
<td>Wild shrubs grove greening</td>
<td>0.10</td>
</tr>
<tr>
<td>Grove shrubs greening</td>
<td>0.15</td>
</tr>
<tr>
<td>Grove greening up to 1.5 m in height</td>
<td>0.20</td>
</tr>
<tr>
<td>Intensive greening</td>
<td></td>
</tr>
<tr>
<td>Lawn</td>
<td>0.05</td>
</tr>
<tr>
<td>Low shrubs and grove</td>
<td>0.10</td>
</tr>
<tr>
<td>Shrub and bushes up to 1.5 m in height</td>
<td>0.20</td>
</tr>
<tr>
<td>Bushes up to 3 m in height</td>
<td>0.30</td>
</tr>
<tr>
<td>Large bushes 1) up to 6 m in height</td>
<td>0.40</td>
</tr>
<tr>
<td>Small trees 1) up to 10 m in height</td>
<td>0.60</td>
</tr>
<tr>
<td>Trees 1) up to 15 m in height</td>
<td>1.50</td>
</tr>
</tbody>
</table>

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

Note:
More information on the configuration of green roof surfaces can be obtained in the “Guideline for the planning, execution, and maintenance of green roofs—green roof guideline” (2008 edition) from the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. (FLL). www.fll.de
### Extensive green roof

Extensive green roofs ([Fig. 25](#)) require little maintenance—possibly one or two inspections a year.

Irrigation and fertilisation 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 well suited for extreme conditions and regenerate quickly, e.g. expansive short plants (max. 15 cm in height). 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. Several green roof contractors offer substrate layers that act both as a fertiliser 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 take into account the properties of the substrate mixtures on the designated plant types as well as their appearance as early as in the planning phase.

### Intensive green roof

Intensive green roofs ([Fig. 28](#)) 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 of up to 1.5 m in height.

High-maintenance intensive green roofs, however, have to be planned thoroughly and need the constant care of a gardener. They require irrigation, fertilisation, mowing, and weeding. 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 m. The possibilities regarding use and design of such roofs are practically boundless.

Most suitable are plants used for extensive and simple intensive green roofs, ornamental lawns, high-maintenance bushes between 3 and 6 m in height, as well as short and tall trees. In order to permanently maintain either extensive or intensive green inverted roofs, certain aspects 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 waterproofing layer, following the course of the water. To protect the waterproofing layer from damages caused by penetrating roots, only root-resistant membranes should be used. The Fachvereinigung Bauwerksbegrünung e. V. (FBB, 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 FBB (www.fbb.de).

During the construction of inverted green roofs, the root-barrier membrane must never be installed above the thermal insulation boards made of extruded rigid polystyrene foam, because they would act as a vapour barrier on the wrong side and cause the accumulation of moisture within the insulation material.

Filter and seepage layer = drainage
The vegetation layer of green roofs should be allowed to store great amounts of water in order for the plants to survive potential periods of drought. Excessive 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.
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. 30).

Seepage 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. 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 drainage layers. The entangled polymeric filament mat has a tight non-woven textile 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 to 80% of the original outlet cross section is generally to be calculated (Fig. 31). Manufacturers provide the relevant information for pre-fabricated drainage elements.

Seepage layer consisting of concrete drainage stones
Concrete drainage stones only make sense in combination with thicker plant substrate layers. In general, they are not as suitable for green roofs because they may cause structural damage. The constant subjection 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.
Roof drainage and roof outlets
The drainage layer must cover the entire roof surface up to any adjacent structural units, 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 m² may be combined as one drainage unit. The roof surface must exhibit a total incline of at least 2.5%.

When 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 (Figs. 32 and 33). In the substrate layer, a separation barrier of gravel measuring 30 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. 34).

When a green roof is bordering 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. 35).
Wind loads are determined in DIN 1055-4, DIN EN 1991-1-4, and the “Notes on the determination of loads” of the German Roofing Contractors Association (ZVDH). The required load to secure the boards against wind suction has to be implemented in accordance with DIBt approval Z-23.4-222. Moreover, a separation barrier of gravel along the parapet will provide fire protection and prevent plants from growing over the roof edge.

Table 5 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 object. 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.
Fire protection

The IS-ARGEBAU (German Conference of the Ministers of Building) has passed fire protection requirements for green roofs as an amendment to already 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. 36).

Table 5: Standard layer thicknesses and distributed loads for various types of vegetation.

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

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

Fig. 36: Gravel strip along the roof edge and roof penetrations.
In all buildings—including terraced houses—, the building’s outer wall, firewalls, or those 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. 37).

5.6 Patio Roof

According to DIN 4108-2, waterproofing and thermal insulation of patio roofs are installed in the same way as on gravel or green inverted roofs. The top layer can be a stable, walkable pavement made of washed concrete slabs, pre-constructed 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 (Figs. 38 and 39).

Fig. 37: Fire section of a flat roof with extensive greening.

Fig. 38: Patio roof configuration.

Fig. 39: Profile of an inverted patio roof with concrete slabs on a gravel bed.
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 decks are insulated with Styrodur® boards following the principle of inverted roof constructions (Fig. 40). In accordance with the general technical approval Z-23.4-222 (download area of www.styrodur.de), the following configurations are possible:

- Pre-fabricated concrete slabs on supports
- Composite stone pavement laid on gravel
- In-situ concrete slabs on incline

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

Fig. 41 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. 41 right), the waterproofing layer is protected from such dynamic loads by the thermal insulation layer.

A second possible configuration is the use of pavement slab supports (Fig. 43) 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.

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.

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

Reinforced pre-fabricated 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. 42). 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 waterproofing—does not show any warping and the insulation boards are laid on a fully even surface.
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 (Figs. 43 and 44). 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 pre-constructed 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. 45).

![Fig. 43: Parking roof with small-size reinforced concrete slabs on pavement slab supports.](image)

![Fig. 44: Concrete slabs laid on Styrodur® using a pavement slab support system.](image)

![Fig. 45: Parking roof with concrete slabs laid on an inverted roof with Styrodur®.](image)
**Configurations**

**Parking Roof**

**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 predetermined 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. The composite stone pavement should preferably have a thickness of at least 10 cm (Fig. 46). 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. 47).

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.

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.

The composite stone pavement

Jointing sand

Bedding layer

Geotextile approx. 140 g/m²

Styrodur®

Roof waterproofing

Reinforced concrete floor

Fig. 46: Parking roof design with composite stone pavement on a bedding layer.

Fig. 48: Composite stone pavement with grass joints for a parking roof on top of a gymnasium.

Fig. 49: Concrete pavement on Styrodur® boards.
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 lots. This construction requires thorough planning and execution.

The basic structure of a parking roof with in-situ concrete driving surface is illustrated in Figs. 50 and 51. 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 of 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.

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 case of a leak, no rainwater may seep below the waterproofing layer. 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, in the case of damage, both the driving surface and the waterproofing layer can be drained without a backflow of water.
- The outlets must be inspected and cleaned on a regular basis.

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.

Insulation material behaviour in the event of water penetrating the parking roof structure

If the water-draining top layer of in-situ concrete slabs with joint waterproofing becomes permeable, thus allowing water to seep underneath the Styrodur® insulation layer, a worst-case scenario would imply a calculable absorption of moisture in the insulation material. In some areas of the insulation material, moisture contents between 10 and 15% by vol. may occur over a period of 20 years. Such values do not affect the static function of the structure. Damages to the insulation material due to frost are excluded, although the thermal insulation capacity of Styrodur® might decline.

Numerous tests (Fig. 52) and publications have shown that the thermal conductivity of extruded foam rises by about 2.3% per 1% by vol. increase in moisture content.

For example, with a thermal conductivity of 0.0375 W/(m·K) of a dry, 120 mm thick Styrodur® board, moisture absorption resulting from the failure of the joint waterproofing would locally cause thermal conductivity to rise up to 0.046–0.050 W/(m·K). In accordance with approval Z-23.4-222, the rated value of a 120 mm thick board on frequented inverted roofs is specified with 0.041 W/(m·K). Presumably, the deteriorated insulation value would be restricted to areas of the parking roof surrounding the drainage area. Therefore, the additional heat loss would remain minor in relation to the total energy requirement of the building.

Approval Z-23.4-222 specifies Styrodur® 4000 CS or Styrodur® 5000 CS for frequented in-situ concrete slabs.

Fig. 51: Parking roof with in-situ concrete driving surface.

Fig. 52: In-situ concrete driving surface slab, cut open for the scientific examination of its long-term behaviour.
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 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 the “Chemical Resistance” brochure in download area of www.styrodur.de). The instructions of the adhesive manufacturer must be observed when selecting the adhesive.
7. Application Recommendations for Styrodur®

<table>
<thead>
<tr>
<th>Application type according to DIN 4108-10 or</th>
<th>Product properties according to DIN EN 13164 and DIN 4108-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical approval</td>
<td>General</td>
</tr>
<tr>
<td></td>
<td>2800 C</td>
</tr>
<tr>
<td></td>
<td>CS(10/Y)</td>
</tr>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>(20–50 mm)</td>
</tr>
<tr>
<td>Perimeter® floor</td>
<td>DIBt Z-23.5-223, PB</td>
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<tr>
<td>Perimeter® wall</td>
<td>DIBt Z-23.5-223, PW</td>
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<tr>
<td>Perimeter® foundation slab</td>
<td>DIBt Z-23.34-1325</td>
</tr>
<tr>
<td>Perimeter® groundwater</td>
<td>DIBt Z-23.5-223</td>
</tr>
<tr>
<td>Living area floor</td>
<td>DEO</td>
</tr>
<tr>
<td>Industrial and refrigerated warehouse floor</td>
<td>DEO</td>
</tr>
<tr>
<td>Cavity insulation</td>
<td>WZ</td>
</tr>
<tr>
<td>Interior insulation</td>
<td>WI</td>
</tr>
<tr>
<td>Permanent formwork</td>
<td>WAP</td>
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<tr>
<td>Thermal bridges</td>
<td>WAP</td>
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<tr>
<td>Base insulation</td>
<td>WAP</td>
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<tr>
<td>Plaster base</td>
<td>WAP</td>
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<tr>
<td>Inverted roof</td>
<td>DUK</td>
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<tr>
<td>Duo/plus roof</td>
<td>DUK</td>
</tr>
<tr>
<td>Patio roof</td>
<td>DUK</td>
</tr>
<tr>
<td>Green roof</td>
<td>DIBt Z-23.4-222</td>
</tr>
<tr>
<td>Parking roof</td>
<td>DIBt Z-23.4-222</td>
</tr>
<tr>
<td>Conventional flat roof®</td>
<td>DAA</td>
</tr>
<tr>
<td>Parapets/rising building elements</td>
<td>DAA</td>
</tr>
<tr>
<td>Basement ceiling/underground garage ceiling</td>
<td>DI</td>
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<tr>
<td>Attic ceiling</td>
<td>DEO</td>
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<tr>
<td>Pitched roof</td>
<td>DAD</td>
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<tr>
<td>Drywall composite board</td>
<td>WI</td>
</tr>
<tr>
<td>Sandwich core</td>
<td>–</td>
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<tr>
<td>Artificial ice rink</td>
<td>–</td>
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<tr>
<td>Road transport infrastructure/rail construction</td>
<td>–</td>
</tr>
</tbody>
</table>

Styrodur®: product approval: DIBt Z-23.15-1481, extruded polystyrene foam according to DIN EN 13164

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
Styrodur®—a Strong Product Line

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

**Styrodur® 2800 C**
- The thermal insulation board with an embossed honeycomb pattern on both sides and smooth edges for applications in combination with concrete, plaster, and other covering layers.

**Styrodur® 3000 CS**
- The innovative multipurpose thermal insulation board:
  - With smooth surface and shiplap
  - For almost all applications in structural and civil engineering
  - With uniform thermal conductivity across all board thicknesses

**Styrodur® 3035 CS**
- The multipurpose thermal insulation board with smooth surfaces and shiplap that is suitable for almost all applications in structural and civil engineering.

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

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