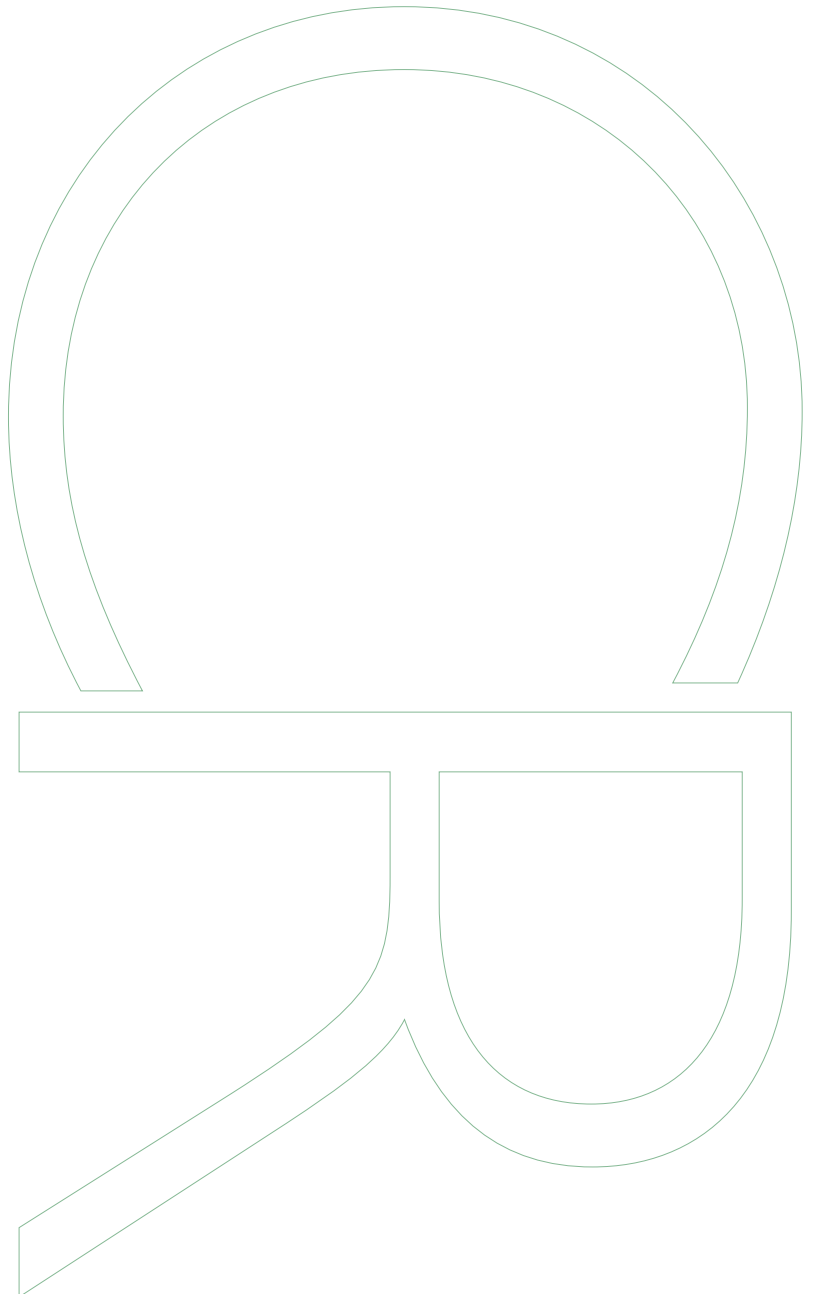




MODERN CONSTRUCTION ROOFS

ANDREW WATTS



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MODERN CONSTRUCTION SERIES

The series is based around the Modern Construction Handbook. Themes of each chapter from the MCH are developed to provide detailed design guides for facades, roofs, materials and fittings. An additional volume of details brings together drawn technical information. Books in the series discuss component design, building assembly, craftsmanship, as well as structural and environmental issues from the MCH.

AIMS OF THIS BOOK

Modern Construction Roofs is a textbook for students and young practitioners of architecture, as well as students of structural and environmental engineering who wish to broaden their study beyond the information provided in the Roofs chapter of the Modern Construction Handbook. It shows the principles of the main roof types used today and illustrates this through typical generic details, together with a built example, that can inform a design at a more detailed stage.

The six chapters examine roofs from the standpoint of the primary material used in their construction, from metal to glass, concrete, timber, plastics and fabrics. Each set of three double page spreads explains a specific form of construction which is accompanied by drawn and annotated details. Throughout the book, built examples by high profile designers are used to illustrate specific principles. As is the case in the Modern Construction Handbook the techniques described can be applied internationally.

INTRODUCTORY ESSAYS

These essays discuss two issues related to roof design: design development, and provisions for maintenance access. There is an increasing tendency to conceal roof gutters and pipes and to integrate them into the depth of the roof construction. Access systems for cleaning and maintaining roofs, as well as equipment mounted on a roof for cleaning facades beneath, has developed considerably over the last 10 years. In addition to cradles hung from the roof on fixed jibs or moving on tracks, the use of abseiling has increased in popularity since the 1980's. The higher levels of safety used in abseiling make it easier to clean roofs and facades of complex geometry without the need for highly visible ladders and cradles. This has considerable advantages for glazed roofs, inclined metal roofs and fabric structures.

METALS CHAPTER

The Metals Chapter discusses the use of metal sheet in roofs both as a substrate and as a watertight covering. When used as a substrate, in the form of profiled metal decking or composite panels, a waterproof membrane can be formed in different materials. Used as a covering material, metal sheet can be used in standing seams, profiled sheet and rainscreens. Solar shading devices formed from metal are also discussed.

GLASS CHAPTER

The Glass Chapter sets out the use of the material as both rooflights and as large glass roofs. Stick framed rooflights and glazing systems are related to those used for walls, but are usually fixed with pressure plates on the two sides parallel with the line of slope. Bolt fixed glazing systems for rooflights and roofs follow principles used in wall construction. Bonded glass decks and rooflights are a development of glass block details, which are also discussed. Finally in this

INTRODUCTION

chapter, glazed canopies are discussed, focusing on those that use point fixings with a minimum of support structure.

CONCRETE CHAPTER

Roof decks constructed in concrete are covered with a variety of waterproof membranes and finishes. When the membrane is applied directly to the concrete, thermal insulation and finishes, such as planting, paving slabs or timber decking, are applied. Construction can also be finished with another roofing system, such as metal standing seams, or rainscreens in other materials. All these types are discussed in this chapter.

TIMBER CHAPTER

Timber roofs are a traditional form of construction that use mainly tiles, slates and shingles in housing projects. In recent years, the increased use of metal sheet on timber roofs has led to an increase in more complex geometries that do not need to follow the principles of those traditional lapped roofing materials. Flat timber roofs, thin planting and metal sheet, in addition to the more traditional single membrane finishes, are set out here.

PLASTICS CHAPTER

GRP panels have the advantage of providing well insulated translucent panels that are more economic than those in glass. They are much lighter than glass, allowing more visually delicate support structures to be used for these panels. Glass reinforced polyester (GRP) can produce opaque roof forms that are free of joints, forming continuous roof structures such as shells and domes that form a monolithic, lightweight material with a watertight finish on its outside face. All these types are explained in this chapter.

FABRIC CHAPTER

The Fabric Chapter discusses tensile roof structures, air supported types and smaller scale canopies. PTFE membranes can be stretched over supporting structures, typically stainless steel cables with tubular steel supports. PTFE sheet is also used to form inflated 'air pillows' that are supported on an aluminium frame. Their advantage of high thermal insulation and lightness in weight is making them an increasingly preferred option for roof structures.

QUALIFYING COMMENTS

The building techniques discussed and the built examples shown are designed to last for an extended period with a relatively high performance. However, buildings for exhibitions and for temporary use are included since the techniques used have proven to be reliable in both short term and long term. In addressing an international readership, references to national legislation, building regulations, codes of practice and national standards have specifically not been included. This book explains the principles of accepted building techniques currently in use. Building codes throughout the world are undergoing increased harmonisation because of increased economic and intellectual globalisation. Building components and assemblies from many different countries are often used in a single building. Since building codes are written to protect users of buildings by providing for their health and safety, good construction practice will always uphold these codes as well as assist their advancement. The components, assemblies and details shown in this book describe many of the building techniques used by the building industry today, but this book does not necessarily endorse or justify their use since techniques in building are in a continual state of change and development. Some of the examples shown are highly developed applications of the techniques described.

INTRODUCTION

(1) An overview of roof systems

- Metals
- Glass
- Concrete
- Timber
- Plastics
- Fabrics

(2) Working with manufacturers, fabricators and installers

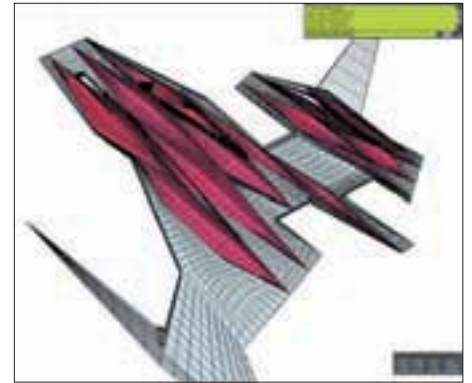
(3) Performance testing of roofs

- Air infiltration test
- Water penetration tests
- Wind resistance tests
- Impact resistance test
- Dismantling of sample

(4) Roof-mounted maintenance systems:

- Davits and monorails
- Trolley systems
- Davit systems
- Monorails
- Trolley systems

Light Wing, New York City. Architect: Tom Wiscombe / Emergent.



An essential change in recent years that has affected roofing systems in all materials is the increased visibility of roof designs, with some forming a continuity with the façade beneath. Where roofs were once considered to be either of traditional appearance, as with tiled and slated pitched roofs, or else completely concealed as flat roofs, they are now increasingly considered to be a part of a completely visible envelope design which is as visually important as the external walls, both in their appearance and their technical performance. The increased performance of roofing systems in all materials has led to greater experimentation, both technically and visually.

In some recent projects, walls and roofs are taking on a single structural form, with the same construction methods, materials and detailing used on both walls and roof. The increased technical performance and long term reliability of roofing materials of all types has led to a much more ambitious design approach. However, an essential difference between facades and roofs is that facades have rainwater running across their surface, but roofs can be submerged in water during rain. A roof has to be completely sealed in areas where water can collect, such as parapet gutters, with the assumption that rainwater will be expected to remain on the roof if the rainwater outlets become blocked. Even pitched roofs assume that the surface of the roof will

become submerged in a thin film of water running across it, so that the principles of a second line of defence used in facade design have a limited application on roofs. Some designs take the idea of the roof as a completely watertight, single layer membrane and use it to cover the complete external envelope. This is very much a principle of the roof taken down over the walls, rather than facade design taken over the roof. Both approaches are taken in sculptural forms where wall and roof are combined in a single design.

Increasingly, roof systems are influencing facade designs, and facade techniques are being incorporated into roof design. Bolt fixed glazing, rainscreens, silicone bonding and unitised panels are being absorbed into roof design, while ETFE cushions, polymer membranes and fabric structures are finding their way into facade design.

Metals

A development in metal roofs over the past 10 years has been to improve the visual appearance of all metal roof systems. By the late 1970's, profiled metal sheet roofs had added curved eaves and pressed metal corners to provide concealed gutters that gave the roof a strong 'linear' texture that formed an important part of the design of industrial buildings. The increased reliability of jointing together with the increased use of aluminium sheet instead of steel sheet (with its

increased flexibility) led to more adventurous roof forms without affecting the its waterproofing performance. The gradual move away from the traditional roof with a central ridge led to the use of brighter colours in paint-based finishes which are associated with consumer products, particularly cars, rather than the use of traditional dark colours that imitated traditional materials such as tiles and slates, or galvanised coating on steel sheet. By the 1980's some buildings even imitated the forms of train carriages, with polished stainless steel roof cladding and profiled metal that followed horizontal lines rather than the traditional orientation of the profiled sheet which allows rainwater to drain easily down the slope. By the early 1990's profiled metal roofs were using standing seam joints, which combined the long span capability of profiled sheet with the visually refined and very water tight standing seams which are 'zipped' together by machine on site. Since the introduction of 'zip up' sheeting, the difference between profiled metal and standing seam systems has become slightly blurred as a result of these mixed methods of assembly. This new 'hybrid' system has a lining panel system which can be fixed from metal sheets, with some being hung down from roof level without any scaffolding or access platforms required at all. This makes large roof spans, particularly at high level, such as in covered sports halls, much easier to con-

The innovative design and construction of this roof canopy was a result not only of digital technology, but of an equally innovative use of teamwork, where individuals and groups are brought together for a specific project. The working method was as important to the design team as the aspects of design and fabrication.



struct since scaffolding is not required.

Composite roof panel systems have been in development since the 1980's, with panels that provide an internal ceiling finish and outer roof covering in single panels which are semi-interlocked, with either a lapped metal joint between panels or a metal capping that clips over a standing seam-type joint. Composite panels have still not reached the level of technical ambition of their counterparts in facades. The joint between panels would be ideal to serve as drainage gutters to be set or even as a second line of defence to an outer seal, as used in curtain walling, with a drained and ventilated slot in the joint where water would be released at the base of the roof. Some attempts have been made in this direction, but much development is needed to move this metal system away from an imitation of profiled sheet metal into a complete system in its own right. A modest but useful method of using composite panels is as an insulated structural deck to a separate waterproof membrane set on top. While lacking visibility of the panels, it is very adaptable and economic, with thermal insulation not only filling the voids between peaks and troughs of the metal sheet on its underside but also providing structural stability. These composite roof panels have also been used in facades, where long span cladding panels are required which are difficult to obtain specifically from proprietary cladding systems.

Rainscreen panels are a recent addition

to metal roofing systems. They do not use the outer seam as a first line of defence against rainwater penetration but rather as a protection to the membrane beneath against the effects of the sun and to avoid maintenance staff walking on the exposed membrane. This is becoming a visually more appealing alternative to smooth pebbles, which also have the disadvantage of collecting dirt and dust from which vegetation can grow. Metal rainscreen panels are required to be sufficiently rigid and resistant to impact damage. Composite sheets with a plastic core and thin metal outer facings are popular in this regard since they achieve high levels of flatness and are flexible enough to withstand foot traffic, usually when aluminium sections are silicone-bonded on the underside of panels.

A new development is the use of metal rainscreens in a mixture of opaque and perforated or slotted, panels, which may also be used in soffit (upside down) conditions. Here the panels are more than a semi-decorative covering to an economic roof covering, forming part of the expression of the building envelope in forming a continuity between different parts of a roofscape, ranging from covering air extract terminals, rooflights and gutters to forming a continuous smooth continuation of the facade below. Metal rainscreen panels can also accommodate complex geometries without having to make individual composite panels

to achieve the same visual effect. Although such panels are a kind of 'virtual' metal roof rather than being formed entirely from metal, they can deal with varying methods of translucency and transparency in a single metal layer that can reveal its depth both from inside the building and from outside. A future development of metal rainscreen panels might be to use them in conjunction with a translucent roof such as GRP panels filled with translucent thermal insulation, with varied amounts of daylight, allowing GRP panels to be in different colours, to which they would otherwise be susceptible to colour fading without the perforated or slotted metal panels. They could also be used with polycarbonate sheets or plastic-based glazing in acrylic, for example, where the punched metal panels allow a diffused light but where the aging effects on the materials would be much less apparent and may even contribute to enhancing the coloured effects. This alternative to a glass roof would allow such roof build-ups to be non-linear, even curving in two directions, in the manner of tensioned single layer fabric membrane roofs.

Metal canopies are undergoing major developments. Since they can also be used as solar shading, they often can be considered to be small roof structures in their own right, being able to exploit folding geometries, as experiments for future building envelopes. The use of CNC-based cutting machines, as well as the increasingly eco-

Bruges Pavilion, Belgium. Architect: Toyo Ito & Associates.



The design of the structural composite panels, or 'sandwich' panels, underwent much development in the workshop. The extensive use of prototyping allowed an ambitious design to be developed for a relatively small building.



conomic stamping tools to make individual patterns in punched sheets, makes specially patterned and cut panels for each project easier to obtain in different materials.

A change over the past 10 years which has influenced all types of metal construction is the increased quality of the finishes. The quality of powder coating has improved enormously, with greater durability and colour-fastness, so that it competes strongly with the more expensive PVDF finishes. Consequently, the main constraint in the design of metal roofs in any of these systems is that metal sheet is produced in widths of around 1200mm or 1500mm, but is usually available in long lengths where coil material is used, that is, where the metal is rolled into a long coil in the factory. Most metal panels in facades are made from coil material, where a similar constraint applies in material width. Thicker plate, at 4mm thickness and above, is made in flat sheet form, at around 1000mm x 2000mm in size, with larger sheets being more difficult to obtain easily in large quantity. Working with the width of the coil in forming joints, and allowing for the folding or turning of the material at the joints, is the main constraint, but the material can be curved and folded economically to achieve almost any form required, in a durable material, with finishes that will retain their crisp appearance up to around 25 years.

Glass

Glass systems have developed considerably over the past 25 years in order to address the issue of improved weather tightness. So-called 'patent' glazing originally referred to patented systems for greenhouse glazing with metal glazing bars and clips that secured the glass quickly and reliably. The term patent glazing is still used but these are now usually thermally broken and hold double glazed units. The outer seals are able to remain watertight at much higher wind pressures from wind driven rain, and are drained and internally ventilated in the manner of facade systems. Rainwater penetration of joints in glazing systems has long been associated with a pressure difference between the external air and the air pressure inside the glazing system if it is completely sealed. A lower pressure inside the system than outside drew water in through joints which resulted in leaks through both glazed roofs and glazed walls. This issue has long been resolved by draining away any water that passes through the outer seals in drainage grooves set adjacent to the edges of the double glazed units, beneath the pressure plate that holds the glass in place. Water is drained at the bottom, where air is allowed to enter into the area in which the drainage chamber is located to ensure there is no pressure difference between inside and outside.

Although drained and ventilated systems

have been in use for the past 25 years, the issue of the water tightness of the horizontal joint has been undergoing continual development. Glazing bars have been used to support glass down the slope of the roof where they do not impede the passage of rainwater. Horizontal joints have been supported with stepped joints where water running off the top of the upper glass down onto a lower glass. The glass is traditionally secured with clips and is sealed with a proprietary sealant. This joint is difficult to seal reliably in order to achieve water tightness for higher wind pressures, and is difficult to adapt to a drained and ventilated system. This issue has been resolved over the past 20 years with the development of silicone bonded glazing that was originally used in glazed curtain walls. In the new method, a metal channel is set along the top and bottom of double glazed units, with the units being set flush with one another along the horizontal joints. The units are then secured with metal clips within the depth of the joint to provide a mechanical restraint. The horizontal joint between units is then sealed with silicone. The aluminium frame onto which the glass is fixed has ventilated drainage channels to take away any water that passes through the outer silicone seal. With the development of silicone bonding techniques in recent years, the double glazed unit can also be bonded to aluminium profiles which are mechanically fixed with



Like a twin wall facade, this roof design incorporates both glazing and solar shading. The use of internal shading allows daylight to be directed within the space, allowing daylight to be reflected off the internal shading to adjust the quality of daylight.



screws to a supporting frame. The joint between the glass units is then sealed with silicone in the same way as the previous example. An alternative approach has been to introduce horizontal glazing bars with pressure plates that are shaped to allow as much water to drain down the roof as possible, and accepts that the same water will be trapped behind the upper edge of the pressure plate. This small amount of rainwater will evaporate, and any small amounts of water that find their way through the outer seal will be drained away within the system. Both the recessed fixing method with a silicone seal, and the modified pressure plate system have been proved very reliable in their performance.

Bolt fixed glazing for rooflights has been applied more slowly to new roof designs than its use in facades. The technical success of bolt fixed glazing is in part dependent on high levels of workmanship on site to form the joints between glazed units. This led to some difficulties in the early application of bolt fixed glazing in roofs but this has been subsequently solved. An advantage of bolt fixed glazing over framed systems is their ability to be fixed from either inside or outside. Where framing glazing has the supporting extrusions on the inside, even if the glazing bar extends to the outside of the roof, the grid of metal framing remains visible. With bolt fixed glazing the rooflight is seen increasingly as an uninterrupted plane of

glass forming a continuous rooflight with the supporting structure and solar shading, where required, set outside the glass. Where a rooflight is seen mainly from outside, and the structure is set on the inside, the rooflight is seen in terms of its volume, almost as a solid block of glass without visible structure. The preference for the uninterrupted plane of glass with a certain reflectivity is developing alongside the preference for transparency in rooflight design. Where bolt fixed glazing for rooflights was preferred originally for its greater transparency as a result of its frameless, point fixed, design, this method is now being used more for the uninterrupted planes and modelled forms of glass it creates. This is seen in the technical development of the systems, where the bolt fixing supports only one side of the double glazed unit, with the outer sheet of the double glazed unit having no bolt fixing penetration, and consequently no visible fixings on the external face of the glass. This takes bolt fixed glazing a step further towards a glazing system with no visible fixings.

The use of bolt fixed glazing to provide greater visual transparency has led to an increased use of cable net supporting structures. Cable nets for bolt fixed glazing comprise cables, usually in a rectilinear grid of stainless steel cables where bolt fixings are set at the intersection points of the cables. The effect of these structures is like a tennis racquet, where visually lightweight cables are

held in a perimeter frame that supports the cables in the form of a ring beam. Where the rooflight is surrounded by an opaque roof, where it forms an opening in a concrete roof deck for example, the ring beam is not visible, but where it forms a complete roof, the resulting perimeter structure can be visually dominant, so this approach is highly dependent upon the visual elegance of the perimeter structure when this structure is exposed. Bolt fixed rooflights are moving away gradually from a dependence on the X-shaped cast bracket, which is very characteristic of the technique used to date, towards more flat plates and welded brackets, which are both more economic and ensure more visual emphasis on planes or forms created by the glass than on the fixing system of brackets and bolts.

Bonded glass rooflights are a recent development in glazed roofs, where double glazed units are bonded directly onto a lightweight metal frame that has no visible fixings on its external face. But where bolt fixed glazing can conceal the fixing bolt within the double glazed unit on one side, structural silicone glazing has no visible structure at all, with supporting glazing bars being concealed within the width of the joint behind the external seal. This has led to greater freedom in the forms used for rooflights in this technique, where the position of the glazing bars, and how they intersect, does not have to be considered in rooflight design. The conical-

International Port Terminal, Yokohama, Japan. Architect: Foreign Office Architects.



The innovative use of a folded steel plate structure allowed the roof structure to be completely visible within the building, while providing an innovative topography of the external roofscape.



shape rooflight described in Chapter 2 has a painted top which is shown formed in metal, but could also be made in cast glass. There is an absence of glazing bars and cappings (which require relatively simple, or large radiused forms in order to fix them) are not required in this glazing system, so that very sculptured forms can be made, where the glass dominates rather than any visible grid of framing members, capping pieces or a close arrangement of bolt fixings that would be required with other glazing methods. Bonded glazing has encouraged the use of structural glass beams, which suit well a structurally glazed rooflights. Most bonded glass rooflights with a gently sloping, but planar surface are derived in part from examples of glass floor decks and staircases used in buildings that have been developed over the past 15 years. The increased use of glass beams is set to continue with the greater reliability and understanding of the behaviour of glass beams when accidental damage occurs. This technique may well find a development in translucent plastics rather than in the continued use of glass alone.

Concrete

Developments in waterproofing membranes for concrete roofs over the past 25 years have focused on increasing the flexibility of the material used. Asphalt, a well established material for concrete decks, suffered traditionally from an inability to take up

movement from either the building structure or from solar gain when exposed to the effects of the sun. A solution to this problem has been the 'inverted' roof configuration, where thermal insulation is fixed above, rather than below, the waterproof membrane in order to keep its temperature cool and relatively constant. Pebbles or paving slabs are set onto the insulation. But asphalt is still required to span movement joints and interface with other materials. The introduction of polymers into asphalt to provide this greater flexibility has led to the material being easier to apply on site, particularly as torch-on membrane sheet rather than in liquid applied form. However, polymer materials, mainly thermoplastics and elastomers, are becoming more economic. Polymer materials have the advantage of increasingly being able to be exposed to sunlight, which is leading to roofs being covered in a few of these materials as a self-finish, with some buildings taking the membrane down the facades to form a complete building envelope. Where a smooth or level substrate can be formed, with foam-applied thermal insulation or with a board-material finish with thermal insulation beneath, these waterproofing layers, which can also be used on metal and timber roof decks, can be formed in the same way as fabric membranes, which are welded together in the factory to form a membrane with straight and crisply formed joints that can form a visible self finish to a roof, with an

appearance similar to that of fabric 'tent' membranes. This change from roof membranes which are kept concealed due to their poor visual aspect are now capable of being an active part of the visual design. Some manufacturers offer upstand angles in the same material as the membrane, typically for PVC membranes, which can be used to direct rainwater across the roof in the same way as standing seam metal roofing. This development also allows joints between membrane pieces to be joined with standing seam joints in order to visually refine the laps between strips of membrane. Roof membranes are set to become visible finishes in their own right rather than being concealed, which will no doubt lead to more refined roof edges, where a parapet wall will not be required to conceal the roof behind, allowing balustrades to be used at roof edges rather than using a parapet as a visual barrier to conceal the exposed roof membrane.

On pitched roofs, visually exposed polymer-based membranes, or polymer modified asphalt sheet, is beginning to be used as a material in its own right rather than imitating the appearance of traditional roof tiles or shingles. The more refined fixing techniques that are being made available by manufacturers will assist in this change. Waterproof membranes are increasingly being used on unusual substrates such as folded steel sheet decks and foam insulation-clad roof decks where there is a strong modelling of the

Tram Station, Strasbourg, France. Architect: Zaha Hadid Architects.



This folded concrete deck provides a roof canopy that has a strong visual form that is not visually weakened by the typical demands of waterproofing and rainwater drainage.

roof structure seen either from inside or from outside the building. Membranes are required to accommodate more structural movement and higher temperatures combined with an external wearing surface that can be walked upon without reasonable risk of damage, for maintenance access. The use of membranes, both visible and concealed are set to develop along these lines over the next 10 years.

Planted roofs have been in use for the past 20 years on more lightweight buildings rather than their more established application on concrete roof decks. A difficulty encountered with planted roofs has been the weight of soil and drainage required to grow vegetation which increases the cost of the building structure. Over the past 20 years, thin planted roofs have evolved that require only 50mm of growing medium to produce a roof covered in low height vegetation. This, in part, is due to better designed drainage layers in polystyrene which hold a controlled amount of water, optimised for the needs of the vegetation, so that the weight of soil and water can be reduced to a minimum. This allows planted roofs to be used on lightweight roofs in all materials. This technique has been popular where the external appearance of a roof is intended to have the least visual impact on its surroundings, mainly in semi-rural areas, without the need for complex and expensive structure to support the vegetation. Irrigation devices

have become more complex, with electronically controlled valves that irrigate roofs to suit the vegetation for different times of year.

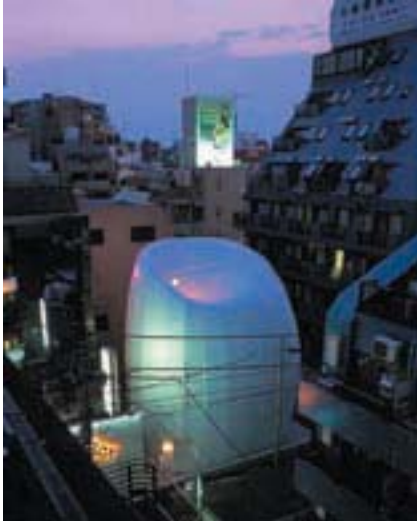
Timber

Timber-based roofs have developed over the past 20 years to improve their thermal insulation performance. Most techniques of tiles and slates are based on long tradition, but not with the high levels of thermal insulation required in recent years with the need to reduce energy consumption within buildings. Cold roofs, with the insulation set at ceiling level with the roof void being ventilated, continue to be used, but warm roofs have undergone much development in order to properly deal with the needs of ventilation to avoid condensation occurring within the roof construction. Some manufacturers prefer to have no ventilation within the roof construction where it cannot be easily provided by using a high performance vapour barrier on the inside face of the wall construction immediately behind the internal finishes. In practice, this is difficult to always achieve, particularly around penetrations through the roof such as pipes and ventilation ducts. Manufacturers also provide increasingly higher performance vents to ensure that air can be drawn through the void between the roof tiles, slates or shingles, and the breather membrane or roofing felt that is set above the thermal insulation. Most of the effort in ventilating pitched

roofs of this type is in trying to retain the appearance of traditional roofs, where ventilation ducts and boiler flues did not, until recently, play a part. Modern tiled, slated and shingled roofs use two lines of defence against rainwater penetration, where the outer layer is the outer line of defence to, and protection for, a waterproof membrane or breather membrane beneath. As requirements for thermal insulation increase in order to reduce energy consumption within buildings, the requirements for the avoidance of interstitial condensation within the roof construction will increase correspondingly. As a result, roof forms will no doubt change, as will the currently dominant requirement to imitate traditional lapped construction. The increasing use of photovoltaic panels as a substitute for tiles in certain areas of a pitched roof (which also imitate the appearance of traditional tiles and slates) will probably increase, as will the use of tiles as solar collectors for hot water systems in temperate climates. These will no doubt influence the design of pitched roofs for dwellings in the years to come.

An interesting development in pitched roofs has been the use of metal shingles. This technique is a hybrid of lapped tile roofing and standing seam facades, and can be used to form both wall and roof in a single system that is both economic and able to deal with a variety of fixing angles. Where shingles or tiles are hung from their top edge, metal shingles

Natural Ellipse, Tokyo, Japan. Architect: Masaki Endoh and Masahiro Ikeda.



are folded over into a seam on their sides and lower edge, or edges, if the shingles are not rectilinear, but are set at 45° to the vertical, for example. The top edge or edges are fixed with nails or screws with the shingle immediately above being lapped over the top of the nailed fixing in the manner of tiling. This fixing method secures the shingles on all sides while retaining a visual lap, allowing the shingle to be fixed in any position, even in a soffit condition. The fixing method usually follows rainscreen principles by assuming that rainwater will pass through the joints, which are drained in a ventilated cavity behind. Metal shingles are economic to fabricate, since they can be cut easily from sheet metal, from aluminium, mild steel, copper or zinc. In addition, tiles can be formed to a curved shape in a press to give a very textured facade with a 3-dimensional quality that has yet to be explored in this technique.

Plastics

Translucent plastics are used mainly both to imitate the appearance of glass rooflights as flat sheet materials, and as composite panels. This is gradually changing as plastics are no longer seen as economic substitutes for other materials but as construction materials in their own right. Earlier examples of plastic rooflights suffered from the effects of colour fading or of yellowing in transparent / translucent rooflights. The materials and finishes used in bonding are superior to those used

30 years ago, ensuring that colour fading is far less pronounced than it was. This is partly due to the coatings used, which are often paint-based finishes on opaque panels. A greater acceptance of plastics as durable and capable of being moulded economically to complex shape has undergone the beginnings of a revival in roof design. Some panels have been used as translucent rainscreen panels with lighting or graphic displays set beneath the outer plastic skin. The essential difficulties for plastics remains in their perception as being less durable than either glass or metal, for which polymer materials are seen as economic substitutes. This perception will change only when more complex geometries of external enveloped are demonstrated in buildings which could not otherwise have the budget available for such work in other materials. Working with plastics and composites is still undertaken in relatively small-scale workshops, where mock-ups can be produced easily and economically, allowing an interaction between designer and fabricator that is more difficult in larger scale factory-based methods where repeatability of large numbers of identical components still dominates production methods.

Glass reinforced polyester (GRP) is a material that is growing in popularity but is restricted to having only a finished surface on one side only as a result of using single-face moulds. Moulded items are bonded together back to back where components or panels

The membrane covering of this building mixes the methods of concealed polymer membranes, which are usually concealed, with the language of both tensile structures and plastic-based forms. This innovative use of an economic material allows 3D forms to be created economically, and without the need for traditional roofing elements.

where two-sided finishes are required, as is the case with opaque rooflights where both an internal decorative and an external weatherproof finish are required. Smaller scale polymer-based components have yet to use injection moulding techniques due to any significant amount due to the costs involved. This may change over the next 10 years as machinery costs reduce, particularly CNC milling and cutting machines which are well adapted to working with plastics and composites. An essential difference between plastic-based materials and metals is that plastics can be moulded to very large single forms without the joints required in sheet-based metal. Where metal roofs require cover strips and flashings at interfaces to deal with junctions between components, this is not required in plastics. The complexity of detailing in metals gives a certain visual richness that is not present in plastic-based materials that imitate similar forms, but new forms of double curves, twin layer construction of high levels of thermal insulation, and integrated rooflight and electrical lighting installations can give plastics a language all of their own. Examples of the moulding ability and flexibility of the material is seen in consumer products and vehicles, and the possibilities are beginning to find their way into building construction.

Fabrics

The use of woven textiles made from

The use of polycarbonate panels provides a visually lightweight canopy that appears to float above the surrounding space. The crisp assembly, expressed as separate roof elements, gives the roof an elegant, durable quality.



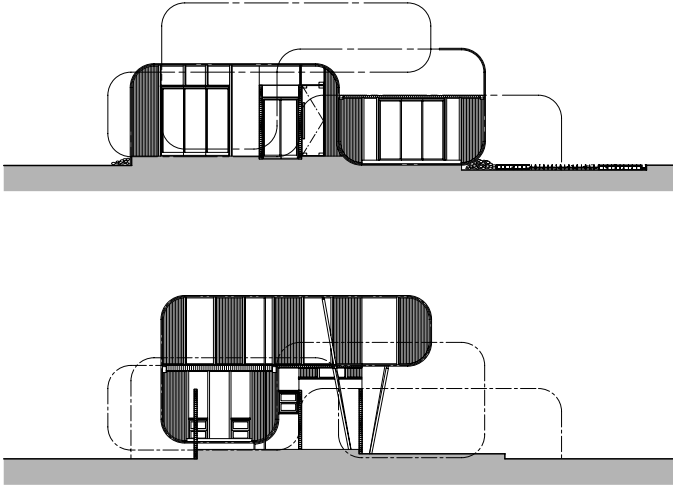
polymers is relatively new to building construction and its use has been focused on its application to create tent-like roof forms. Tension structures that imitate the geometry of traditional tents from around the world have developed from early examples of canopies of 35 years ago. Tent-based structures stretch a single membrane sheet, which is waterproofed on its external face, over a supporting structure that may use a mast to support the tent, and cables to hold the membrane in position, in the imitation of a traditional tent. This has led to some interesting developments in the connection of membrane to cable and restraint of cables to adjoining structure. Alternatively, membranes are stretched over more sculptured supporting frames, which are derived more from the established language of building construction than from the masts and cables of tent-based roofs. The design life of these roofs is gradually increasing as both a result of observing earlier examples and developing them, as well as an improvement in the performance of the protective coatings applied. Most coatings aim to reduce surface friction as low as possible to reduce the amount of dust and dirt that accumulates on roofs, so that it is cleaned efficiently by natural rainfall rather than relying exclusively on washing the membranes by hand in regular cleaning maintenance. This is usually successful, bearing in mind that most fabric roofs are difficult to access on a regular basis for washing by hand.

The large scale nature of most membrane roofs also makes cleaning difficult. The introduction of double layer membrane roofs will no doubt change their use from purely weather barrier to a thermally insulated roof, making them more attractive for roofs to internal spaces than shelters for sports stadiums and semi-open courtyards in buildings. More translucent insulation materials reduce the amount of light transmission lost through these roofs, with research being undertaken to form an economic and highly translucent thermal insulation material that would suit double layer membranes. An alternative method of insulating membranes is to fill the gap in a double layer membrane roof with air to form an inflatable roof. The concern with this approach is that it relies on a constant supply of air to hold the roof in place rather than by a supporting frame which does not rely on electrical machinery to retain its structural integrity. Although inflatable structures are used in temporary or seasonal roof enclosures, this method has been adapted as small 'cushions' or 'pillows' filled with air to provide an insulated fabric membrane roof. The most visually striking examples use ETFE foil which is both very durable when compared to other polymer fabrics, and also highly transparent. While this can be a disadvantage in rooflights where some amount of solar shading is usually required, it is ideal for many facades and is finding use in complete building envelopes, where wall and roof is

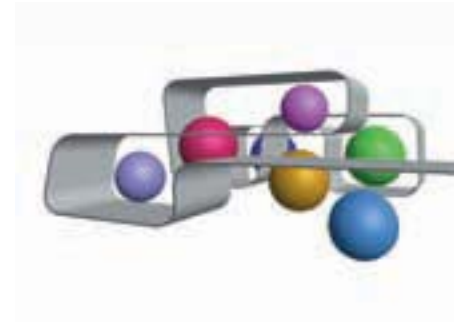
formed from a mixture of transparent and translucent panels. These panels are inflated, fixed to a permanent air supply that periodically refreshes the cushions with more air to maintain the pressure required to give them structural stability. The use of fabric is set to grow, with air cushions that can be used in conjunction with external solar shading or internal screen walls in a variety of twin roof or twin wall applications. Like sheet plastic materials, ETFE cushions are just beginning to be liberated from the design language of glass rooflights, with more complex geometries to form curved roofs. Loadbearing air cushions, which do not require any supporting structure, are in their early stages of development and application, and we are likely to see much of this development in roof structures and self-supporting envelope structures in the coming years.

Fabric membranes are currently limited by the width in which they are manufactured, though ETFE/glass fibre sheet is much wider than the PVC/polyester type. The joints in the membrane, similar to those used in polymer membranes on roof decks in concrete, metal and timber; could see a convergence of technologies, with waterproofing membranes, glass sheet and plastic sheet finding a combined language in a single roof rather than being entirely different solutions for a single roof design. The combining of these technologies in less rectilinear-based roof designs could lead to ever new roofing techniques.

Atelier and House, Biwa-cho, Shiga Prefecture, Japan. Architect: Shuhei Endo Architect Institute.



This building uses a roof structure which is continuous with the external walls to create a single 'wrap' for the envelope. While this design approach has been used on larger-scale projects, its use in small-scale buildings is innovative.



As roof design approaches the visual complexity of facades, the amount of detailed design, mock-ups and testing is increasing towards that of facades, particularly where the roof is either large in relation to the size of the envelope, or where the roof forms a visual continuity with the facades beneath.

Roofs and roof coverings are installed in a mixture of manufacturers' proprietary components or systems, fabricators assemble and installers' work on site in fixing these items. Most roofs are based on manufacturers' systems, except on smaller projects, where traditional techniques are still used. Traditional techniques are largely absorbed into manufacturers' proprietary systems, which focus on reliability, economy and ever increasing amounts of thermal insulation, while overcoming condensation problems associated with these developments.

Roofs made primarily from metal, concrete and timber are, for the design team, primarily manufacturer/installer based, while glass, plastic and fabrics are manufacturer/fabricator based. Having established the general appearance of a roof, the design team proceeds to the detailed design in a variety of ways depending on the material used.

Metal roofs are mostly proprietary systems, made by manufacturers with the exception of rainscreen panels and canopies, which are usually undertaken by fabricators. Standing seam, profiled metal and composite panel systems are made by manufacturers who can be approached at an early stage of the project to request general technical infor-

mation. Where the roof design varies little from these standard systems, little additional information is needed in order to proceed to tender with a drawn solution that will suit a range of manufacturers whose systems could be used. If the proposed system is fundamentally different from established systems, then one or two manufacturers are usually invited at an early stage to see whether they would like to develop the system further before tender, leading to negotiations for the contract at a point when it becomes clear which manufacturer or fabricator can undertake the project within the budget allowed. This is particularly important in the case of mixed systems, rainscreens, or double layered roofs, where there are fewer precedents, and where detailed design and testing is required to ensure their long term performance as part of the completed building.

Glazed roofs usually follow the standards of glazed curtain walling, and are well defined in their range of details. However, the design team will need to consult manufacturers at an early stage if an outer layer of solar shading is required, for example, as penetrations through framing members and through joints (in the case of bolt fixed glazing) are less commonly used in rooflights. Some large curtain walling companies have branched into specialised roof structures that can provide advice, at an early stage, for unusual designs. Companies that fabricate unusual glazed roofs, who are based in steel fabrication, can also provide useful information at an early stage about the relationship between sup-

porting structure and glazing, particularly in providing structural loading information which can be incorporated into the overall structural design for the building.

Concrete roofs, which are usually sealed with proprietary membranes, require little consultation with manufacturers before tender, with movement joints and typical junctions being detailed in a similar way by a range of manufacturers. The exception is in planted roofs, where soil depth, or the relatively thin depth of an equivalent growing medium, and its attendant loads, need to be established at an early stage in order to allow for a minimum of two or three different proprietary planted roof systems to be used. Flat concrete roof decks require close coordination with the rainwater drainage system to ensure that they can be accommodated, particularly where drainage outlets are closely coordinated with the facades or with the ceiling layout below. The increased use of 2-way rainwater outlets at the edge of roofs, rather than visible outlets in accessible roof decks, makes this requirement for coordination more acute.

Timber roofs usually use well established systems, with even metal shingle roofs being provided as tested systems. They are usually capable of being fully designed by the design team prior to tender, since the techniques involved are well known. Lapped tiles, slates and shingles are undergoing constant development in the building industry, and the latest improvements will be offered by installers during the tender stage. The choice of specif-

The external membrane uses a spray-applied polymer-based coating which mixes the visual language of asphalt and liquid-applied roofing membranes with the technology of polymers to create an innovative appearance that is set to develop in the coming years.



ic tile or slate or shingle is usually made at early stage of the project, with approximate costs being provided by manufacturers for the supply of the materials at an early stage. Contractors, or installers, usually bid to install a system which is already specified by the design team. Asphalt-based materials are already well developed and can be detailed with confidence by the design team ready for tender.

GRP roofs are made as proprietary systems, with smaller manufacturers offering individually designed systems which are a mixture of panels and specially formed components, such as nosings and gutter sections. Where plastic-based roofs are made as structural shells, they are usually designed for each individual project and fabricated in the workshop. The design team usually ensures that the design will suit two or three tenderers, but a preferred contractor may be chosen at an early stage due to the specialist nature of the work. Negotiation of costs at an early stage is advisable in plastics for this reason.

Fabric membrane roofs and ETFE cushion roofs can be designed by the design team with the assistance of structural engineers specialising in these tensile structures, which allows the design to develop rapidly without involving specific manufacturers, who may be reluctant to produce a detailed geometry and determine the forces that would be applied to the supporting structure. The choice of material, and hence the width of material available to form a seamed mem-

brane, can be made at an early stage in consultation with fabricators. Once the material and budget have been matched, a specialist structural engineer can proceed with an initial design, where supporting structure can be developed in parallel with the fabric membranes.

In general, working with manufacturers of roof systems is not as flexible as with facade systems, but this situation is quickly changing with the development of new systems in most materials. As roofs move increasingly towards the visual complexity and technical performance of facades, manufacturers are making themselves more available to develop their systems with architects and engineers. The ability to negotiate costs for the supply of a system to site assists in this matter, with the tender being restricted to the installation of a particular system which has been adapted by the design team for a specific project. A visit to the factory of the proposed system supplier helps the design team to understand both how components are made and the constraints under which they are manufactured. It also helps to see whether any part of the system which the design team would like to modify can be accommodated without adding significant extra costs to the project.

Fabricators are becoming more ambitious both technically and in terms of visual quality offered, mainly in metals, glazing, plastics and fabric membranes. They are usually able to respond at an early stage of a project, and if appointed early on, become more

closely linked to the design team. It is important to visit their facilities at an early stage of the project to establish their capability both in terms of complexity and scale as well as their experience in previous projects.

Installers, particularly if they are also general building contractors, can provide information at an early stage about the suitability of a design for ease of construction as well as associated costs of bringing materials to site. If a suitable method can be agreed for bringing certain materials to site and lifting them onto the roof easily, for example, then more ambitious designs can be realised within a more modest budget. The amount of on site installation and off-site fabrication can then be optimised by the design team to achieve the required design without adding significant time to the construction period on site.

Above all, an essential understanding of the properties of each material, and the working methods associated with each, should be grasped from the outset, together with an idea of how the materials are transported to site and assembled as a complete roof. This can assist the contractor when entering discussions about the merits of the setting up a temporary workshop on or near the site, as opposed to transporting assemblies over long distances from a factory. When the design team better understands the materials with which they are working, the quality of construction is enhanced as a result.



The testing of a roof system is undertaken typically with a small test panel that contains the full range of joints that comprise the system as well as the maximum span that the system can accommodate. This is to ensure that adequate weatherproofing can be provided while the system experiences maximum deflections from both positive and negative wind pressures.

Testing of water tightness of mock-ups has until recently been restricted mainly to facades. Roof structures are usually tested in a specialist laboratory when they differ technically from standard systems, or have an unusual combination of standard systems. Testing is usually restricted to systems in metal, glass and plastics. Concrete, timber and fabric do not usually require test mock-ups, since their performance is well established both in the systems used, and as industry-wide specifications. Test rigs determine the ability of the mock-up to remain watertight and airtight when the various design loads are applied to the mock-up. In addition, the effect of a falling object onto the roof is tested when it is considered essential to withstand the load to protect building users beneath when they are at possible risk, from higher buildings adjacent to the roof, for example. A test that is particular to roofs, and is not undertaken in facades, is the flood test. An area of roof is filled with water up to a level anticipated in the event of rainwater outlets being blocked and left standing for up to several days. This is usually undertaken on flat roofs where there would be standing water in the event of blocked outlets, and applies to pitched roofs only at gutters or drainage points. This test is usually undertaken on site, typically for single membrane roofs on a flat roof deck in either concrete, steel or timber.

Mock-ups for performance testing have the added benefit of revealing the installation

problems inherent in the system, particularly if some innovation is involved, and allowing the design team to see how the roof will appear before proceeding with the work in the workshop or on site. The mock-up can also be used to establish an accepted level of quality of construction, particularly with regard to visual crispness of assembly, flatness of materials, visible joint widths, finishes and colour.

The workshop usually has at least one panel or set of joints that covers an area sufficiently large to provide full structural deflections of framing members, as well as internal ventilation and drainage in the case of glazed roofs. There is little point in testing a panel 300mm x 300mm in size that includes only one joint, since the overall effects of movement under full design wind load cannot be determined unless a full panel is tested. The test mock-up panel is set at the same angle at which it is to be used in the completed installation. Where a range of angles are encountered, the most vulnerable, or extreme, angles are taken to form the mock-up. The roof mock-up is set 1500mm to 2000mm above the ground level to allow the underside to be inspected easily, and set typically on a concrete slab. The roof sample is usually supported on a steel frame at its edges in a way that simulates the structure used in the building. The space beneath the roof is then enclosed, usually with plywood sheets which are sealed at the interfaces with the mock-up and with the floor slab or deck

beneath to provide as air tight an enclosure as possible. A door is provided into the chamber which is able to be clamped shut during the testing.

The test chamber is pressurised with an air supply in order to establish the amount of air infiltration through the system. The air supply is provided usually by a flexible hose that passes through an opening in the plywood chamber enclosure. The hose is connected to a centrifugal fan which can either supply air to, or extract air from, the test chamber.

The largest external component in the testing is an aero engine with propellers which acts as a generator for the wind pressures applied to the test mock-up. A grid of water spray nozzles is set above the mock-up in order to simulate rainfall onto the roof.

A canvas bag filled with small diameter glass spheres is provided for the soft body impact test, which is typically dropped from a mobile platform or temporary scaffolding tower set next to the test sample.

Air infiltration test

In order to establish the rate at which air filtrates through the assembly, the mock-up is first subjected to a single positive pressure 'pulse' which is held for 10 seconds, which corresponds to half of the design pressure for the roof system. This is done in order to pressurise the test chamber and ensure that the chamber has been properly sealed. This is done before testing commences. The pres-



The test chamber, which is capable of being fully sealed, is fitted with an air supply to provide both positive and negative air pressures on the internal face of the roof sample panel.

sure inside the chamber is now increased to a difference of 600 Pascals between inside and outside. The roof sample is first sealed with tape to determine chamber leakage, and measurements of airflow are taken, which, for fixed rooflights should not, typically, exceed 1.1 m^3 per hour per m^2 . The airflow test is repeated with the tape removed. The difference between the two readings indicates the air infiltration rate through the roof sample.

Water penetration tests

These tests are conducted both under static air pressure, that is, with no significant wind blowing across the sample, and at dynamic air pressure, where an aero engine blows air onto the sample. In the first test, the static air pressure water penetration test, water is sprayed from nozzles onto the roof mock-up at a rate of at least 3.4 litres/ m^2 /minute. The water spray nozzles are set out on a grid so that nozzles are no more than 700mm apart, and are fixed at around 400mm from the face of the sample. This ensures that all parts of the roof sample are sprayed with water. A pressure differential corresponding to 600 Pascals is applied across the sample for 15 minutes. The interior face of the mock-up is checked for any water penetration. The test is repeated at the same pressure with a propeller-type aero engine to provide the same 600 Pascal pressure difference across the sample. The underside of the mock-up, inside the chamber, is checked to ensure that no water drops are

visible as a result of penetrating the roof assembly.

Wind resistance tests

In these tests, pressure transducers are fixed to the inside face of the roof sample, in positions where the deflectors are most critical, such as at the centre of framing members, or the centre of panels. Transducers are telescopic gauges that measure deflections, usually to an accuracy of 0.25mm. Readings are taken digitally at a distance from the test chamber. The transducers are set by applying a positive pressure 'pulse' of 50% of the positive wind pressure for 10 seconds. After a recovery period of up to 5 minutes, the pressure transducers are set to zero to establish a 'zero' level for the test. A positive pressure is then applied to the roof mock-up and held for 10 seconds at different pressure deflections. Readings are taken at 50%, 75% and 100% of the positive design wind pressure. After a period of up to 5 minutes, any remaining (or permanent deflections) in the sample are recorded. This process is repeated for negative wind pressure, where air is drawn out of the test chamber. The test starts again from the beginning, with a 50% pulse held for 10 seconds in order to establish a 'zero' level for the transducers.

These two sets of tests for positive and negative wind pressures establish whether the mock-up deflects within the limits set out in the design, at the design wind pressure (typically 1400 Pascals). These two tests are

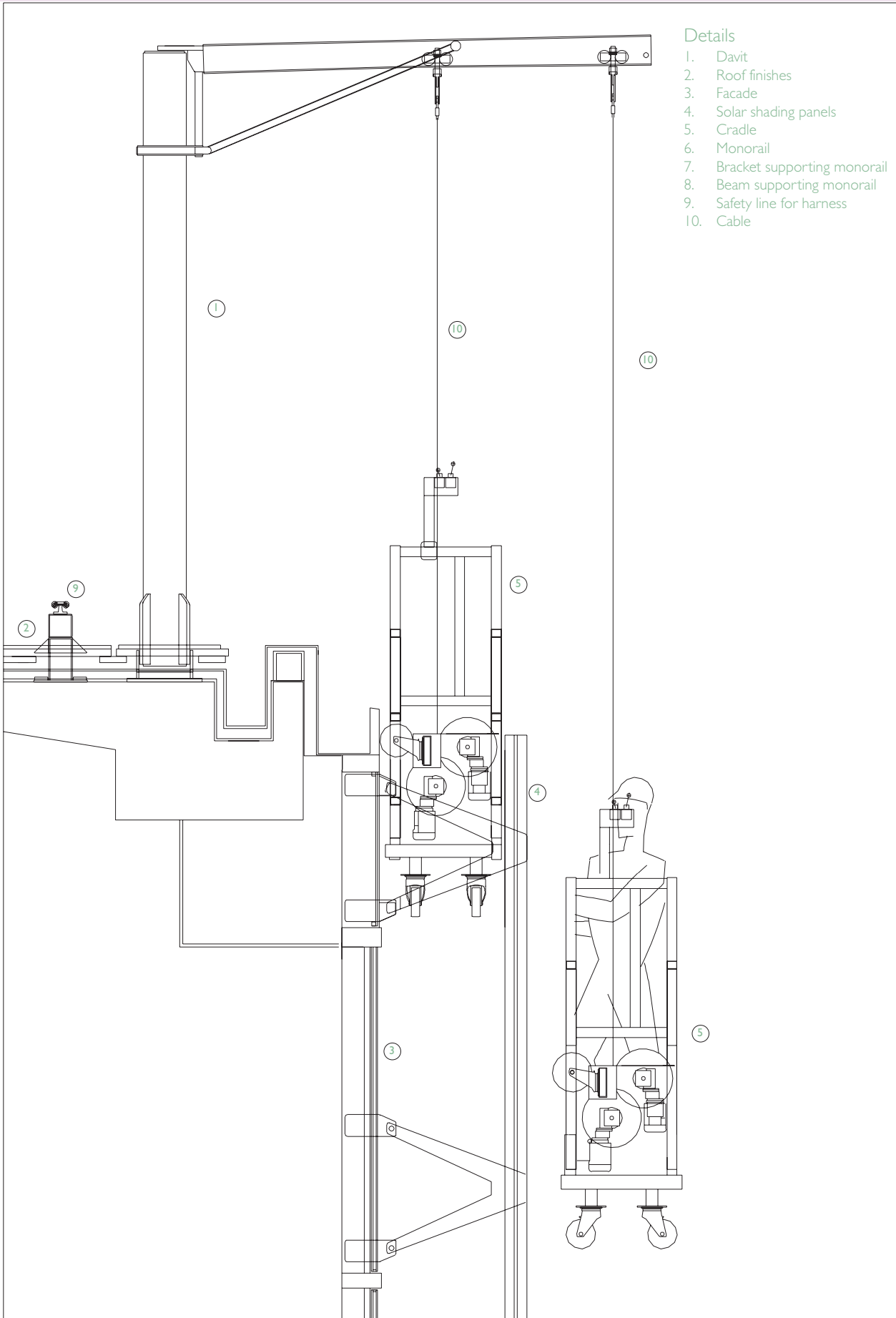
repeated at 1.5 times the design wind pressure in a safety test. The pressure is then increased to a maximum of 2.0 times design wind pressure to examine what would happen in the event of failure if this limit is not reached. Typically, failure occurs in a seal in the roof assembly, or a glass panel may break in a rooflight, but this occurs usually when the 2.0 times design wind pressure is exceeded.

Impact resistance test

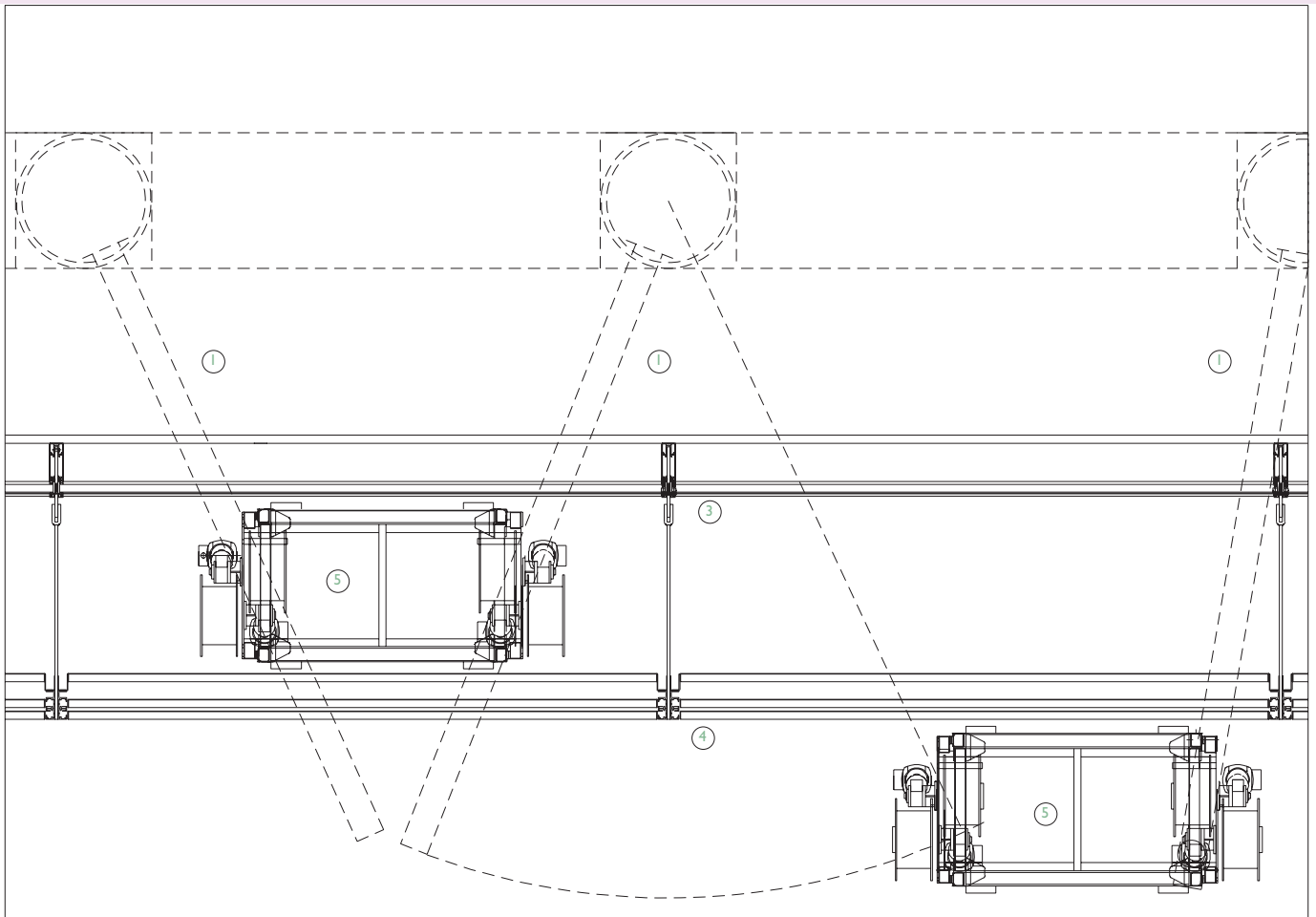
The ability of a lightweight roof, typically a glazed or plastic-based rooflight, to withstand an object falling on it is simulated with a canvas bag 400mm in diameter, filled with the glass balls already described, to a mass of around 50kg. The bag is dropped from a height of around 750mm to simulate an impact energy of around 350 Nm in a safety test. The test is performed on joints and panels to establish that the complete roof assembly would not fail under these impact energies.

Dismantling of sample

When the tests are complete, the roof mock-up is dismantled to ensure that the mock-up was built exactly in the way it would be applied on the roof of the finished building. In the event of a test failure, this dismantle assists the design team to understand how to resolve the matter, and prepare the mock-up for a second round of testing if required.



Section I:25. Davit supporting cradle in two positions.



Plan 1:25. Davit supporting cradle in two positions.

With the increased use of metal, glass and composite materials in facade design there has been a greater requirement for cleaning and maintenance. Building facades 30 years ago were detailed with low levels of maintenance envisaged, with the use of brick, concrete, stone and timber dominating architectural design. Facades would be cleaned only rarely, with details that would weather well with the passage of time. Windows in masonry walls were detailed to be openable, partly to admit fresh air for ventilation and partly for cleaning access. With the increased use of sealed facades without openable windows came an increased requirement for cleaning equipment.

Facade cleaning systems for twin wall

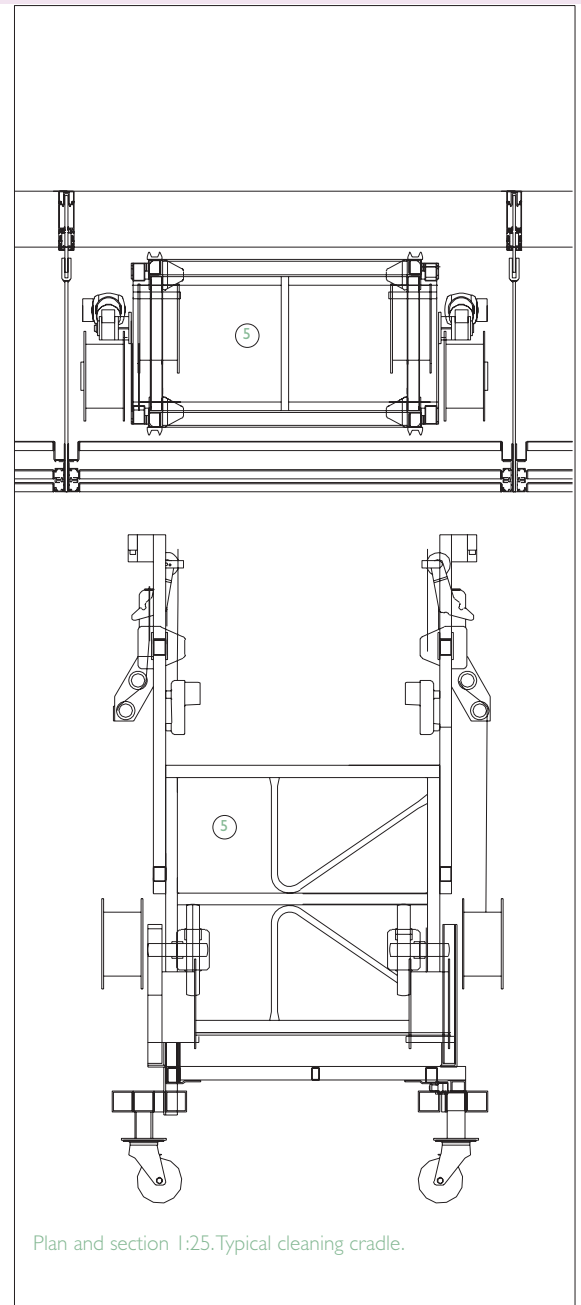
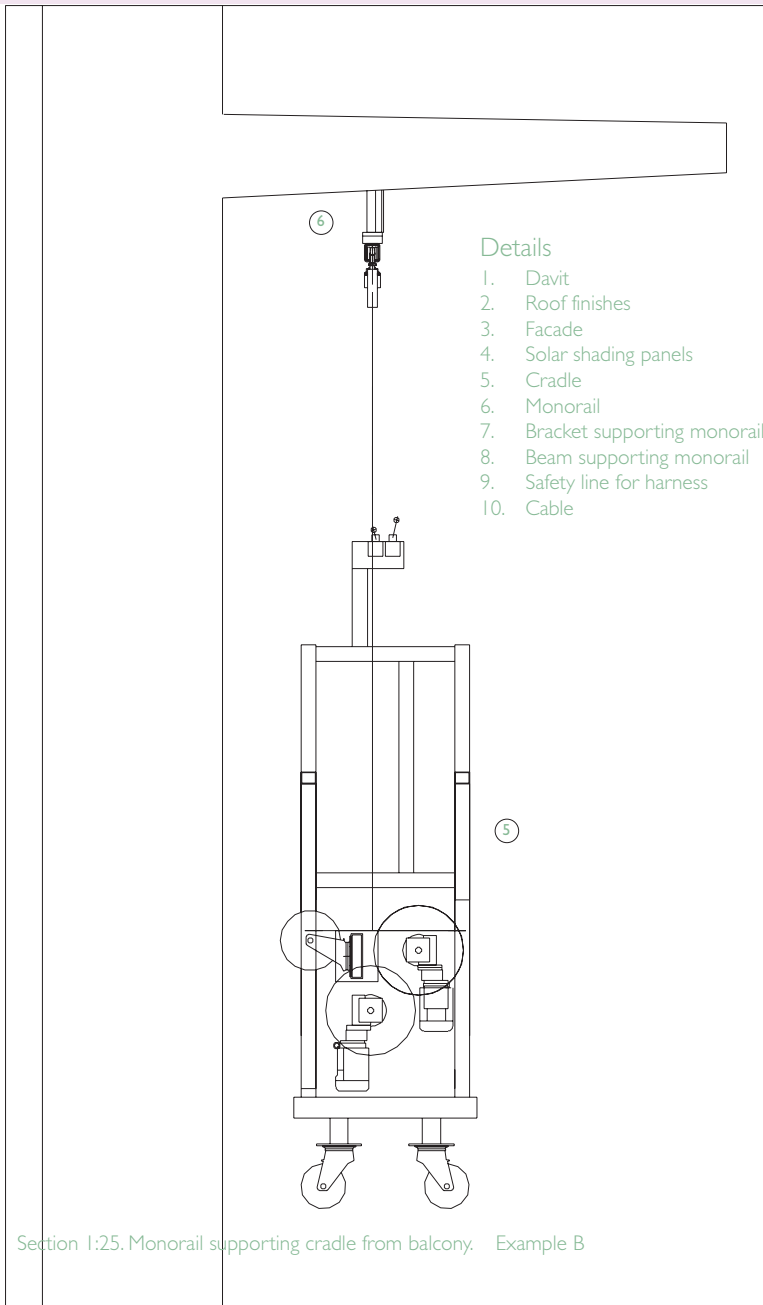
facades (discussed in *Modern Construction Facades*) are often provided in the form of walkways set at each floor level. Most systems, however, are roof-mounted and are required to be integrated into the roof design, usually with a minimum of visible equipment. These roof-mounted types are discussed here. Most facades are cleaned with either davits, monorails or trolley systems mounted at roof level, with larger buildings having a mixture of these systems on a single roof.

Davit systems

A davit is a jib or scaffold-shaped frame from which a cleaning cradle is hung. A single cleaning cradle, holding one or two persons,

is usually hung on cables from a davit at each end of the cradle. Davits are moveable and when in use are secured to bases in fixed positions near the roof edge. Davits are very useful for roofs where the permanent visual presence of a monorail or trolley system is not the preferred solution to facade maintenance.

Davits are usually made of mild steel or aluminium tube and are moved with wheels at their base. This makes them sufficiently lightweight and mobile to be handled by one or two people when they are moved into position and fixed for use. Davits are usually dropped into position onto a set of bolts projecting up from the roof surface, typically as either plinths in the form of short



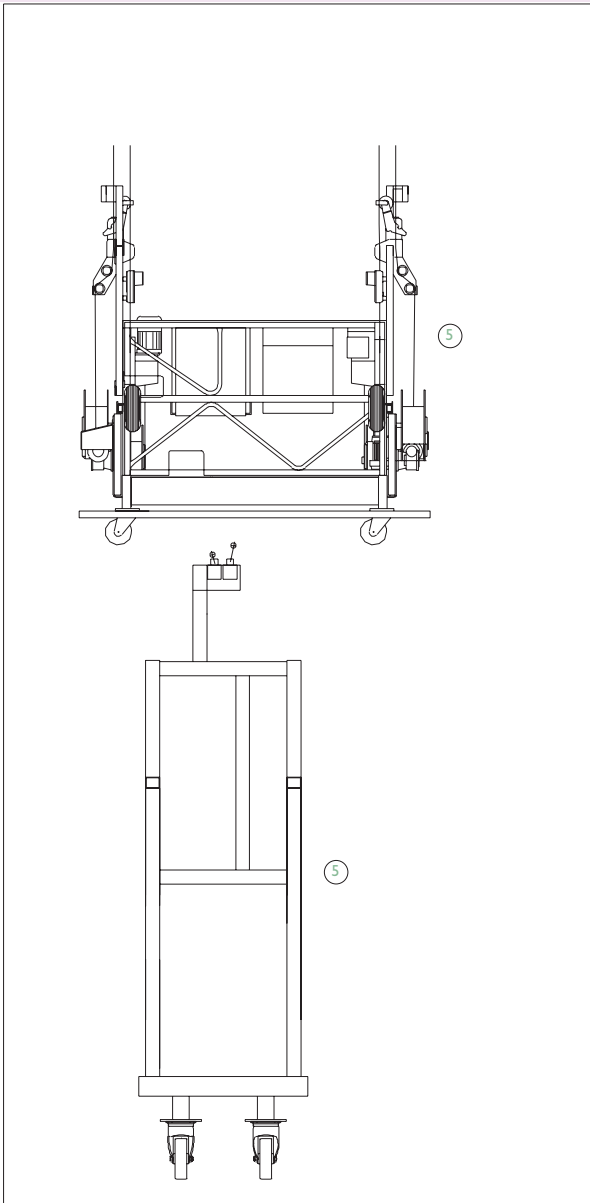
columns, or as a recessed box below the level of the roof finishes where the bolts are concealed from view, as on an accessible roof terrace. The davit is lifted into position, usually by a person pulling it up with a rope secured to the top of the post. The arm of the davit can be swung outward once it is fixed in place. Cables, secured to the end of the davit arm before it is lifted into position, are lowered down the facade to be attached to the cleaning cradle below, at the base of the facade. The cradles usually have wheels which enable them to be moved to suit each new pick-up position for the davits as they are moved to each new fixing point on the roof. The cables are connected to the cradle, allowing it to be raised up the facade. The

cradle is fitted with an electric winding mechanism and rubber fenders to avoid direct contact with the facade. There is no winding mechanism at the level of the davit; whose function is to support the cables only. The electrical power supply for the cradle motors is from points either at roof level or at the base of the facade, supplied to the cradle by a power cable. In the event of a power supply failure, a manual system in the winch allows the cradles to be lowered to the ground. Various proprietary systems of winch motors and lifting equipment are available, all with different safety features.

When one vertical strip of facade is cleaned by a cradle that is raised and lowered from a pair of davits, the cradle is

moved to its next position by descending to its lowest level and disconnecting the cables. The davits are then unbolted and lowered from their bases before being moved to the adjacent base positions for re-connection.

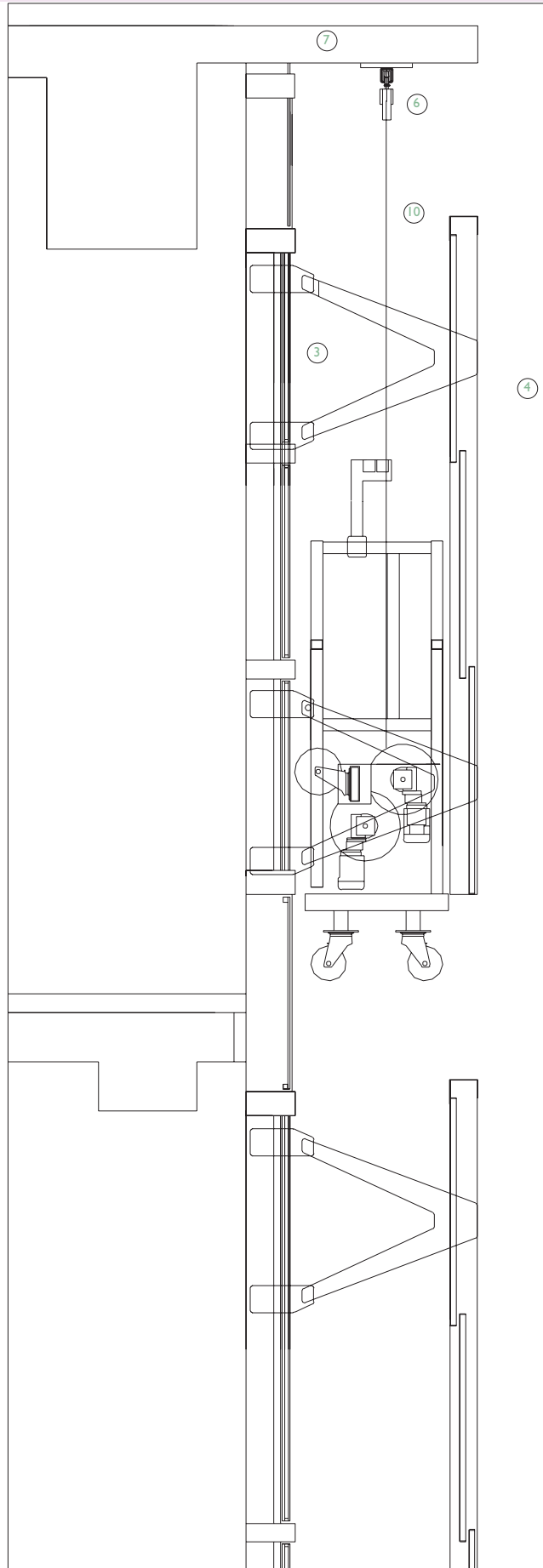
While this is a relatively slow process involving erecting davits, setting up the cables and cradle, then disconnecting the parts and moving the davits again, this method avoids a permanent and visible cleaning system being mounted on the roof. The davit system is most commonly used where the roof is used as an accessible roof terrace, or garden, where a permanent cleaning system would not be visually desirable.



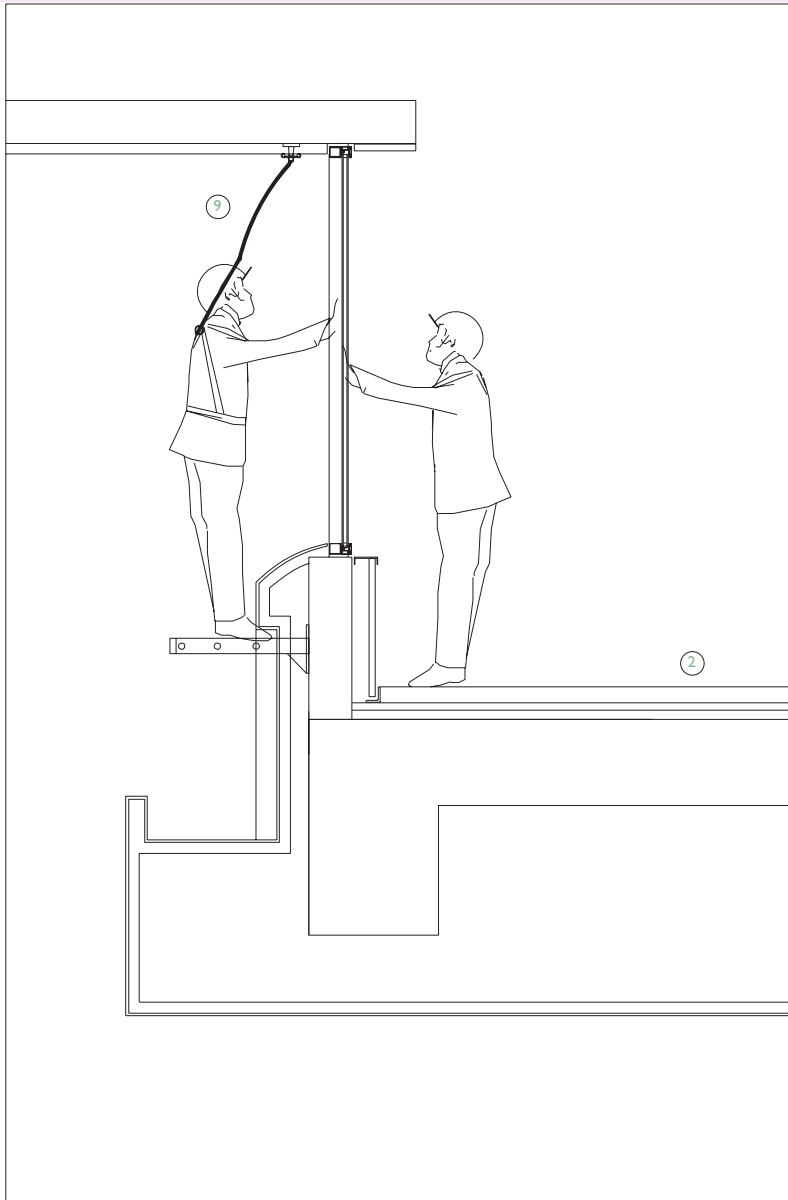
Elevations 1:25. Typical cleaning cradle.

Monorails

In the monorail system, a continuous single rail is fixed at roof level, from which a cleaning cradle is hung from a cable at each end. The monorail is set around 500mm beyond the edge of the roof to allow the cradle to hang slightly forward of the facade, typically on brackets cantilevered from the roof structure as shown in (A). The monorail is a visually strong element that is integrated into the overall design for the edge of the roof. An alternative to cantilevered fixing brackets is to cantilever the edge of the roof out by around 500mm as shown in (B). The rail is usually made from mild steel which is painted or enclosed in a decorative metal cover, usually in folded aluminium sheet.



Section 1:25. Monorail supporting cradle from beam.

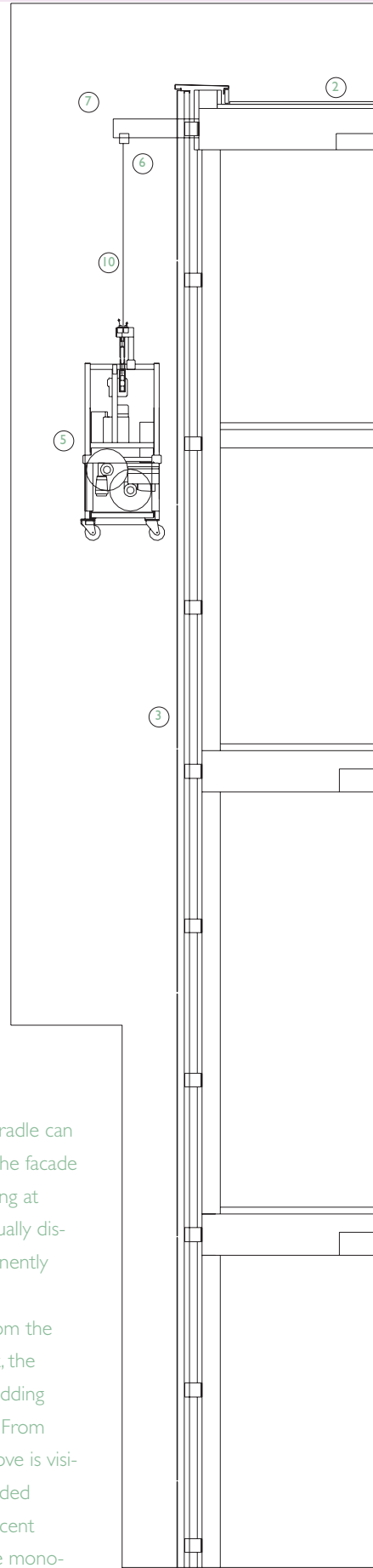


Section 1:40. Cleaning with harness on platform.

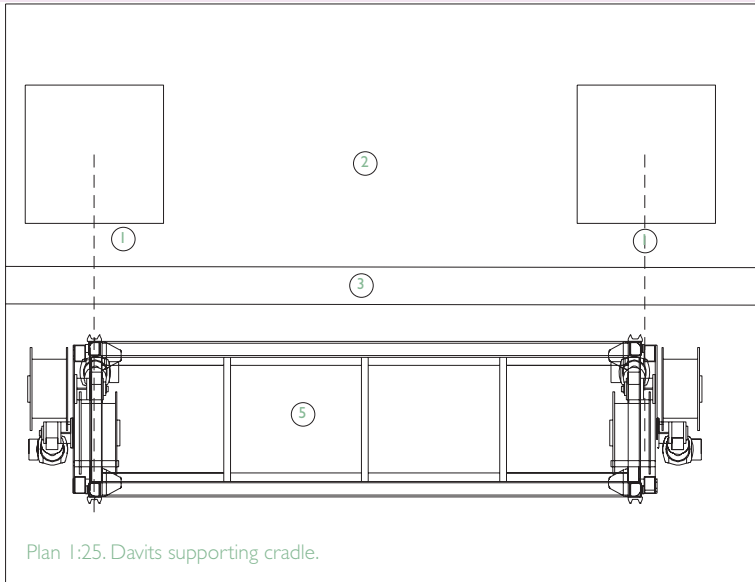
Where cantilevered support arms are used these can be castings or standard structural steel sections to suit the design. The monorail, set horizontally, is usually formed as a channel-shaped section that allows a pair of wheels to run inside the rail. Sets of wheels are operated either by sliding the cleaning cradle beneath manually, or under electrical power for larger installations. As with the davit system, cables are connected from wheeled pulleys which travel inside the monorail. The cables are lowered down and connected to the cleaning cradle, which is set at the bottom of the facade. As each vertical strip of facade is cleaned, the cradle is moved along the facade, usually when it is at roof level, just below the level of the mono-

rail. When manually operated, the cradle can be moved when at the bottom of the facade if maintenance personnel are assisting at roof level. The monorail offers a visually discreet method of providing a permanently fixed cleaning system at roof level.

Where the monorail is hung from the underside of a balcony or slab soffit, the monorail can be concealed with cladding panels set on either side of the rail. From below, only a single continuous groove is visible. A gap of around 20mm is provided between the monorail and the adjacent panel to allow for movement of the monorail itself when in use. This joint is either left open or closed with a flexible seal, typically EPDM sheet.

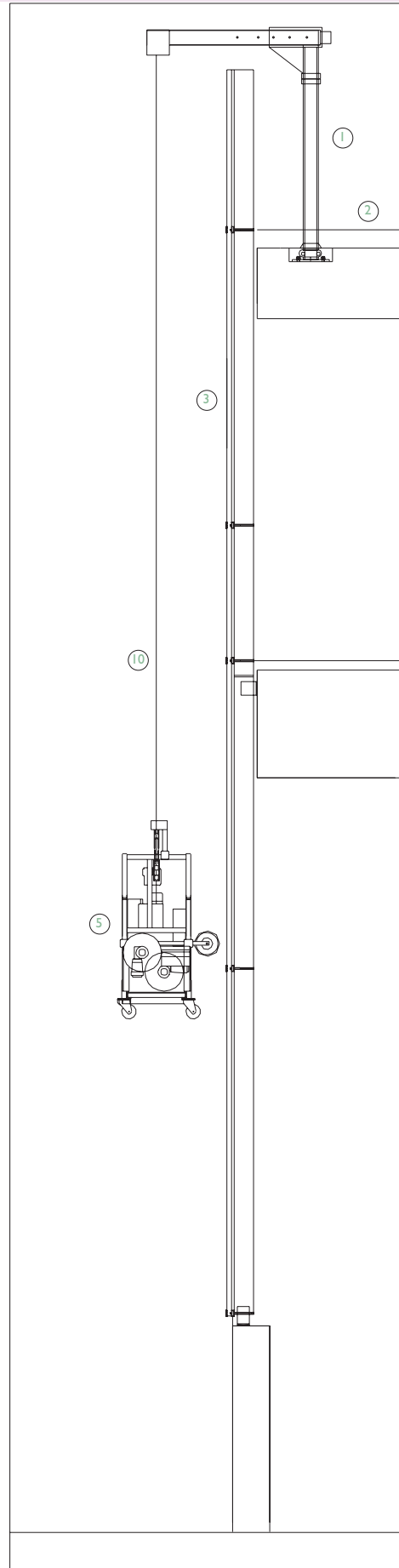
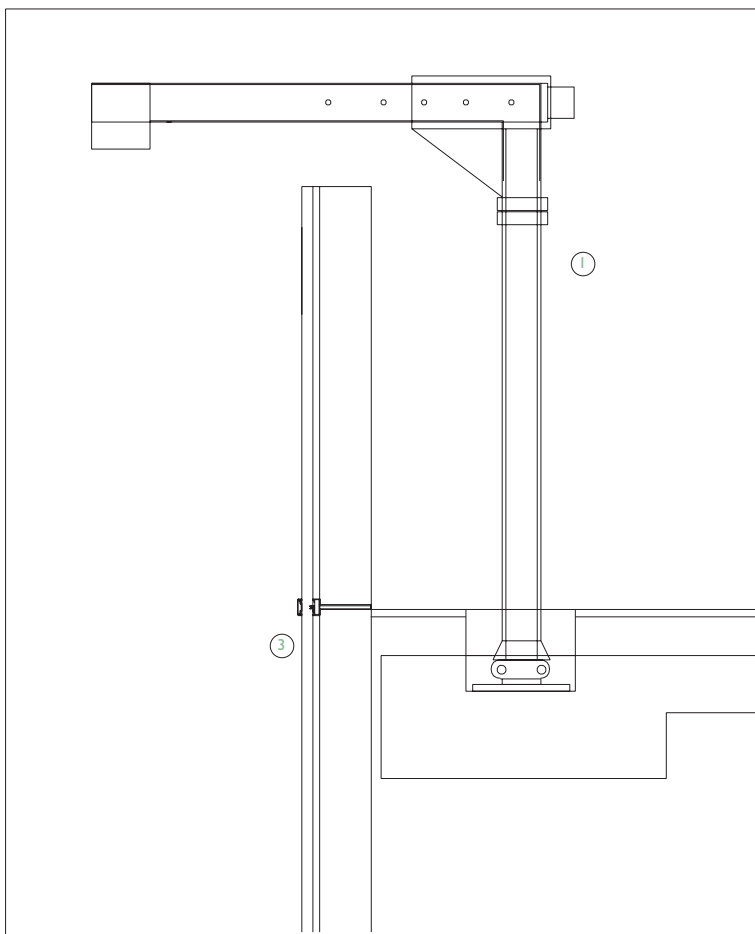


Section 1:50. Monorail supporting cradle from cantilevered brackets. Example A

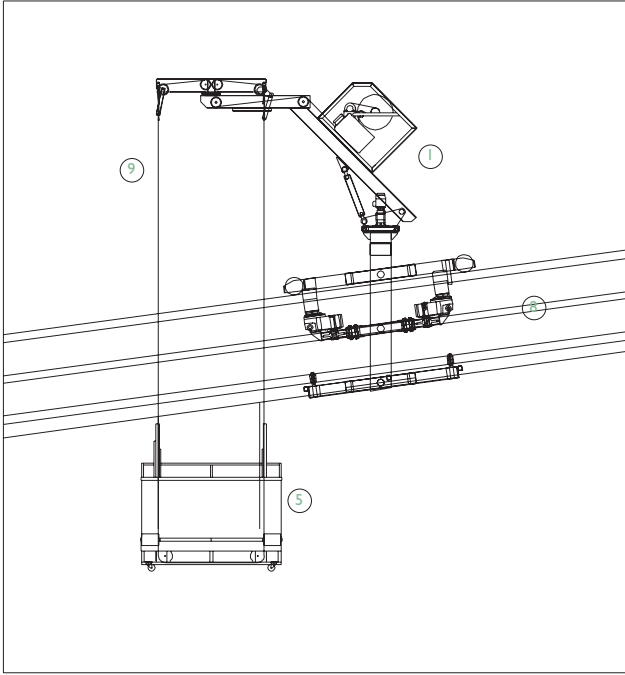


Details

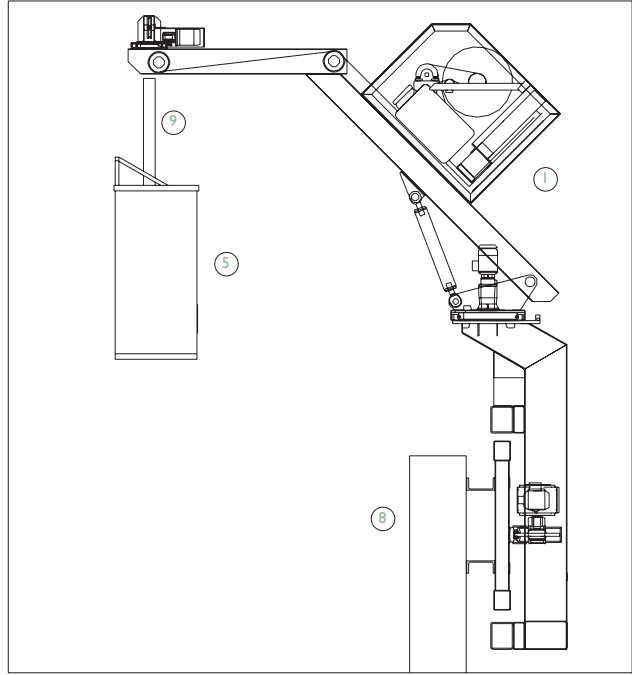
- 1. Davit
- 2. Roof finishes
- 3. Facade
- 4. Solar shading panels
- 5. Cradle
- 6. Monorail
- 7. Bracket supporting monorail
- 8. Beam supporting monorail
- 9. Safety line for harness
- 10. Cable



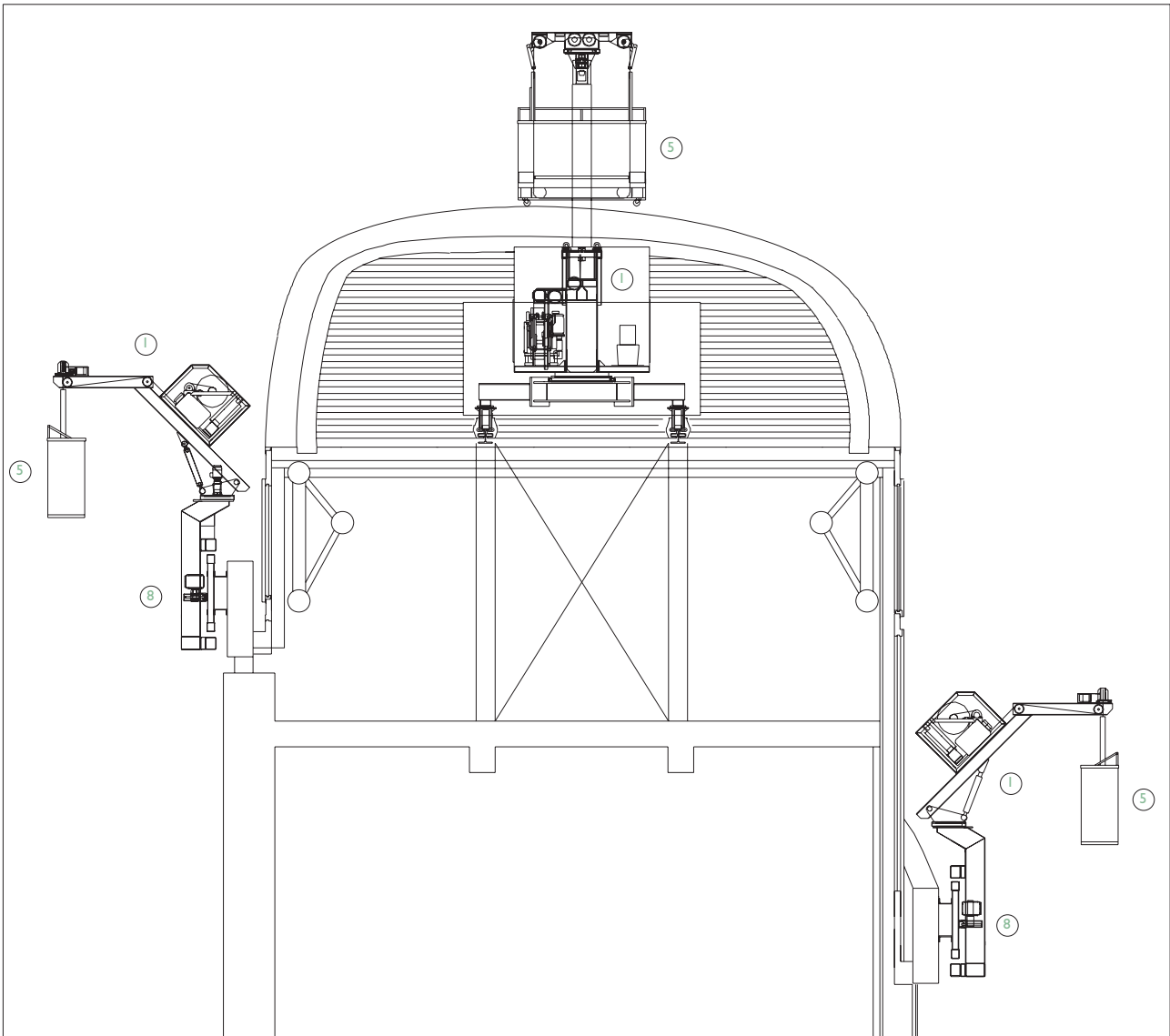
Roof-mounted maintenance systems :Trolley systems



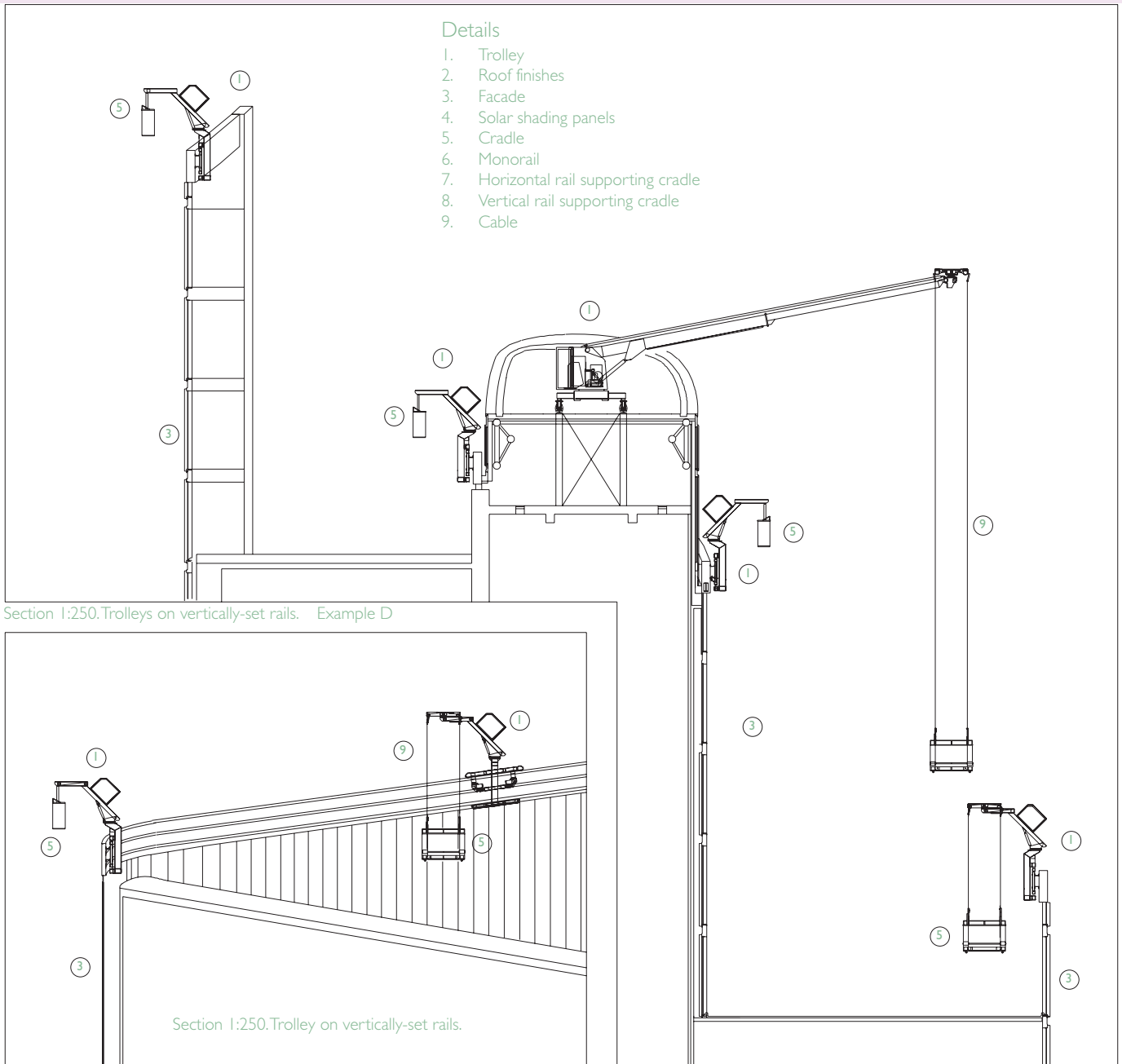
Elevation 1:100.Trolley supporting cradle.



Section 1:50.Trolley on vertically-set rails.



Elevation 1:100.Trolleys supporting cradle.



Trolley systems

Where a facade is required to be cleaned from a roof which is either sloping, or has a stepped profile in elevation, a horizontal monorail is a much less practical solution for supporting cleaning cradles. Davits are usually difficult to handle on sloping roofs. Trolley systems are better adapted to reaching facades from a sloping roof and where the facade itself is of complex geometry. Trolleys are typically mounted on wheels and are secured to a continuous track, which may be beneath the trolley, as roof-mounted rails, as (C), or may be set vertically as (D). The trolley usually has arms which project out over the edge of the roof which support a cleaning cradle from cables fixed to the ends of the arms.

The arms are sometimes telescopic (hydraulically operated) in order to reach either the facade or, for example, solar shading panels in front of the facade. The arms are usually raised or lowered to bring the cradle in and out from the facade and to bring it to rest at roof level. The trolley itself houses the motors for moving the equipment along its rails, moving the arms, and raising and lowering the cradle itself. The trolley is usually controlled from within the cradle, allowing it to move both vertically and horizontally.

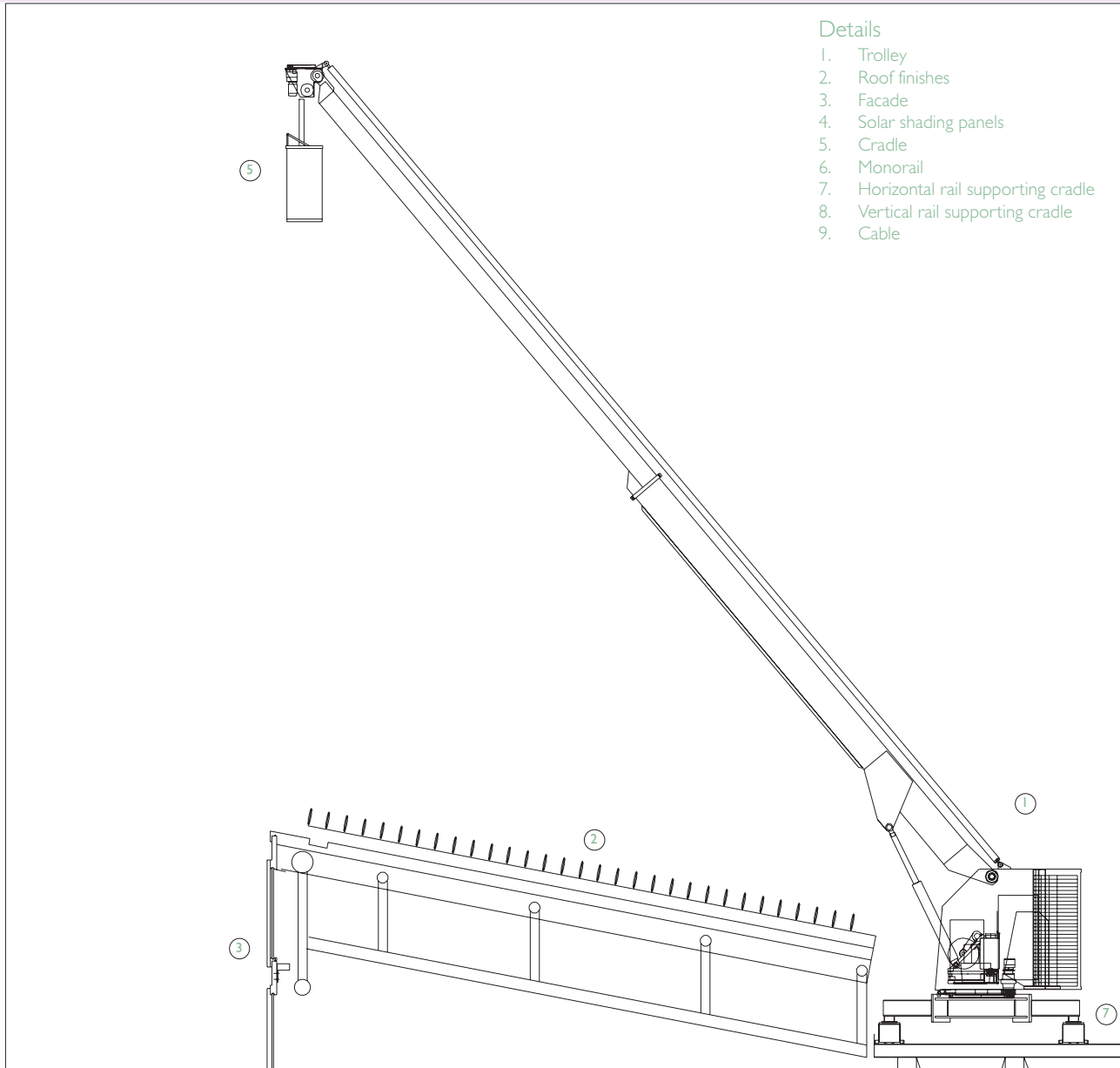
This system is not usually suited to roofs which are fully accessible to building users due to the presence of rails, or a dedicated path, as well as the visual presence of the

trolley itself. As the trolley is controlled remotely, safety at roof level is a critical consideration. Where roofs are required to be accessible, rails are mounted above the roof, but their dominant appearance may deter this solution in practice. Where the trolley can be seen from below, it is usually concealed behind a screen or in a small enclosure, allowing it to be protected from the effects of the weather. Trolley systems are well suited to being mounted on sloping or curved roofs where they climb steep slopes, typically up to around 45°.

Where facades step in at a lower level, the cradle can be offset from its supporting cables by the use of counterweights attached to the cleaning cradle. The cradle can be

Details

1. Trolley
2. Roof finishes
3. Facade
4. Solar shading panels
5. Cradle
6. Monorail
7. Horizontal rail supporting cradle
8. Vertical rail supporting cradle
9. Cable

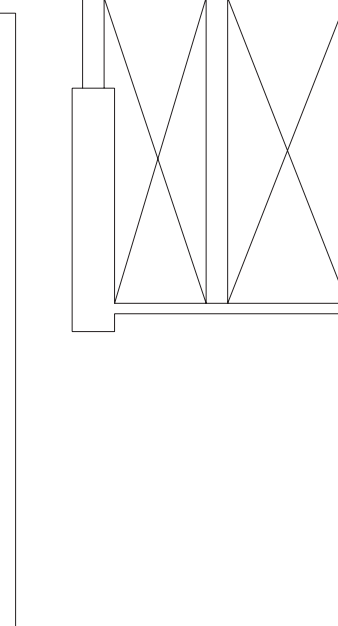


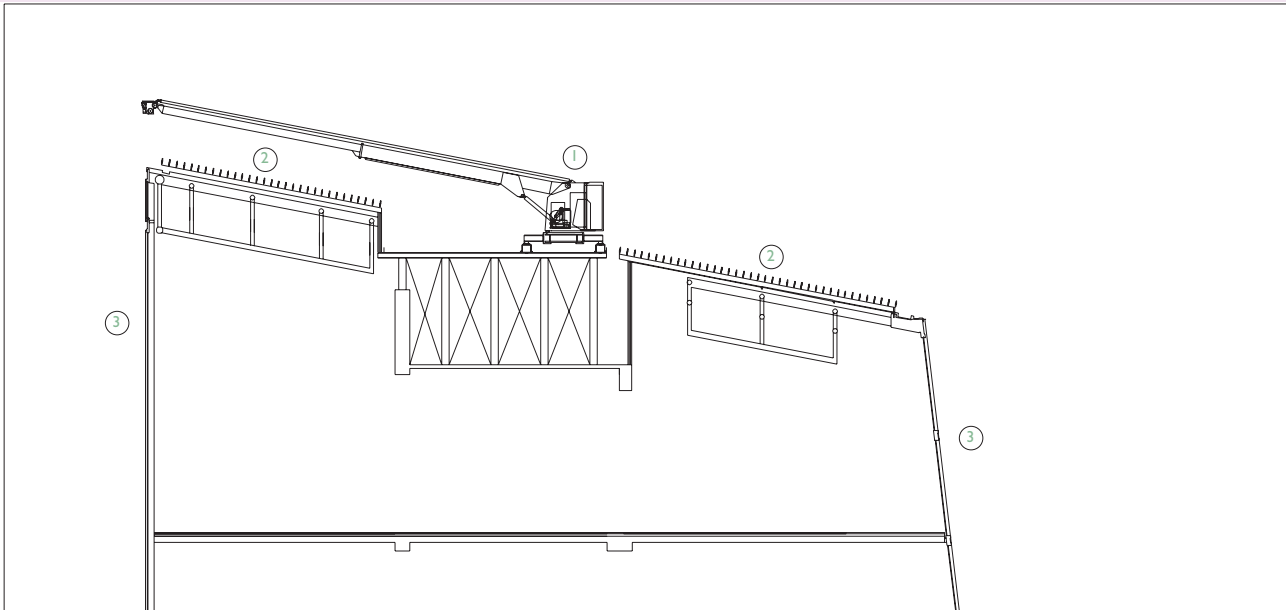
Elevation 1:100. Trolley with reach over adjacent facades. Example C

moved by an arm fixed directly to the supporting cables. As the arm moves from a vertical position to the horizontal, the cradle swings away from its cable. The movement is balanced by a counterweight at the other end of the arm which keeps the cradle level and stable. This method is useful in facades which either step outwards as rise up or are inclined outwards through their height. The mixture of a trolley system and cradles allows complex facade and roof forms to be cleaned and maintained from a single cleaning cradle. With facade and roofs of complex geometry, the trolley rails can be concealed in a gutter at roof level where facade and roof form a single and continuous form.

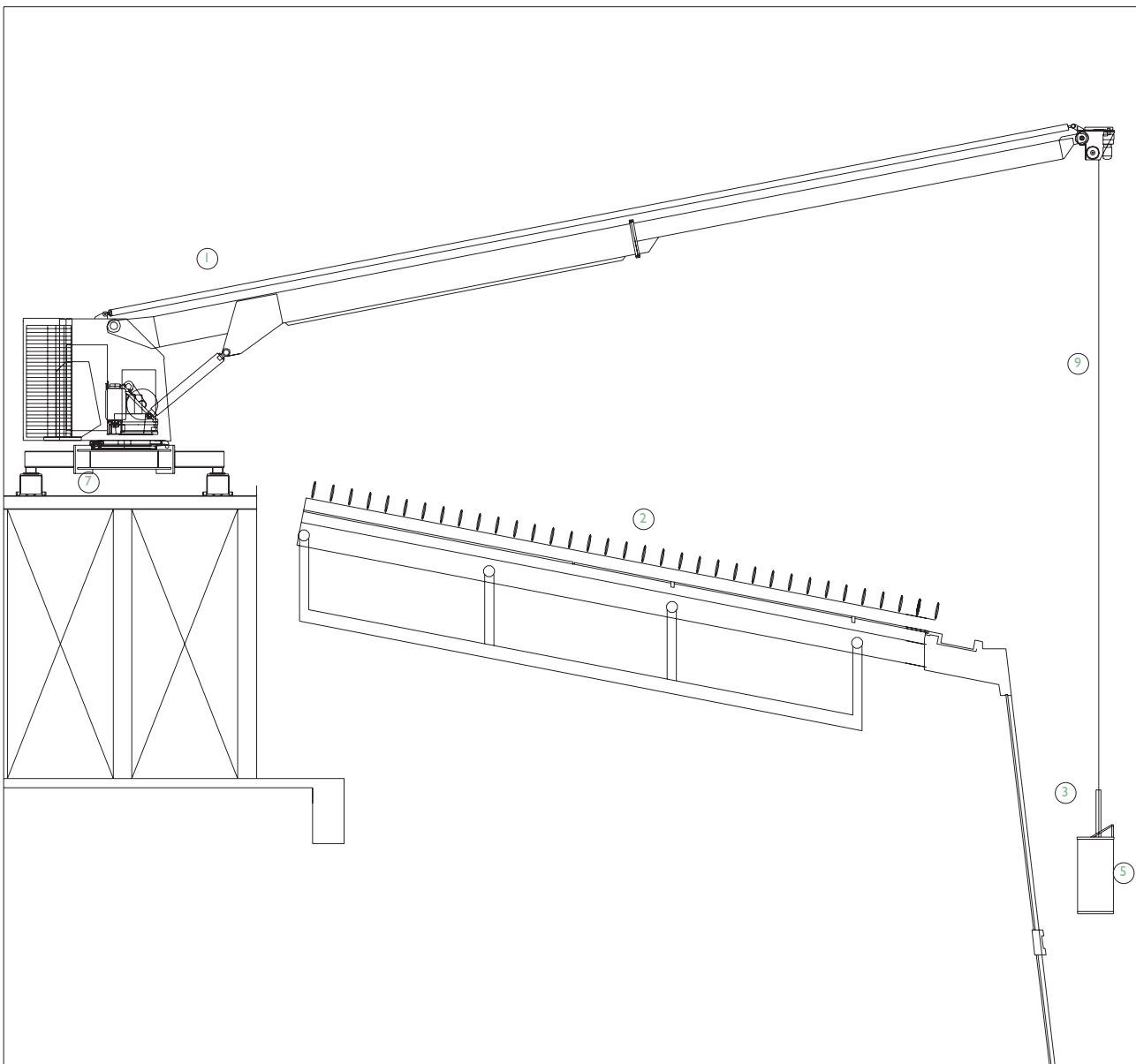
In the example above a trolley is set

behind a parapet formed by solar control louvres. It is set on a track that forms a continuous loop to suit the shape of the building. As the trolley moves around its circuit it is able to reach all parts of the facade. The trolley is able to reach the facades with telescopic arms that can be adjusted both in length and height to suit the facade being cleaned. A single trolley is usually provided for a single building, but more than one may be required, working on the same track, to suit different facade geometries beneath. Not all large-scale trolleys require tracks to restrain them. Trolleys with wheels, that move on a raised portion of roof deck, are also used.

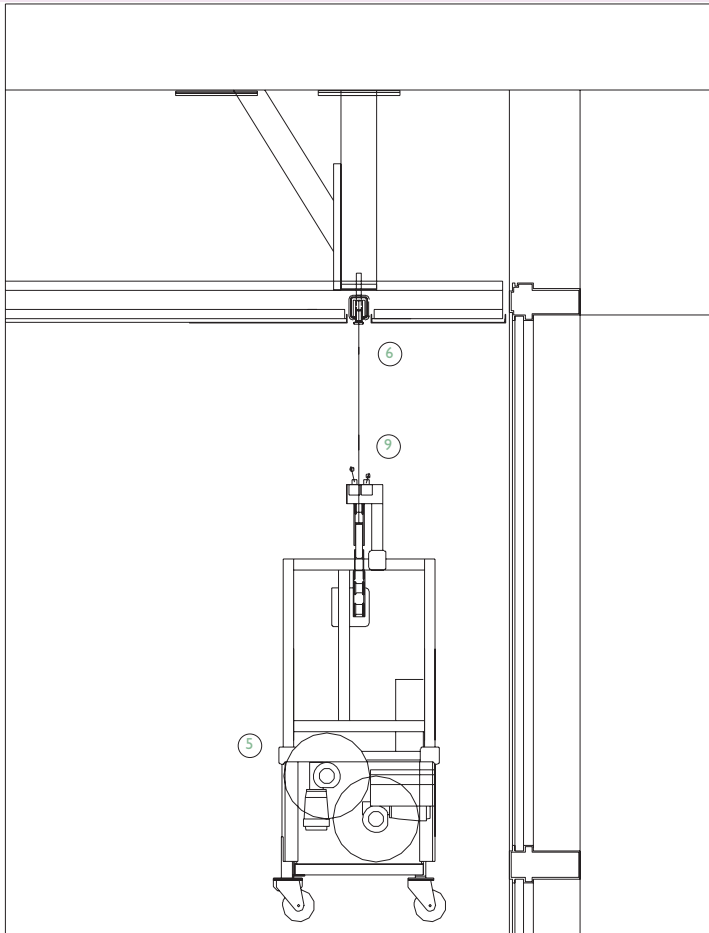




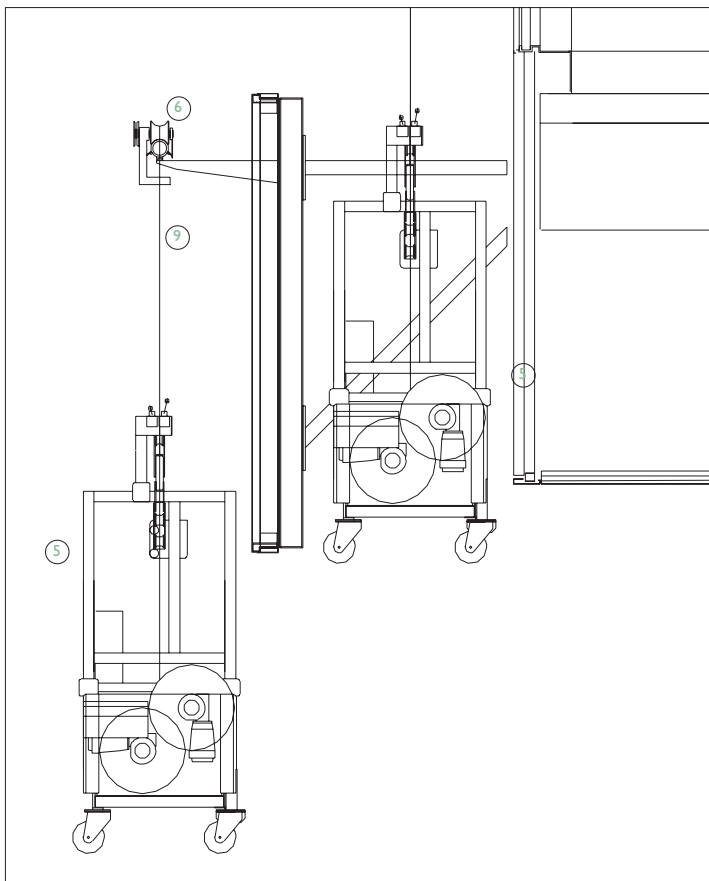
Elevation 1: 250. Trolley with reach over adjacent facades..



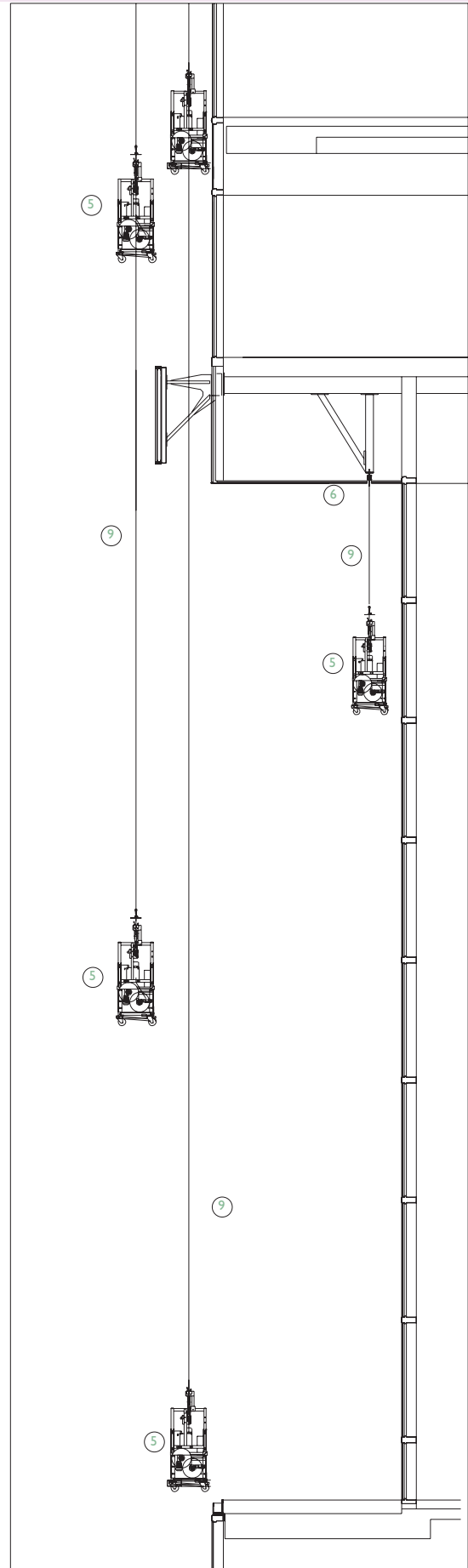
Elevation 1: 100. Trolley with reach over adjacent facades.



Section I:25. Cradle hanging from trolley.



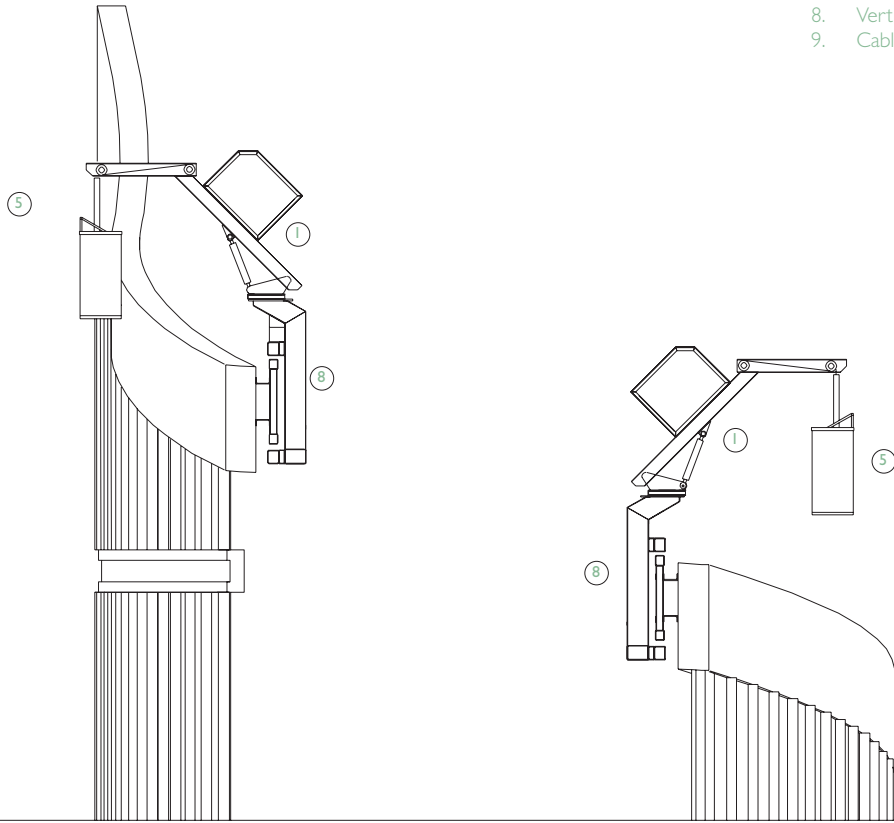
Section I:25. Cradles hanging from monorail.



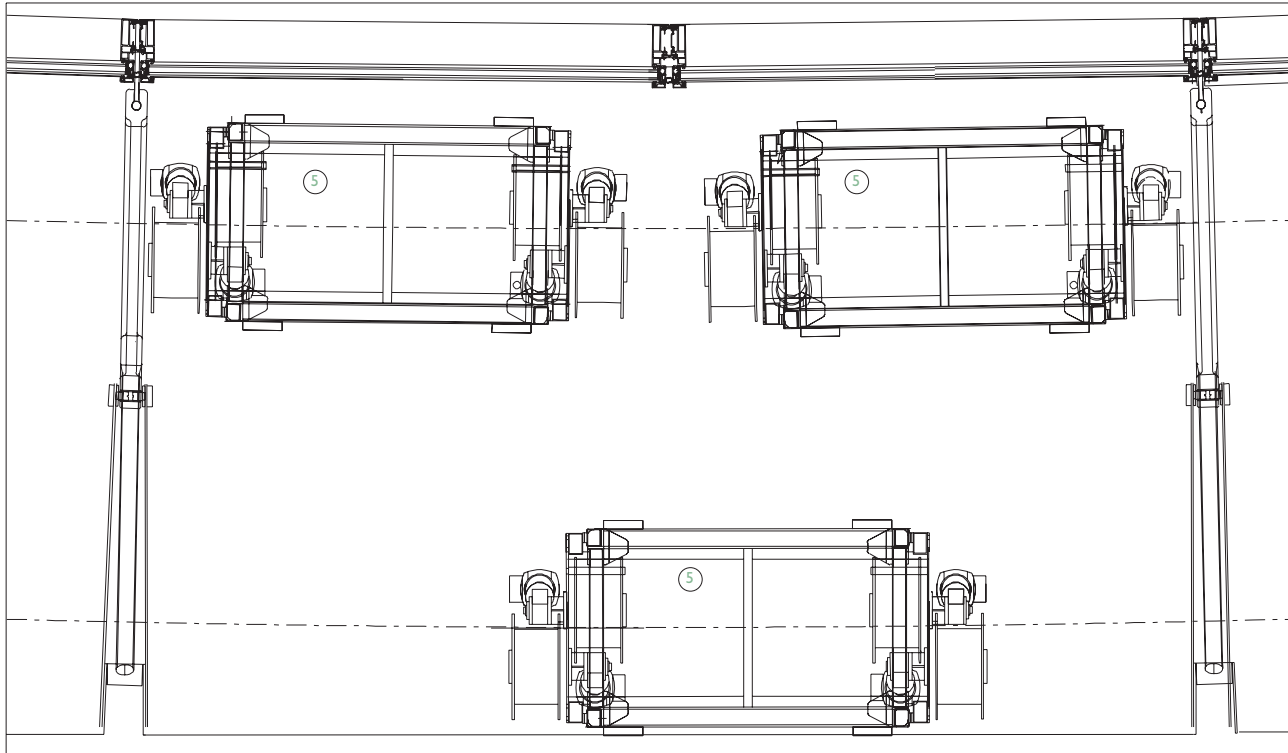
Section I:100. Cradles hanging from trolley and monorail.

Details

1. Trolley
2. Roof finishes
3. Facade
4. Solar shading panels
5. Cradle
6. Monorail
7. Horizontal rail supporting cradle
8. Vertical rail supporting cradle
9. Cable



Section 1:100. Trolleys on vertically-set rails.



Plan 1:25. Cradles hanging from trolley.



METAL

(1) Metal standing seam

- Site-based method
- Prefabricated methods
- Sealed and ventilated roofs
- Roof openings
- Ridges and valleys
- Eaves and parapets

(2) Profiled metal sheet

- Profiled metal decks
- as substrates
- Profiled metal roof sheeting
- Sealed and ventilated methods
- Twin skin construction
- Ridges
- Openings
- Eaves and parapets
- Ridges and valleys

(3) Composite panels

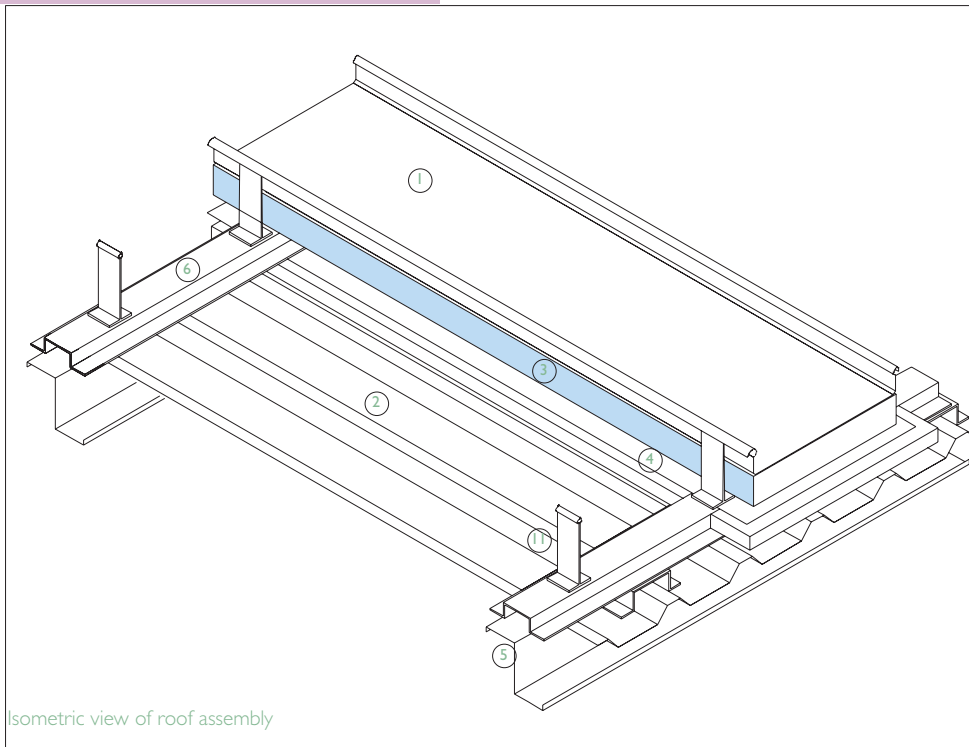
- Single wall composite panels
- Twin wall panels
- Ridges
- Verges
- Eaves
- Parapets and valley gutters

(4) Rainscreens

- Panel arrangement
- Parapets
- Monopitch ridges and verges
- Roof geometry
- Roof soffits

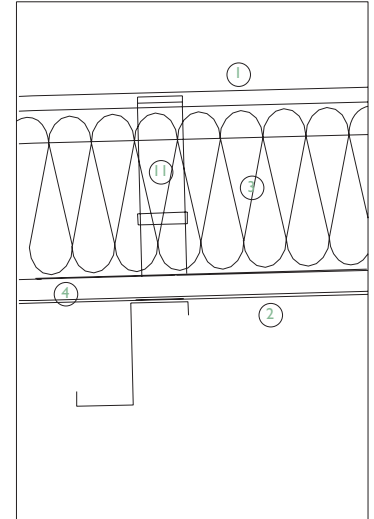
(5) Metal canopies

- Bolt fixed panels
- Fixed metal louvre canopies
- Electrically operated louvres



Isometric view of roof assembly

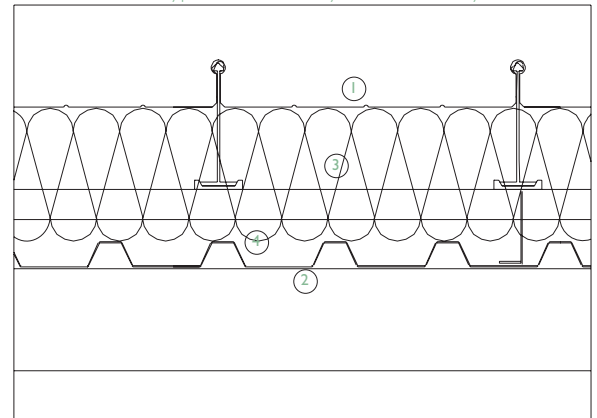
Long section I:10.
Typical roof assembly with acoustic layer



Museum, Arnhem, Holland. Architect: Mecanoo architecten



Cross section I:10. Typical roof assembly with acoustic layer



Standing seam roofs are increasingly being used for industrial and commercial buildings in preference to profiled metal sheet where concealed fixings and low roof pitches are required for visual reasons. This is because standing seam roofing is both economic and has crisp, uninterrupted joint lines that allow it to be made a visible part of the building design, often with as much architectural presence as the facade beneath. The main advantage of standing seam roofs over profiled metal roofs is that almost no fixings pass through from outside to inside the construction. This gives the roof surface a visually crisp appearance with very few visible fixings. The standing seams allow the technique to be used on very low pitch roofs.

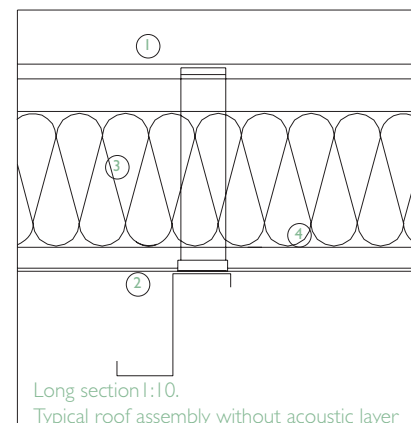
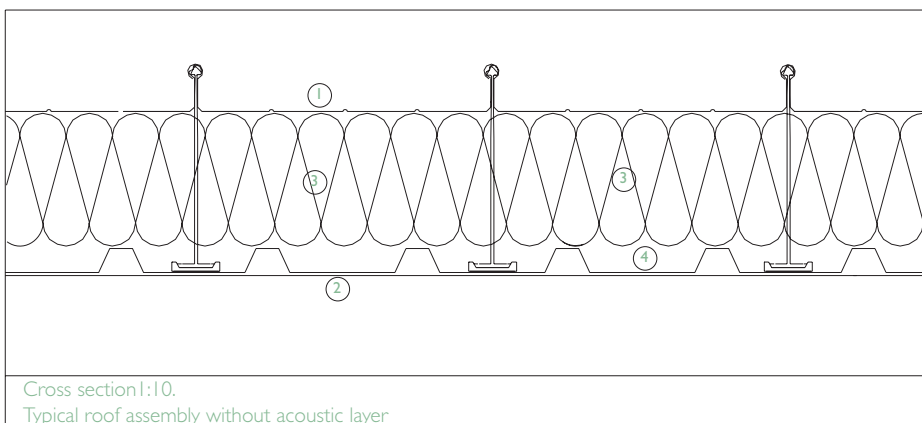
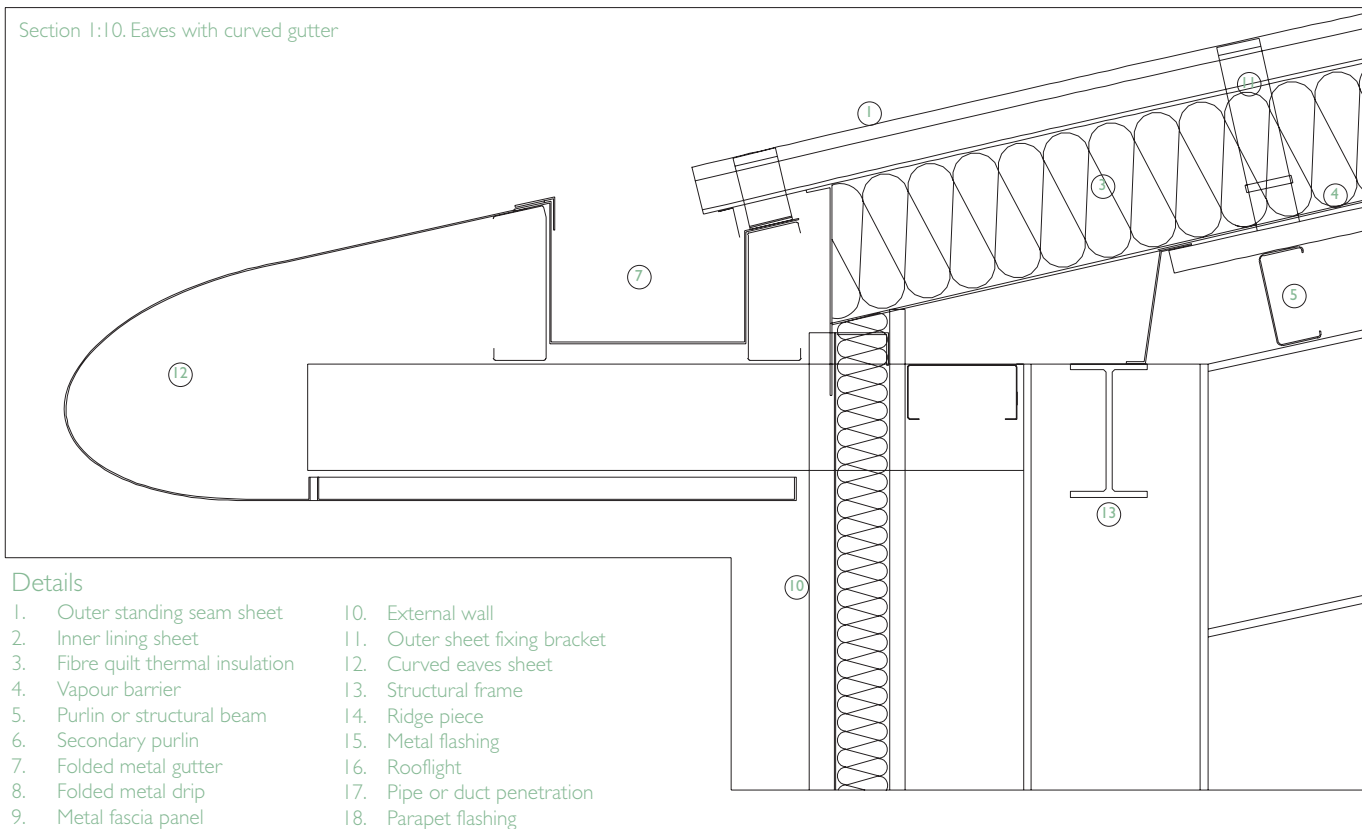
The traditional method of forming a standing seam roof is to set the sheet onto a timber substrate, and to fold the long edges of the metal upwards to form a standing seam joint. However, this method is increasingly giving way to prefabricated systems where the sheet metal is folded to a specific profile either in a factory or on site with a rolling machine. The folded metal is then secured with a clip-based fixing system rather than onto a continuous substrate. Both types are discussed in this section.

Site-based method

This method of fixing sheet is well suited to small-scale applications, or where complex geometries are used. These applications

make the use of prefabrication both unnecessary and uneconomic, due to the time needed to make special junctions and edges on site. The use of a single sheet metal profile and angle support clips used in prefabricated methods is usually too inflexible for such conditions.

In this traditional method of forming standing seam roofs, timber boards or plywood sheet is used to form a continuous substrate, or supporting surface. Standing seams are formed by timber strips of rectangular or curved section which are set at 450-600mm centres down the slope of the roof, corresponding to the width of the sheet metal used. Sheet metal is laid along the length of the roof from top to bottom,



with the sides of the sheet folded up and over the timber battens. Successive strips of metal sheet are lapped over the next to form a continuous sealed surface. The standing seam joint is formed by folding the metal together to form a seal. Because the roof is formed, effectively, as a series of linked 'gutters', the standing seam between each gutter is above the level of the water draining down it. Rainwater is avoided being drawn through the joint by capillary action by one of two methods, where the joint is either sealed or ventilated. In a sealed joint the seam is pressed tight, as in a traditional lead or copper roof either by folding the metal over itself to form a thin seam, or by forming the metal over a timber roll or section. In a venti-

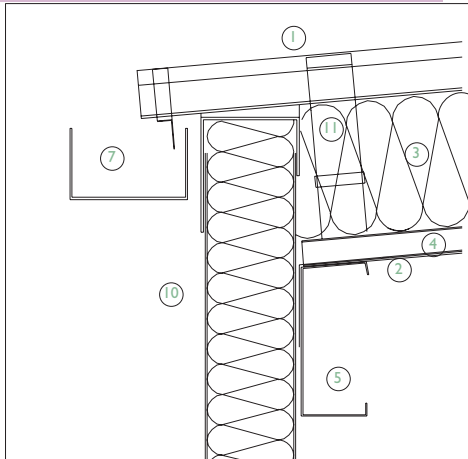
lated joint, a small gap is left between the folded sheets to allow air to pass through but not rainwater:

Sheet metal is fixed to the timber upstand strips either by clips, which avoid penetration of the sheet metal, or by a mechanical fixing through one side of the sheet. The fixing is applied to the side which has the adjacent sheet lapped over it, in order to avoid rainwater passing through the fixing penetration. Timber-based substrates are increasingly being replaced by profiled metal sheet, which has a much greater spanning capability than plywood sheet, helping to reduce the cost of the supporting structure. Timber-based substrates, typically plywood or timber boards, require support at

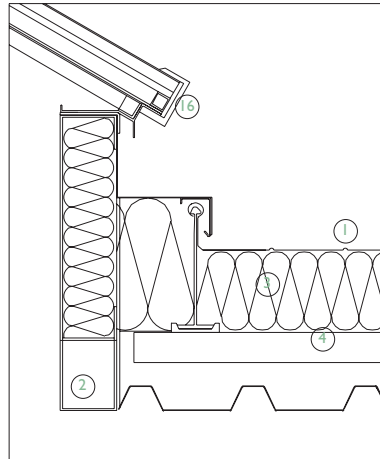
400-600mm centres. Profiled metal sheet is increasingly being used as a substrate, as it provides a self-finished soffit (underside) to the space below the roof. This is particularly useful where acoustic ceilings are used, with perforated sheet that has a paint coating on its underside.

Prefabricated methods

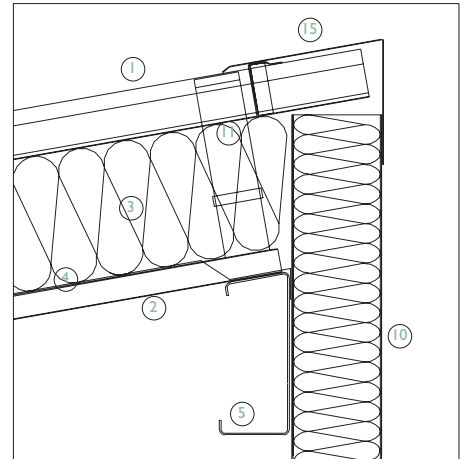
The most common configuration of prefabricated standing seam roofs is a structural deck, typically reinforced concrete or profiled metal sheet, with insulation set on top and an outer (upper) sheet supported on brackets set onto the structural deck. An alternative configuration is to fix the brackets supporting the outer sheet to a set of metal



Section 1:10. Eaves with exposed gutter

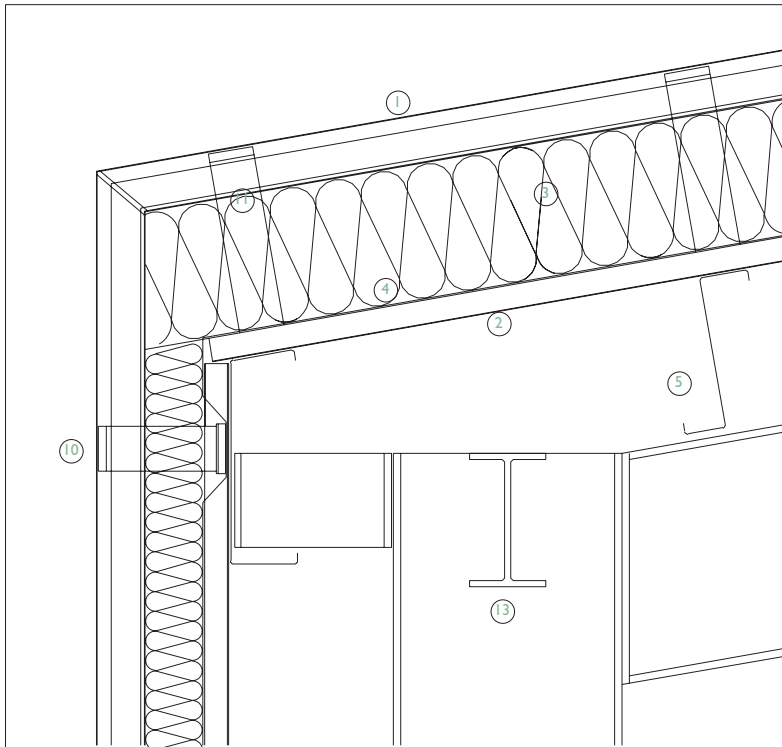


Section 1:10. Junction with rooflight



Section 1:10. Monopitch ridge

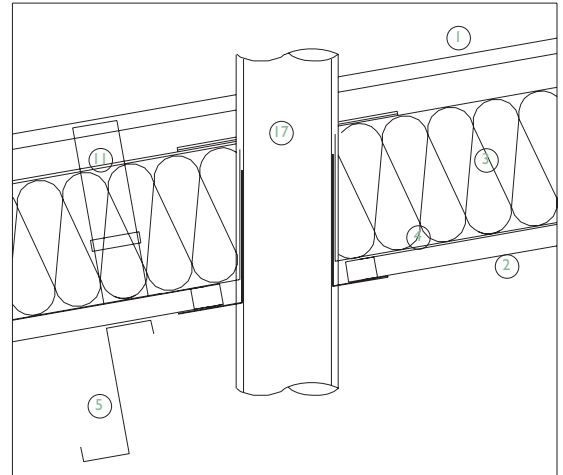
Section 1:10. Folded eaves



Details

- | | |
|-----------------------------------|--------------------------------|
| 1. Outer standing seam sheet | 10. External wall |
| 2. Inner lining sheet | 11. Outer sheet fixing bracket |
| 3. Fibre quilt thermal insulation | 12. Curved eaves sheet |
| 4. Vapour barrier | 13. Structural frame |
| 5. Purlin or structural beam | 14. Ridge piece |
| 6. Secondary purlin | 15. Metal flashing |
| 7. Folded metal gutter | 16. Rooflight |
| 8. Folded metal drip | 17. Pipe or duct penetration |
| 9. Metal fascia panel | 18. Parapet flashing |

Section 1:10. Roof penetration



purlins. A metal liner sheet is set below the purlins to support thermal insulation quilt, set between the purlins. A vapour barrier is set between the insulation quilt and the liner tray on the warm (in winter) side of the thermal insulation. In hot, humid countries an additional vapour barrier is set on top of the insulation where the risk of interstitial condensation is from the outside as well as the inside.

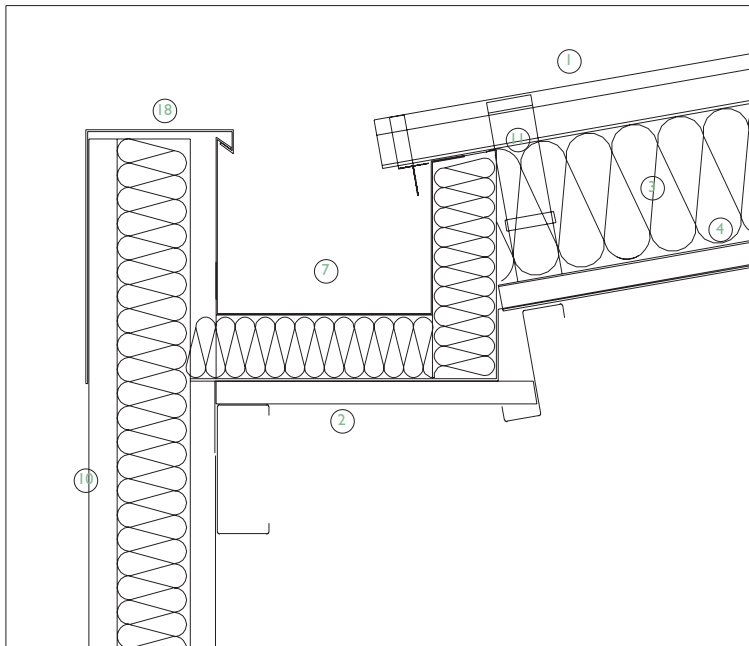
For both construction configurations the roof pitch can go down to 1°, after taking into account any structural deflections that would further reduce this angle. Metal sheets can be made up to 40 metres in length, but road transport is difficult, with long sheets (longer than a trailer length) requiring special

arrangements for road transportation in most countries. For larger projects, long sheets are formed on site with a rolling machine that can form the profile of the standing seam sheet to any length required, the profile being formed from metal coil.

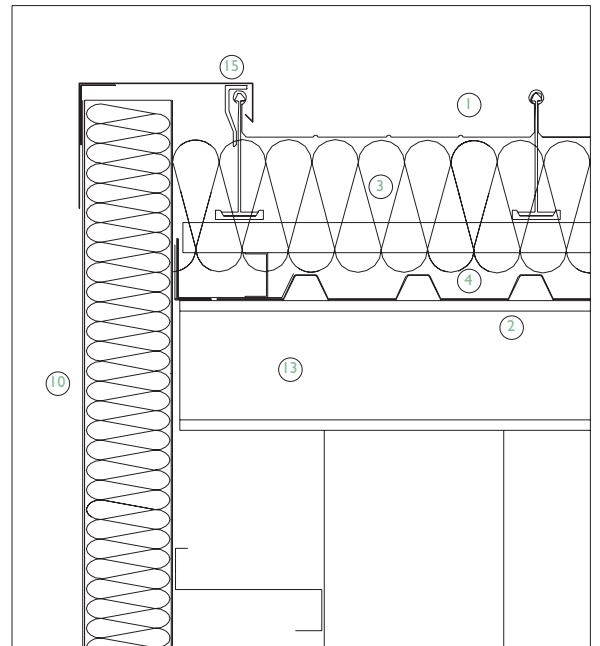
Support brackets are usually T-shaped and are fixed either to the structural deck or to purlins with self-tapping screws. The brackets are usually made from extruded aluminium in order to provide a profile that is both thick enough to form a rigid connection and sufficiently precise in section to retain a given standing seam profile in place. Metal sheet is formed in long lengths of folded trays which are then fixed onto the support brackets. Finally the standing seam

joints are crimped to form a seal, usually with a 'zip up' tool that travels along the joint and across the roof, sealing the joint as it moves along. This fixing method gives very smooth and straight joints, but the long lengths of sheet metal forming the roof surface can result in 'oil canning', where part of the metal surface appears to be crinkled as a result of uneven thermal expansion. Generally, thermal expansion is accommodated by allowing the long lengths of metal sheet to slide over the support clips, with the sheet itself fixed rigidly in only a few places along its length.

Standing seam sheets can form shallow curves by gently bending the metal on site, or alternatively by curving the sheets in the

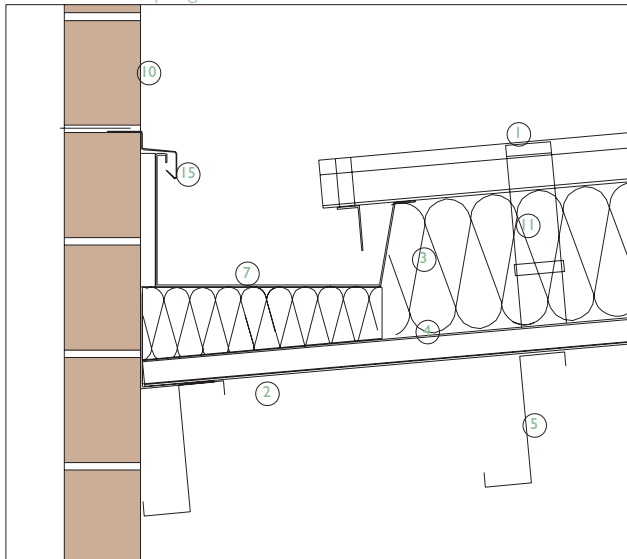


Section 1:10. Concealed eaves gutter

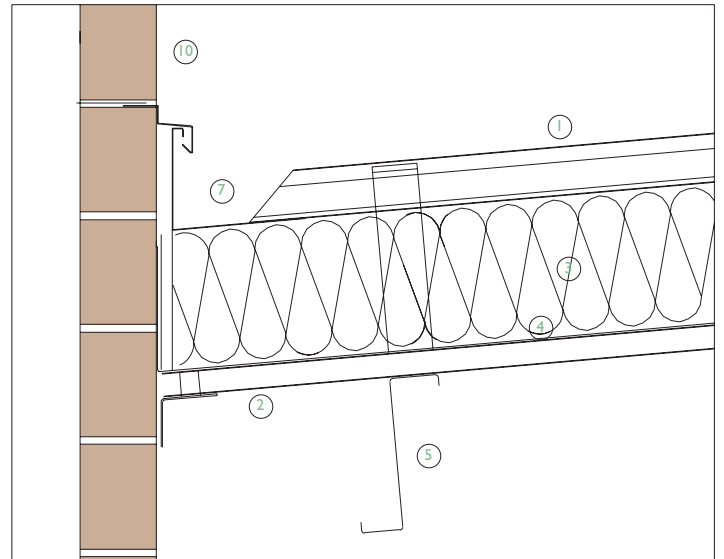


Section 1:10. Verge

Section 1:10. Parapet gutter at abutment



Section 1:10. Parapet gutter at abutment



factory, to give a smooth appearance. Small radius curves are formed by crimping the sheet in the factory, where the material is mechanically formed with small local folds. Sharp folded corners are made by welding two sheets together along the fold line.

Sealed and ventilated roofs

The choice of a sealed or ventilated roof configuration depends upon both the metal used and the nature of the construction beneath. Ventilation is essential if the thermal insulation is set some distance below the metal sheet, as in a pitched roof where the insulation is set horizontally, above a closed ceiling. Ventilated roofs are also suitable where the external roof form has a complex

geometry. This allows the thermal insulation to be set horizontally beneath, while the roof form can be free of the constraints of making the entire roof construction follow the same geometry. Ventilated roofs have slots at ridges, valleys and perimeter gutters to allow air to pass through the construction to ensure that the roof build-up remains dry. Sealed roofs use sealing strips in the standing seam joints to make them both airtight and watertight. Moisture vapour that builds up inside the construction is released by slots for passive ventilation at the ridge and eaves.

Unlike other metals, zinc sheet requires ventilation on the underside to avoid corrosion from water vapour trapped inside the construction. Ventilation for zinc roofs has

traditionally been provided with open jointed timber boards, but this method is being replaced on larger applications by a plastic-based woven mat set onto a substrate, which allows air to pass across the inside face of the zinc while using a continuous substrate material beneath.

Roof openings

Rooflights are set into standing seam roofs in one of two ways: either by forming a pressed metal upstand around the opening so that the rooflight projects up around 150mm above the level of the roof, or by setting it level with the roof finish and forming a gutter around the edges of the rooflight. This second method avoids the

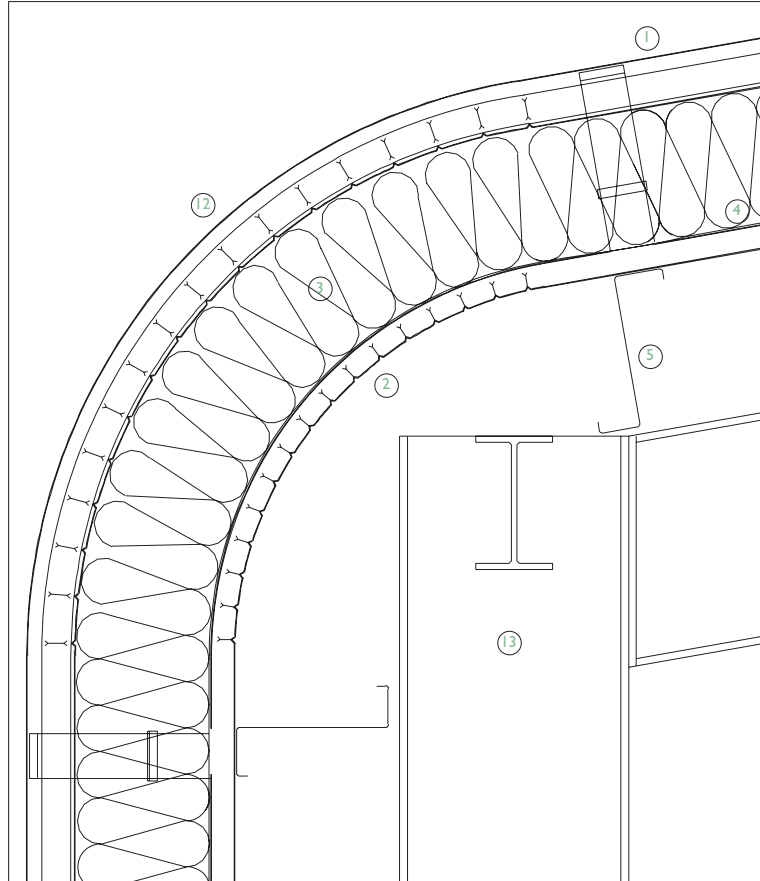
Details

- | | |
|-----------------------------------|--------------------------------|
| 1. Outer standing seam sheet | 10. External wall |
| 2. Inner lining sheet | 11. Outer sheet fixing bracket |
| 3. Fibre quilt thermal insulation | 12. Curved eaves sheet |
| 4. Vapour barrier | 13. Structural frame |
| 5. Purlin or structural beam | 14. Ridge piece |
| 6. Secondary purlin | 15. Metal flashing |
| 7. Folded metal gutter | 16. Rooflight |
| 8. Folded metal drip | 17. Pipe or duct penetration |
| 9. Metal fascia panel | 18. Parapet flashing |

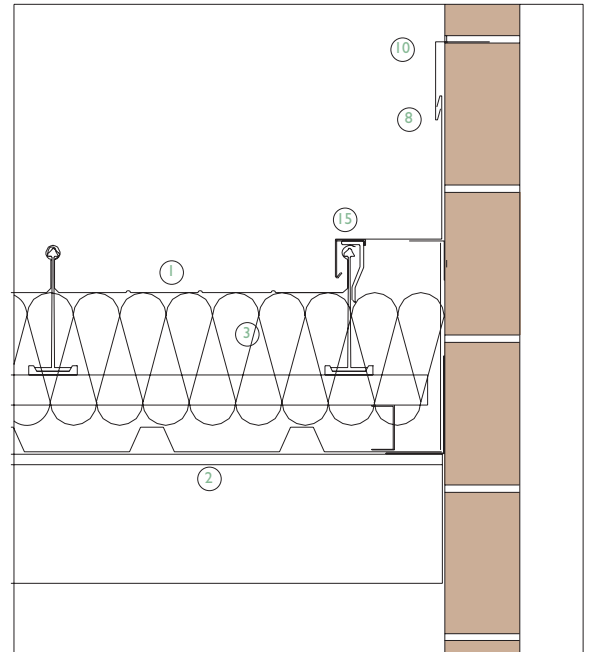


Museum, Arnheim, Holland. Architect: Mecanoo architecten

Section I:10. Curved ridge



Section I:10. Abutment with masonry wall



need for rooflights to appear as projecting box-like forms in an otherwise smooth, continuous roof plane. If the rooflights are set into the opening, then a metal flashing is fixed around its edge, being lapped under the standing seam roof on its top edge. At the sides the flashing forms a standing seam with the adjacent joints running down the roof, and its bottom edge lapped over the top of the roof sheet immediately below it. Penetrations for small ducts and pipes through the standing seam roofs use simplified flashings. An upstand is formed as a continuous skirt around the projecting pipe and a flashing, usually welded to the pipe, folds over the top of the upstand to avoid rainwater from penetrating the joint. The base of the 'skirt' flash-

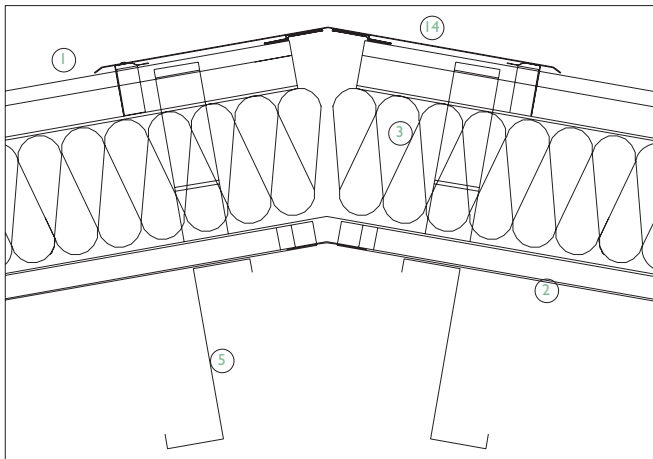
ing is bonded to the metal sheet roof covering and sealed, typically with a silicone-based bond and seal. Standing seams that clash with the base of the skirt flashing are stopped and closed above and below the penetration.

Ridges and valleys

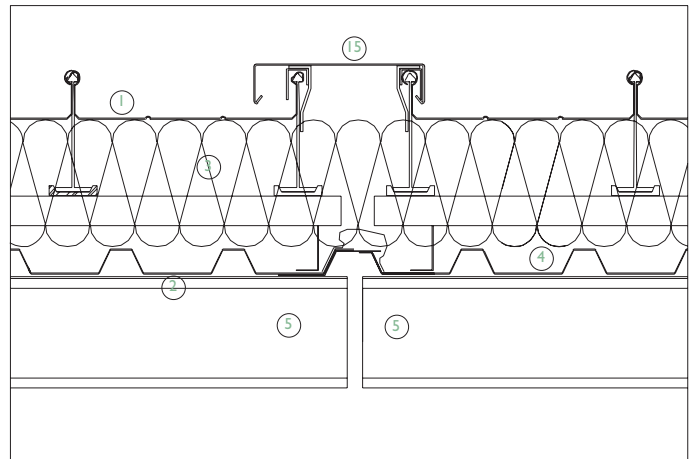
Ridges are formed by a variety of methods. In (A) a folded or curved metal sheet is set over the gap between the two sides of the roof on the level of the top of the standing seam. The gap between the top and bottom of the standing seam is closed with a formed metal filler piece, or strip. In (B) a sharp ridge line is formed as a standing seam joint, with the seams meeting the ridge being

terminated to avoid the need for visually bulky filler pieces being seen from below. In (C) the ridge is treated as a soft fold, without any break in the material. Although this may appear to be the most straightforward of the ridges to form, the alignment of the ridge piece is as critical as in versions (A) and (B) in order to create a straight ridge line. Shadows from the sun cast across the ridge will reveal any waviness in the line of the top of the roof.

Valleys are formed by lapping the ends of the standing seam roof into a folded metal tray forming a continuous gutter. The gutter is often welded at the joint between one length of folded sheet and the adjacent sheet in order to avoid the possibility of a

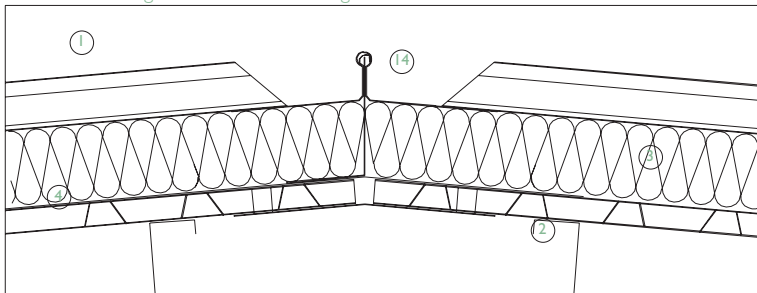


Section 1:10. Ridge with flashing Detail A

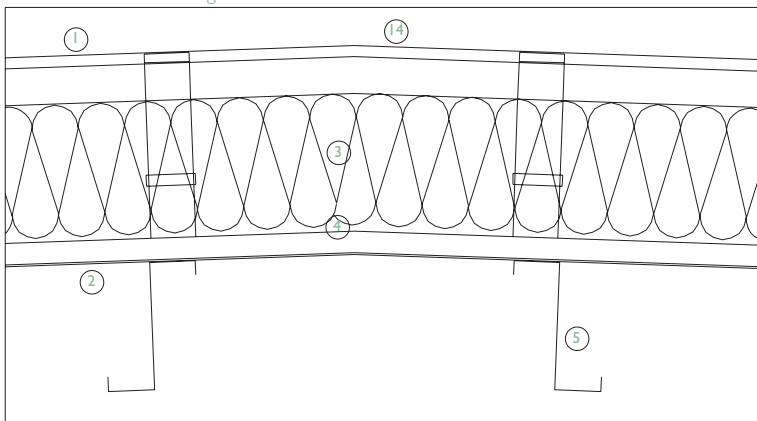


Section 1:10. Expansion joint

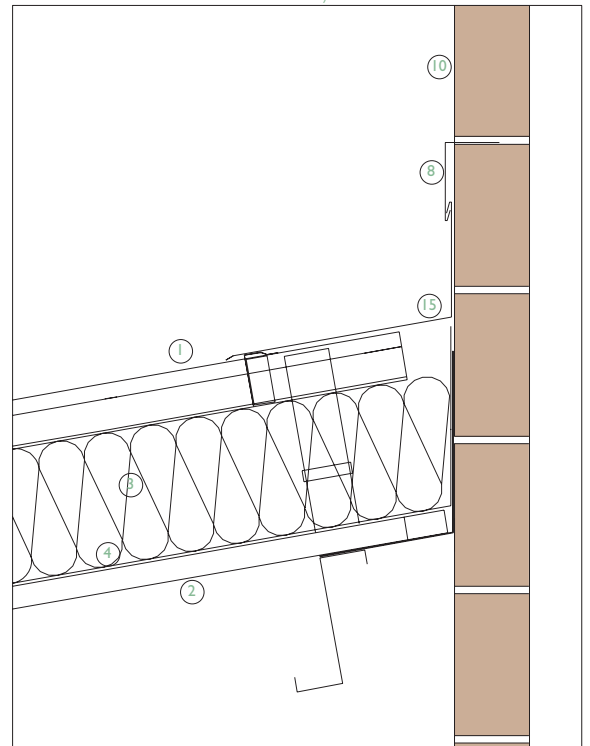
Section 1:10. Ridge with recessed flashing Detail B



Section 1:10. Curved ridge Detail C



Section 1:10. Abutment with masonry wall



water leak in the gutter. Because of the reduced roof depth at gutters, thermal insulation set below it is often thinner than the adjacent areas of roof. The reduced thermal insulation can be improved upon by using either higher performance insulation in that area, or by deepening the structure of the roof beneath where this is possible, to allow the depth of thermal insulation to be increased.

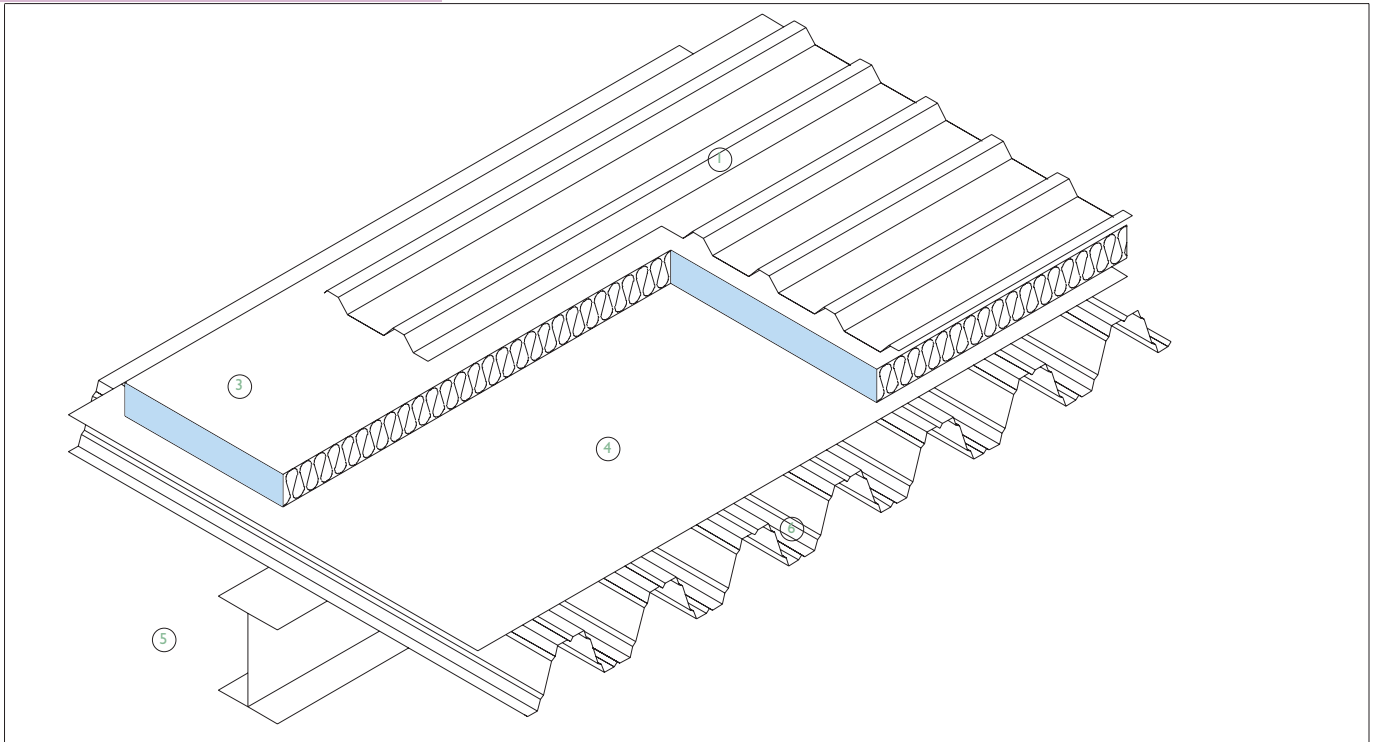
If the roof is ventilated, the gap formed between the top of the gutter upstand and the underside of the standing seam roofing allows the passage of air into the roof void without the need for ventilation slots, visible from below, being set into the outer face of the roof.

Eaves and parapets

Eaves are formed in a similar way to a valley, with a gutter set at the edge of the roof. Increasingly, gutters are being integrated into roof forms in order to avoid a weak visual line formed by a gutter which is not continuous with the smooth lines of the roof. When additional closer pieces are used, such as bull nose profiles, the metal panels are usually designed to be drained and ventilated to the exterior, and the line of waterproofing continues up the external wall to the underside of the standing seam roof.

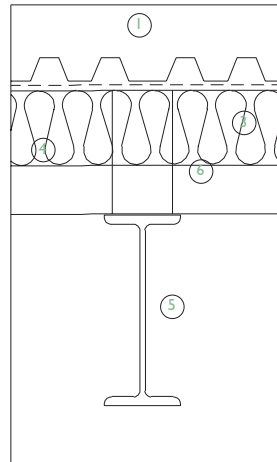
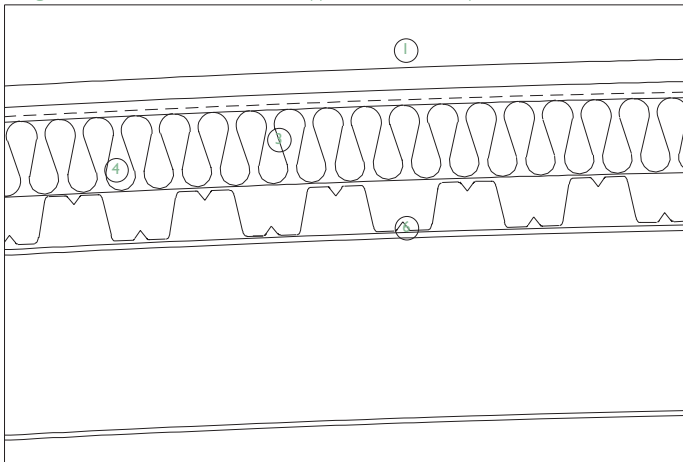
Parapets are formed by taking the side of the gutter that is adjacent to the external wall up to the parapet coping, where it is terminated with a rubber-based seal bonded

to the top of the external wall. A parapet coping is set into this seal as an overcloak flashing and second line of defence against rainwater penetration.



Isometric view of roof assembly

Long section and cross section 1:10. Typical roof assembly



Details

1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved eaves sheet
13. Structural frame
14. Ridge piece
15. Metal flashing
16. Rooflight
17. Pipe or duct penetration
18. Parapet flashing
19. Vented filler piece

The main advantage of profiled metal sheet over other metal roof types is the ability of the material to span economically up to around 3.5 metres between primary structural supports. This self-supporting ability of the material, combined with its weather resistant, painted coating applied during manufacture, makes it able to be used as both a substrate material for a finish in a different material set onto it, or as a single layer structural and weatherproof material. Where standing seam roofing, with its high projecting folds, is suited to long, straight, or gently curving spans, profiled metal sheet can both span between supports and form complex geometries. It is this flexibility of being both structural deck and waterproofing layer that

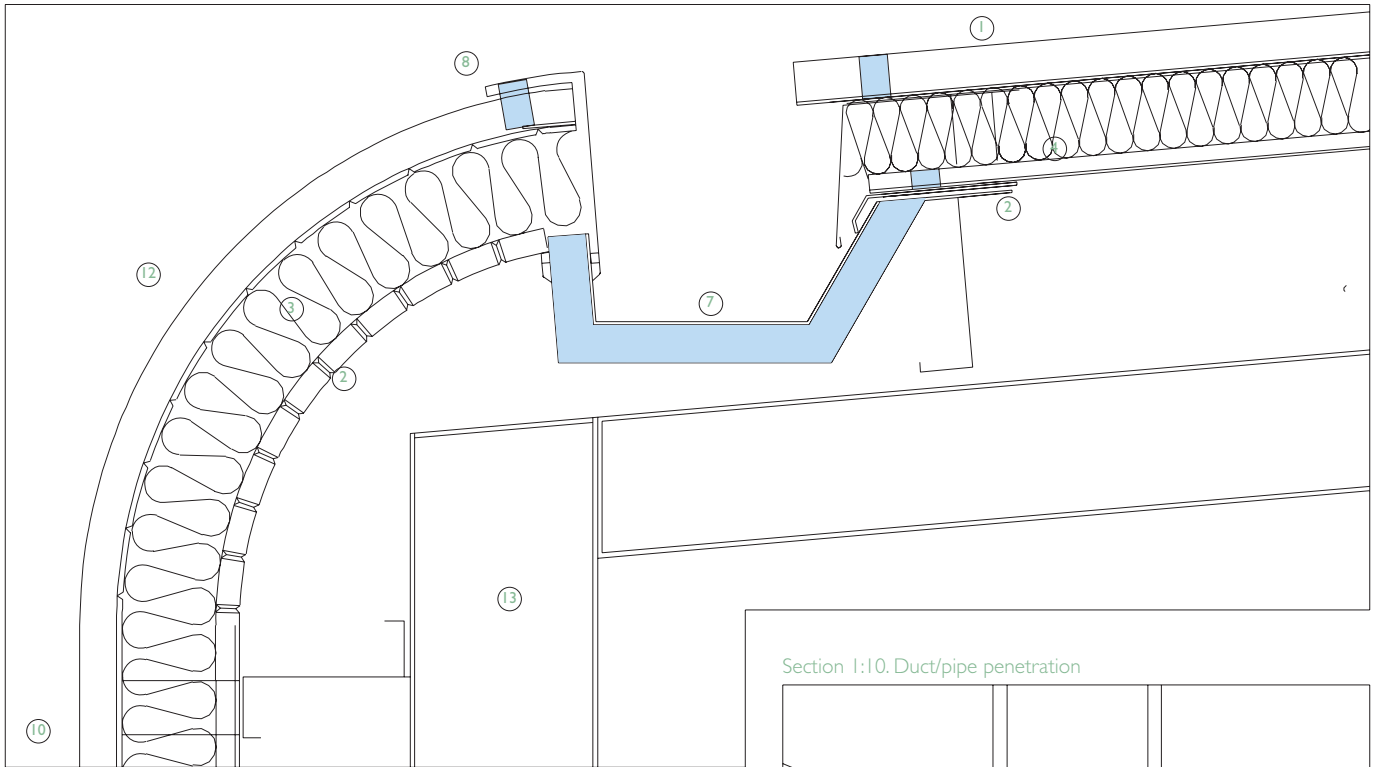
has an advantage where the interior finish is designed to be in a different material, such as dry lining or decorative boarding. In recent years roof pitches have greatly reduced to make the roof as flat as possible, usually for visual reasons. Most profiled sheet is laid to a minimum pitch of around 4°. Standing seam roofs can go down to a 1° pitch, depending on the geometry of the roof.

When used as a substrate, profiled metal sheet can be cut to form complex geometries, typically supported by a steel frame to create a 3-dimensional form. Profiled sheet with an overall depth of 50mm is used typically, but much deeper sections are used for spans above 3.5 metres to around 6.0 metres, with a depth up to around 200mm.

The deep sections are also used in composite roof decks when filled with concrete. For a steel profile, sheets of 0.7mm thick are used for the outer skin; for aluminium a 0.9mm thick sheet is used. Steel is galvanised and coated, while aluminium is mill finished or coated.

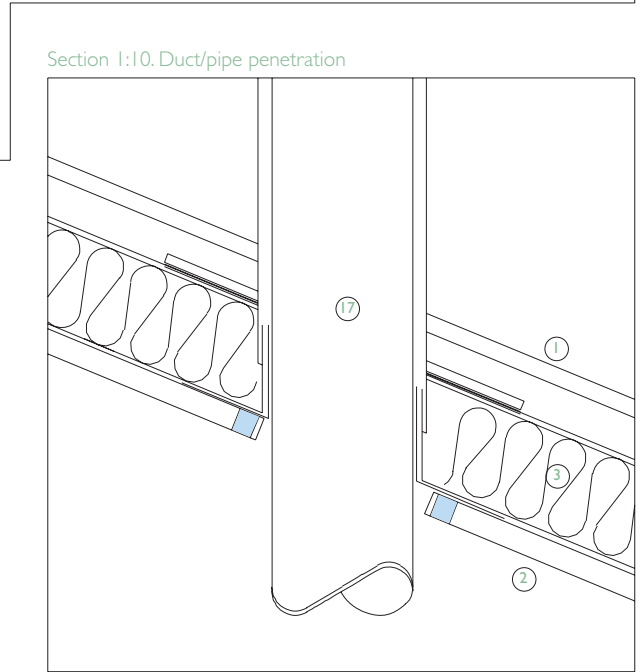
Profiled metal decks as substrates

Where profiled metal is used as a deck rather than as a roofing material, a lightweight build-up is usually applied, since the metal decking is chosen where a lightweight roof is required. The lightweight finishes used are typically an additional layer of profiled sheet, metal standing seam (discussed in the previous section), membranes (mainly elas-



Section 1:10. Curved eaves with concealed gutter

Atelier and House, Biwa-cho, Shiga Prefecture, Japan. Architect: Shuhei Endo Architect Institute



tomers) and light planted roofs. A typical build-up is of closed cell insulation set onto the profiled metal deck, rigid enough to span across the peaks of the profile without deflecting significantly when it is walked upon for maintenance access, which would otherwise stretch the joints in the membrane. A single layer membrane is then set onto this insulation, usually an elastomeric membrane that can be left exposed to the effects of the sun without damage. Sometimes a thin layer of smooth pebbles is laid on top to keep the sun off the membrane and allow maintenance access without risk of puncturing the membrane. The closed cells of the material ensures that any water vapour trapped in the construction is not absorbed by the

insulation which would otherwise cause its deterioration.

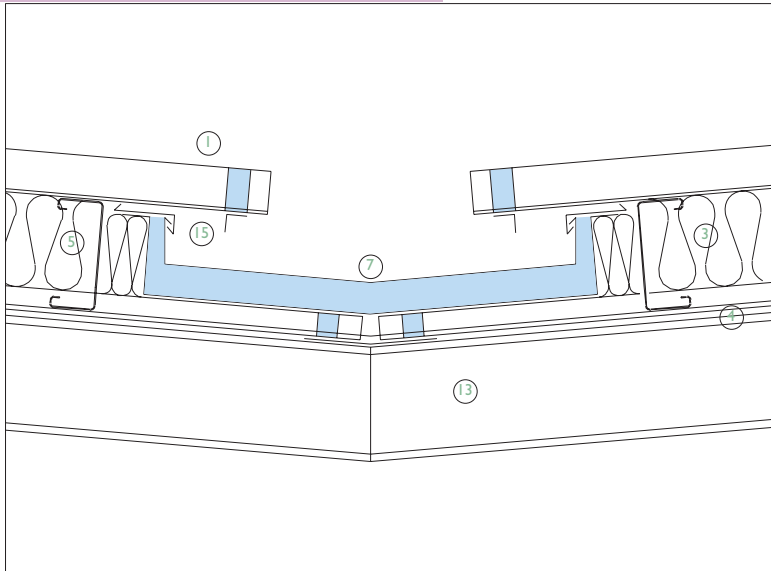
Profiled metal roof sheeting

When used as a finish material, called 'roof sheeting', profiled metal sheet provides a continuous weatherproof skin with the ability to be curved in one direction. A limitation of the material is that openings for rooflights, edges, and junctions with other materials are not easily integrated into the profile of the sheet. Even simple rectilinear openings have few standard profiles to close off the gap between the flat flashing and the gaps between the peak and trough of the profile. However, one of the main advantages of profiled metal sheet is its ability to be

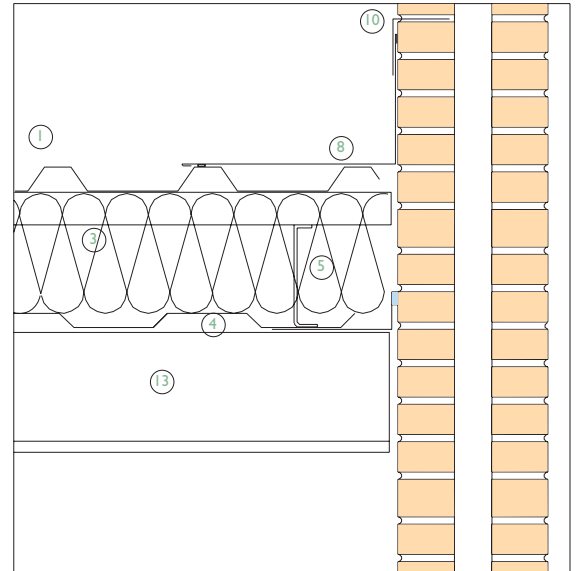
curved easily, where the supporting structure beneath requires only a few structural members to be curved, and most framing can be straight. Used as roof sheeting, the material is lapped on all four sides like metal standing seam roofs. The laps are made long enough to avoid capillary action through the joint. This simple jointing system provides large areas of reliable, weathertight roofing that can be installed quickly.

Sealed and ventilated methods

In common with standing seam roofing, profiled metal roofs can be used as a roof covering in either sealed or ventilated construction. Ventilation is used mainly where a timber supporting structure is used, where

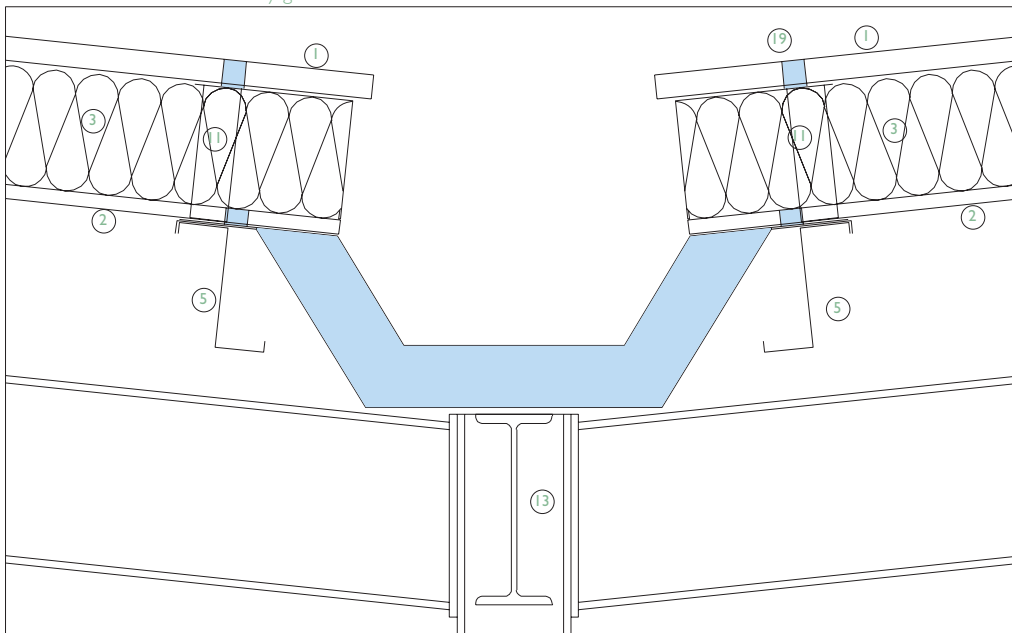


Section 1:10. Folded metal valley gutter



Section 1:10. Abutment with masonry wall Detail A

Section 1:10. Prefabricated valley gutter



Details

1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved eaves sheet
13. Structural frame
14. Ridge piece
15. Metal flashing
16. Rooflight
17. Pipe or duct penetration
18. Parapet flashing
19. Vented filler piece

the timber is ventilated to avoid rot in the material from moist air in the void that would otherwise be trapped within the construction. This is discussed further in the section on timber pitched roofs. The following topics in this section deal with the use of profiled sheet as a sealed roof covering.

In sealed roofs, the thermal insulation usually fills the voids in between the inner and outer skins, but ventilators are often provided at the ridge and eaves to allow some breathing through the ribs of the profiled sheet. This helps to keep the insulation completely dry.

Because the inner lining sheet presents a hard surface under the roof, perforated sheets are used to improve sound absorp-

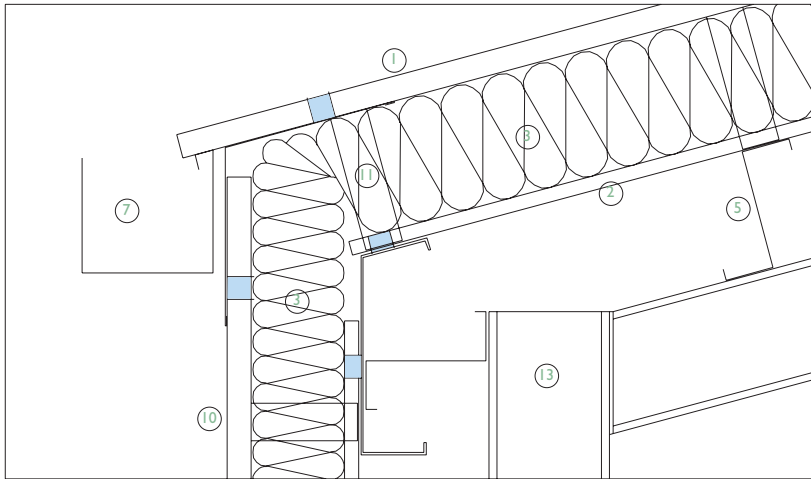
tion. Sound is allowed to be absorbed partly by the insulation quilt. This helps to reduce reverberation, particularly in noisy internal environments. A vapour barrier is set between the thermal insulation and the thin layer of acoustic insulation beneath.

Twin skin construction

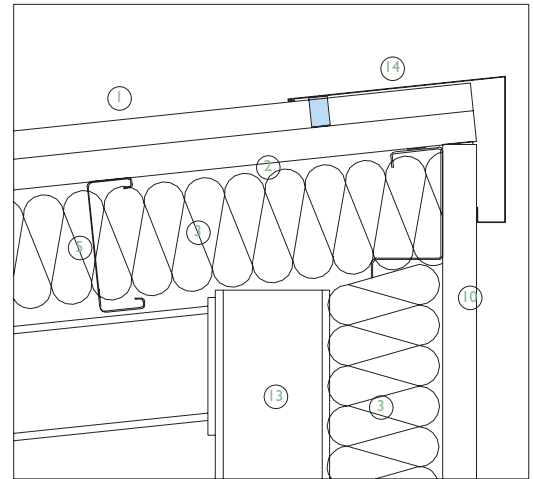
Profiled metal sheet roofs have the ability to conceal the supporting structure within the depth of the roof construction. This gives a smooth finished appearance to the inside face of the roof. An outer metal sheet is supported on metal roof purlins, and an inner lining tray, which supports the thermal insulation, is fixed to their underside. The purlins are usually Z-shaped galvanised steel types,

typically 1.5mm thick, with nylon washers or sleeves between the purlins and the outer and inner sheets to provide a thermal break as well as a pad to seal the screw fixings on the outer roof sheet. In recent years the Z-shape section has developed into to a wide range of section types. Sheets are fixed with self tapping screws which, in addition to fixing the sheets to the supporting structure, are also required to be weathertight. A vapour barrier is provided on the warm (in winter) side of the insulation, between the liner tray and the thermal insulation.

This construction method contrasts with composite panels, where the outer skin, mineral fibre thermal insulation quilt and inner lining are combined into a single panel which

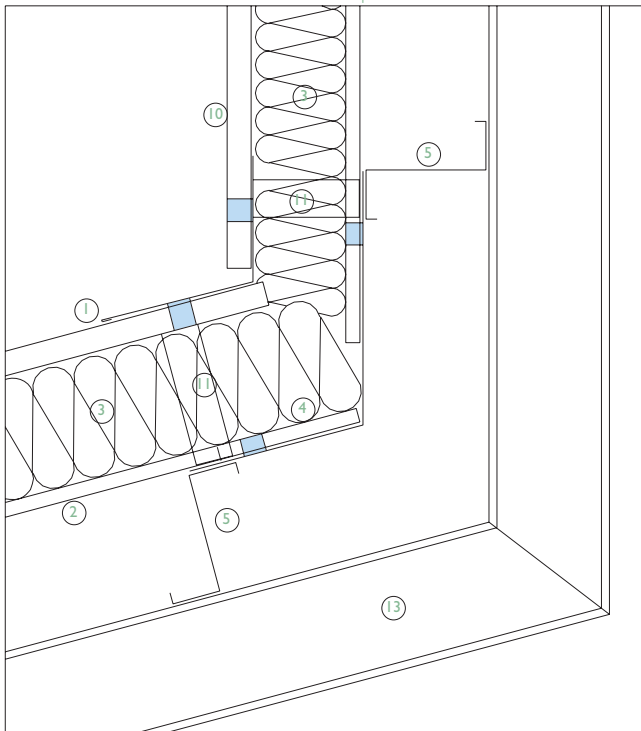


Section 1:10. Eaves with exposed gutter

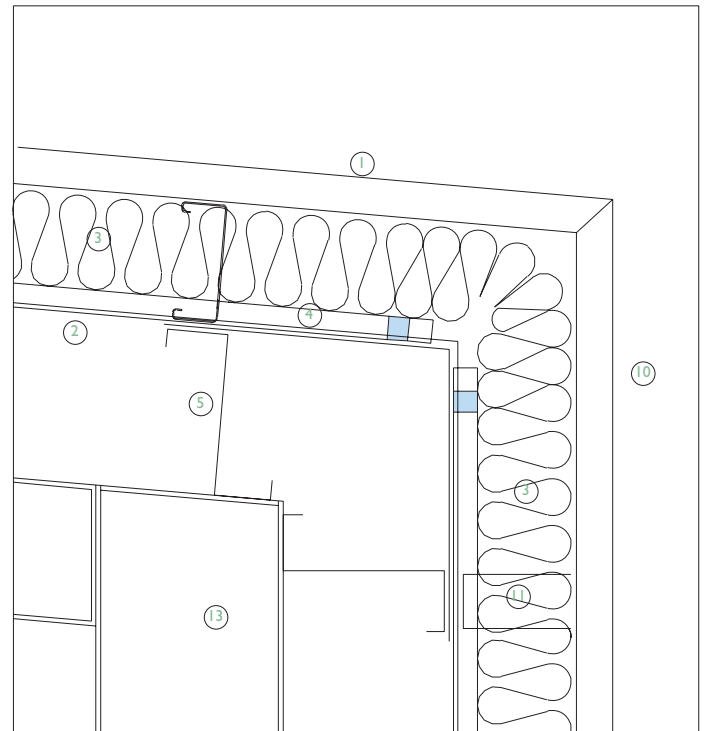


Section 1:10. Monopitch ridge

Section 1:10. Abutment with vertical roof panel



Section 1:10. Folded eaves



is fixed onto a supporting structure which remains visible. The supporting roof structure, visible from below the roof, is either left exposed on its underside or is concealed with a layer of dry lining.

Laps between profiled sheets along their top and bottom edges are sealed with butyl sealant strip. Two strips are normally used, one at the end of the external lap and the other at the top end of the internal lap. The outer seal provides protection against capillary action of rainwater being drawn up into the lap between sheets, while the other provides a vapour barrier that avoids moisture, generated inside the building, from condensing in the joint. Self tapping screws that hold the sheets in place clamp the two sealed

surfaces together. Sheets are normally lapped 150mm over one another, while laps between sheets on their side edges are made with a single lap of profile, with a single seal of butyl tape set at the centre of the lap. In common with standing seam roofs, the thermal insulation quilt is usually 150-200mm thick in order to achieve a U-value of 0.25 W/m²K.

Ridges

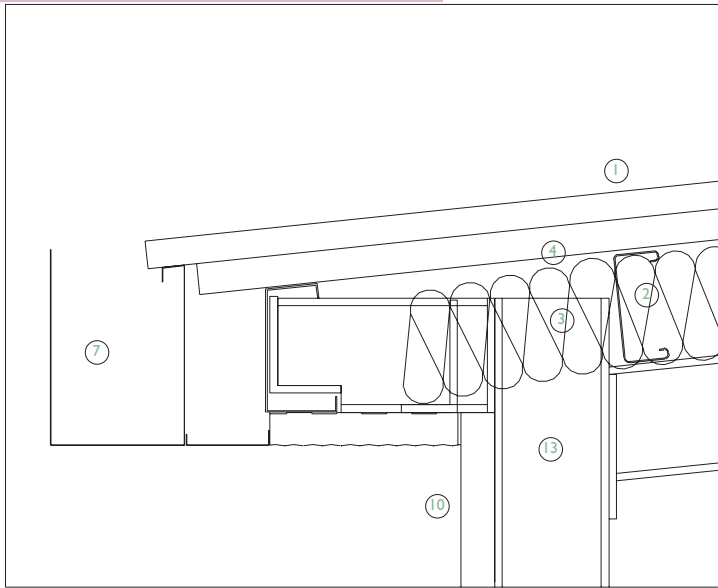
Ridges at the junction of a double pitched roof use a folded metal strip to form a continuous ridge sheet. These sheets can be folded on a straight line or formed to a curved line. The void beneath is filled with thermal insulation in addition to that used

beneath the profiled sheet. Closer strips are used to seal the gaps in the profiled sheet where it meets the ridge cover strip set on top of the profiled sheet.

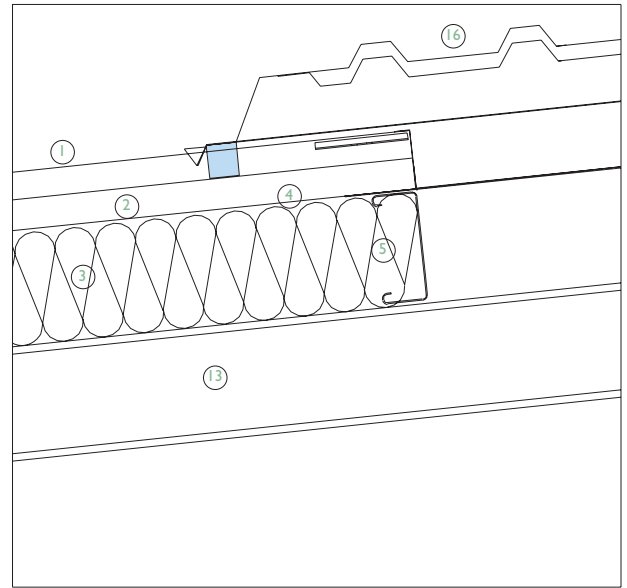
Where a pitched roof meets an abutment with an adjacent wall as in (A), the cover strip between wall and roof is folded up the wall and is fixed to it. A flashing projecting from the wall is lapped over the outside of the ridge strip in order to direct rainwater over it and down onto the roof.

Openings

In common with rooflights fixed into standing seam roofing, a gutter is required along the top edge of rooflights, along which water running down the roof is directed to

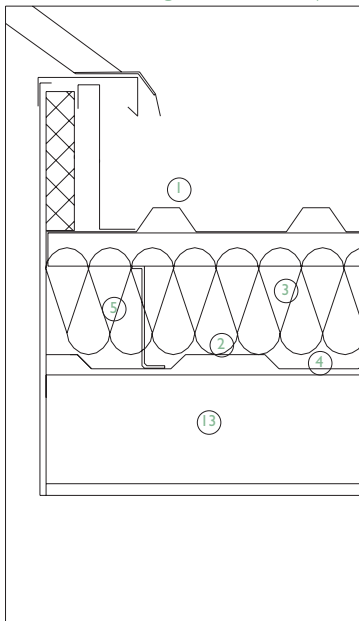


Section 1:10. Eaves with semi concealed gutter

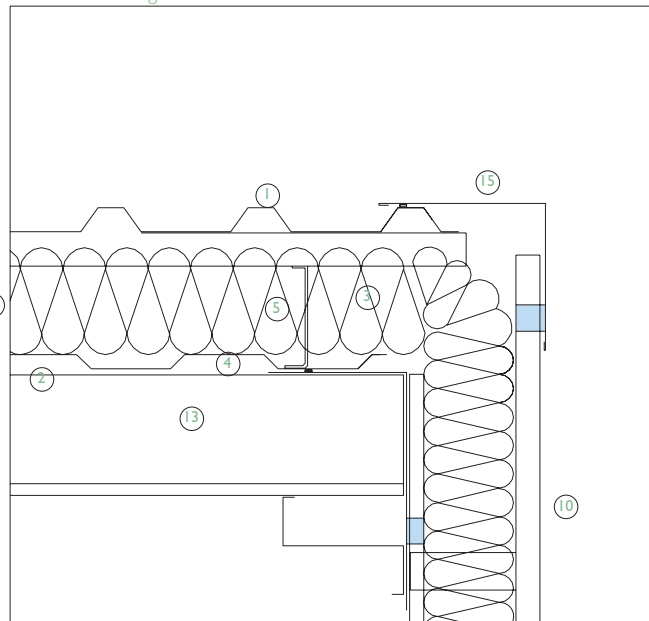


Section 1:10. Rooflight formed as profiled sheet

Section 1:10. Rooflight formed with upstand



Section 1:10. Verge



Details

1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
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13. Structural frame
14. Ridge piece
15. Metal flashing
16. Rooflight
17. Pipe or duct penetration
18. Parapet flashing
19. Vented filler piece

the sides. The gutter can be formed in front of the metal sheet as in a parapet detail, or be concealed by setting the profiled sheet close to the rooflight and concealing the gutter, leaving only a 50mm gap between roof sheet and rooflight. The gutter can be concealed for small rooflights since they carry little rainwater and so do not need to be very big. The sides of rooflights parallel to the slope, and along the bottom edge, have flashings lapped down from the rooflights and onto the adjacent roof sheets.

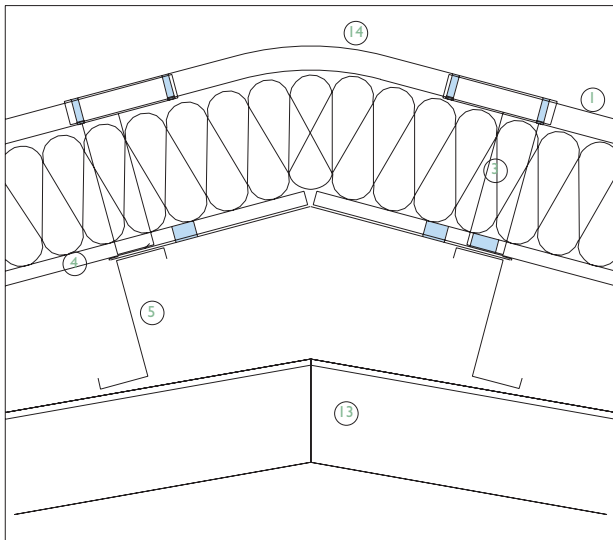
Penetrations for small ducts and pipes through the roof are sealed with a flashing, usually welded to form a single upstand collar around the pipe and fixed to the roof deck. Also in common with standing seam roofs, a

counter flashing is welded or bonded to the upper part of the pipe, above the roof, which laps down over the flashing to protect it from rainwater running down the pipe above the roof level.

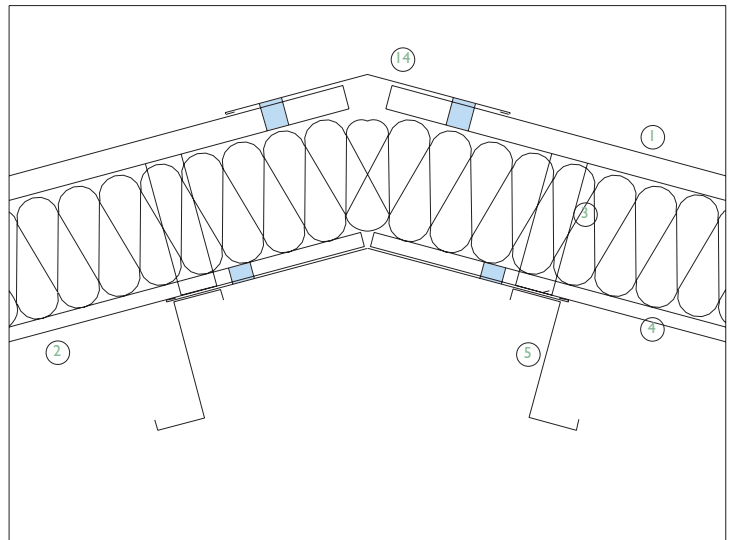
Eaves and parapets

Parapets are formed by creating a gutter at the base of the profiled sheet, then continuing the line of the gutter up to a parapet coping with laps over the top. The gutter is formed from a single folded sheet to avoid the possibility of leaks, and is lapped under the vertical sheet that forms the seal between gutter and coping. Parapets in profiled metal sheet are often used where the external wall is formed in a different materi-

al, so that the parapet forms a visual break between them. However, many profiled metal roofs are used in conjunction with walls in the same material using a concealed gutter that allows wall and roof to be continuous. Manufacturers provide standard curved pieces to different radii in profiled metal sheet that allows the same material to form a gently curved edge or, alternatively, a sharply curved termination to the roof which can be lapped into the profiled sheet forming the wall beneath. Eaves pieces with sharp edges are also manufactured as part of proprietary systems. These are formed to different angles by welding two profiled sheets together to form a continuous smooth fold in the roof. Curved pieces are

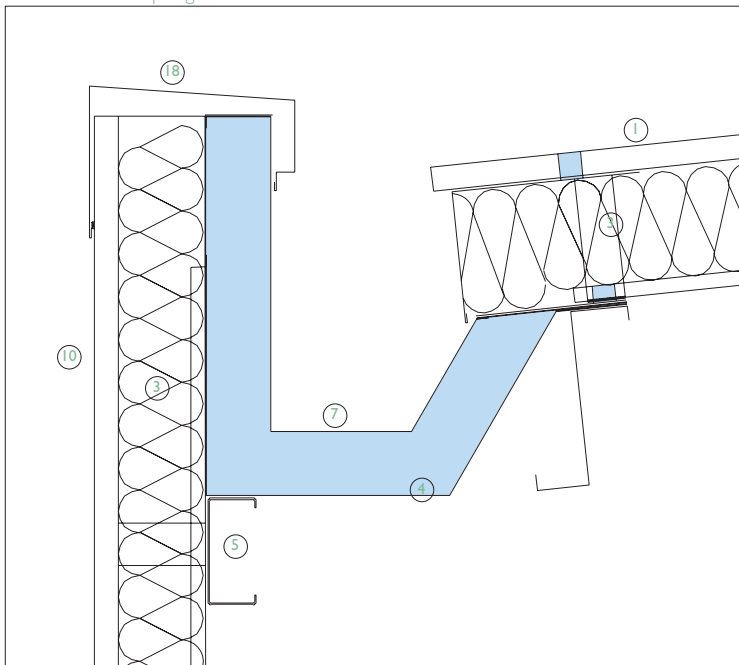


Section 1:10. Ridge with flashing



Section 1:10. Ridge with flashing

Section 1:10. Parapet gutter



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usually made by crimping the material along the vertical edges of the profiled sheet, to give a characteristic appearance, but these pieces are increasingly being made with a continuous smooth appearance.

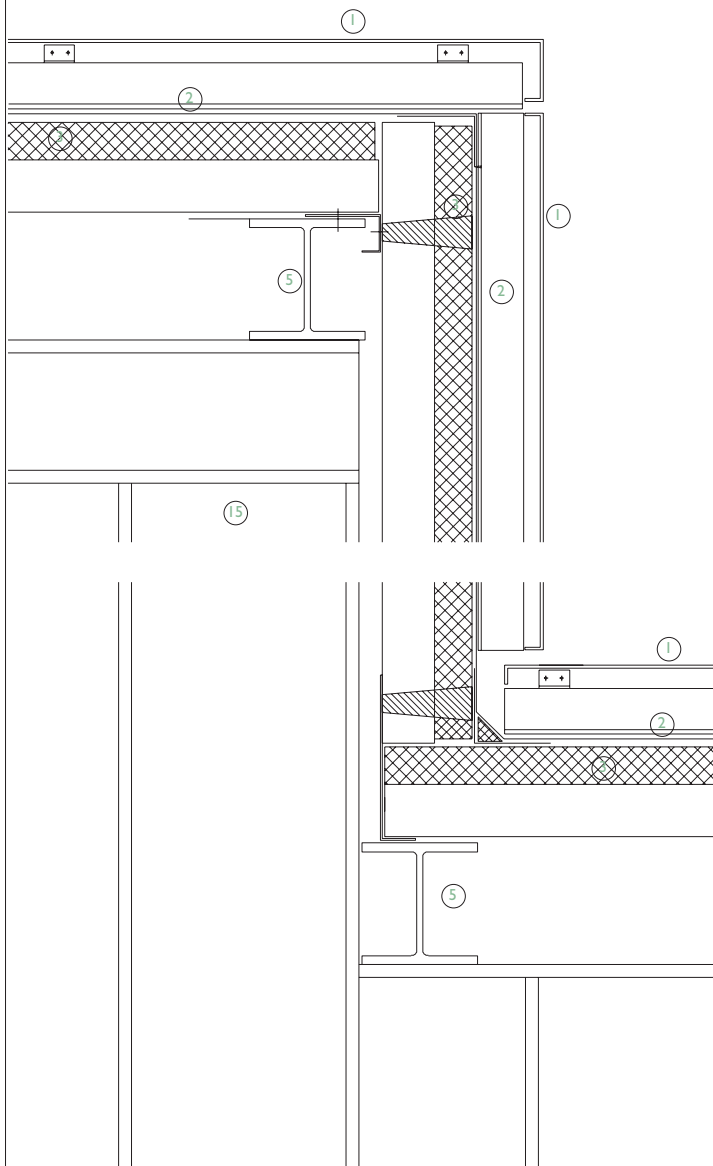
Ridges and valleys

These folds in metal roofs are formed using the same methods discussed in the previous section on standing seam roofs. But where standing seams can be cut down to form a flat ridge without a projecting ridge piece, this not possible in profiled sheet, and instead a folded ridge piece is fixed to the upper surface of the profiled sheet. The gaps between the ridges and troughs of the profiled sheet are filled with a proprietary metal

filler piece, usually forming part of the manufacturer's system. Ventilated roofs do not require this filler piece, with the resulting gap between the folded ridge sheet and the profiled sheet being usually sufficient to provide ventilation into the construction.

Valleys are also formed in a similar way to that discussed in standing seam roofs, with a ventilation gap provided in the gap between the gutter and the underside of the roofing sheet.

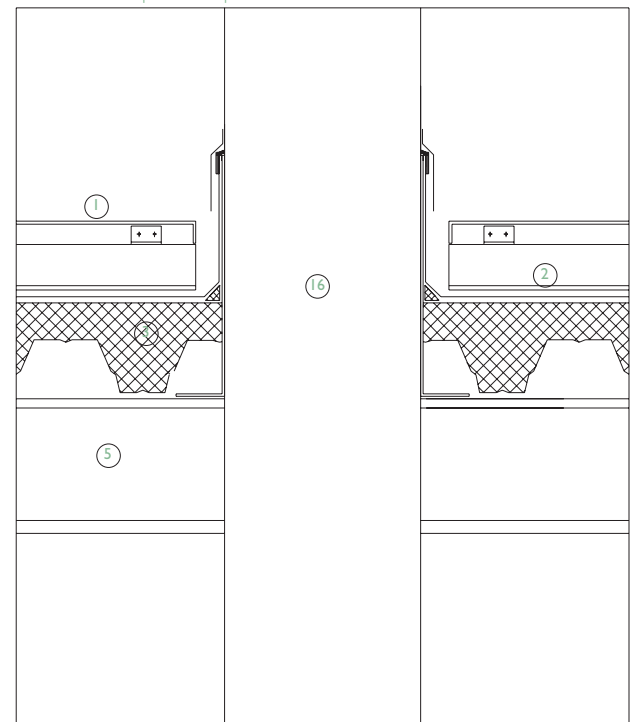
Section I:10. Panels with rainscreen covering at step in roof



Details

- | | |
|------------------------------|--------------------------------|
| 1. Metal rainscreen panel | 9. Metal fascia panel |
| 2. Single layer membrane | 10. External wall |
| 3. Composite panel | 11. Outer sheet fixing bracket |
| 4. Folded metal coping | 12. Panel 1 |
| 5. Purlin or structural beam | 13. Panel 2 |
| 6. Secondary purlin | 14. Ridge piece |
| 7. Folded metal gutter | 15. Structural frame |
| 8. Folded metal drip | 16. Pipe or duct penetration |

Section I:10. Pipe / duct penetration



There are two types of composite panel used for roofs: twin wall and single wall panels. The first is a development of profiled metal sheet, where outer sheet, thermal insulation and inner sheet are combined into a single panel. These are used in pitched roofs and have an appearance very similar to that of profiled metal roofs. Their main advantage over profiled metal roofs is the speed of erection on site, but they are usually a little more expensive than an equivalent profiled metal sheet roof. The second composite roof panel type, single wall panels, consists of profiled metal sheet bonded to a layer of foam type thermal insulation. The insulation is laid face up to receive a separate waterproofing layer; typically a single layer membrane. The

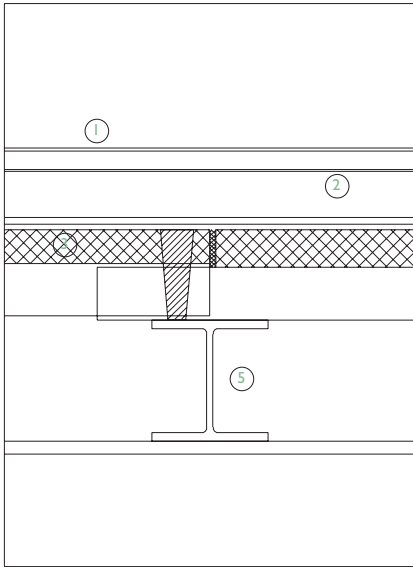
membrane is then typically finished in rainscreen panels or smooth pebbles, depending on the geometry and required appearance of the roof.

A development in composite roof panel construction which has been slow to appear commercially is the truly interlocking panel with integral gutter, where the principles of composite wall panels would be applied to roof panels, making for use in (nominally) flat roofs. These panels would have the smooth face and edges used in wall panels to provide a construction that would be both economic and very elegant. The joints between panels would form gutters that would create a connected grid of drainage channels that could form a crisp joint line between panels.

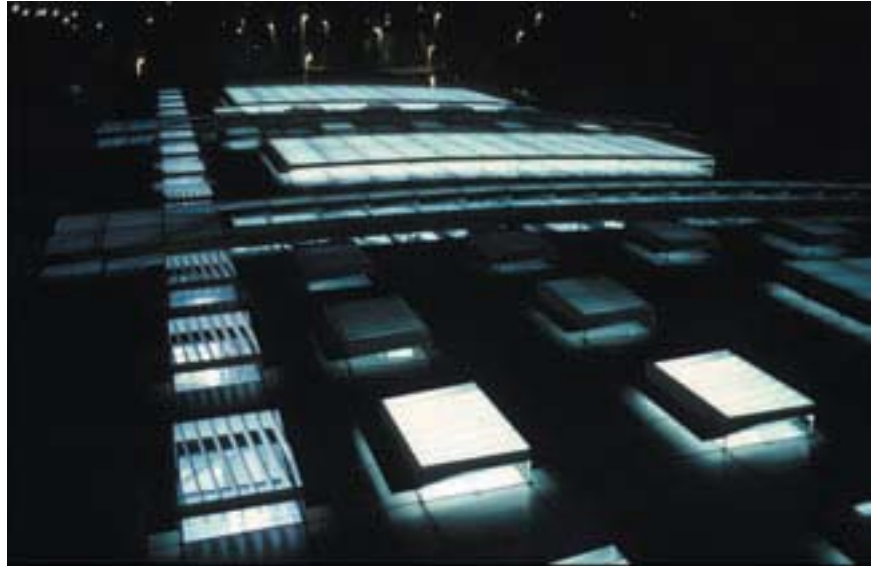
This development of composite panel design has yet to be commercially available in a technically reliable system.

Single wall composite panels

This panel type has a single sheet of profiled metal on the lower loadbearing face of the panel which is bonded to a foam-based insulation that fills all the voids in the profiled sheet, providing a smooth, flat upper surface. The depth of the thermal insulation is determined by the U-value required, and manufacturers are often flexible in this regard. The upper face of the panel is waterproofed with an independent membrane, typically an elastomeric type that requires no upstands or special joints between sheets. Panels are usu-

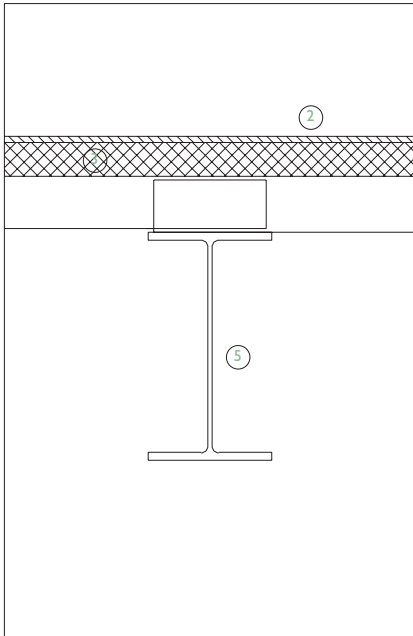


Section 1:10. Typical panel to panel junction

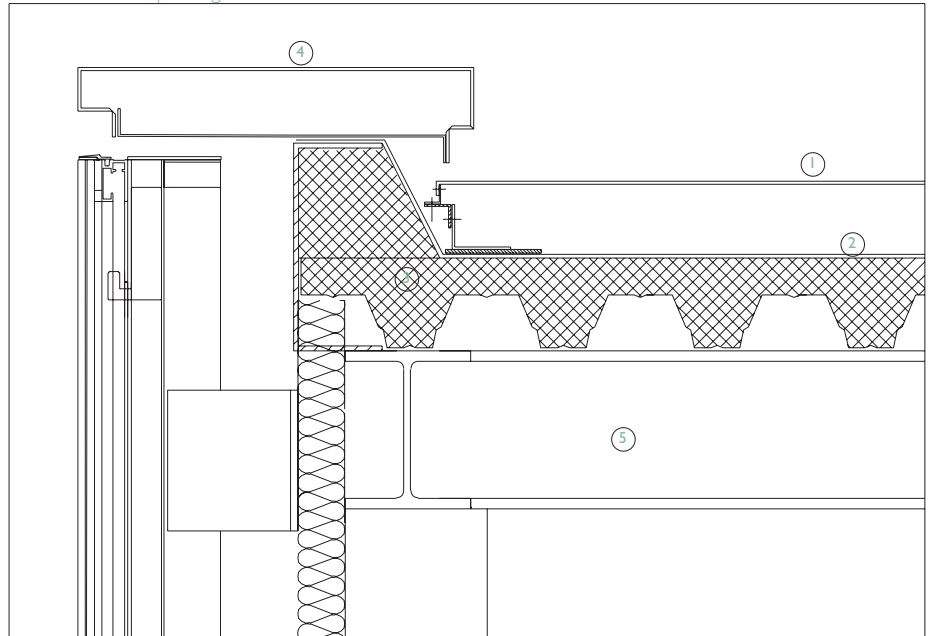


School of Decorative Arts, Limoges, France. Architect: Labfac / Finn Geipel, Nicholas Michelin

Section 1:10. Typical panel to panel junction



Section 1:10. Parapet edge Detail A



ally set butted up to one another, with the gap between panels filled with foam-based thermal insulation. A separating layer is usually set between the waterproof membrane and the insulated panel to allow movement to occur freely in both the membrane and the composite panel substrate. The sheets of waterproof membrane are bonded or torch welded together by lapping one sheet over the other, or by using bonding strips in the same material that form part of the proprietary system. The membrane is often protected with a lightweight covering of smooth pebbles that can be walked upon for maintenance access without puncturing the surface. Metal rainscreen panels are also used to protect the membrane from the effects of

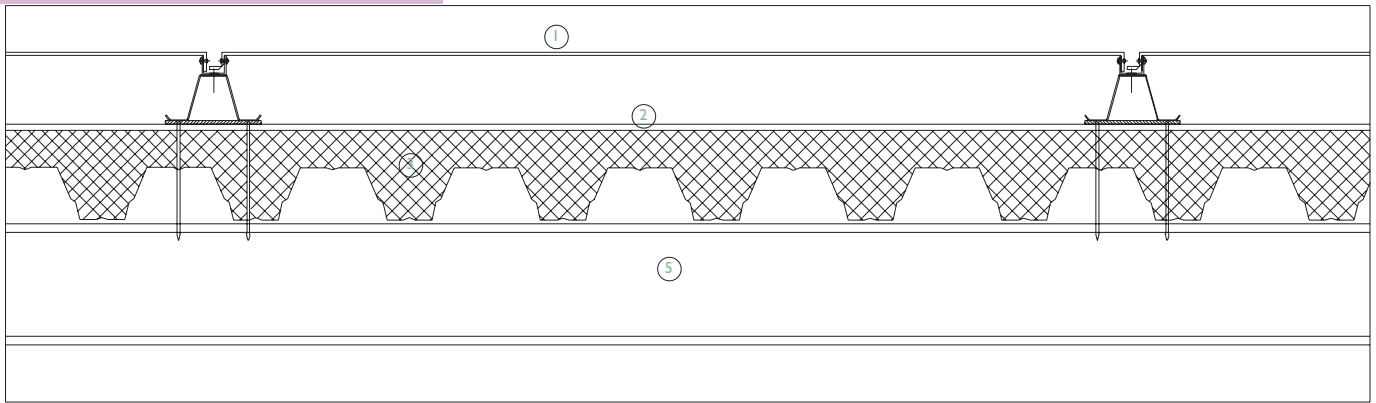
direct sunlight.

At ridges and folds in the roof geometry, panels are joined in the same way, with the gaps between panels filled typically with a foam insulation applied by injection on site. The membrane sheets are usually joined at the fold in the roof, and a strip of the same material is bonded along the joint to provide a weathertight seal.

At parapet gutters, an upstand is formed in the same insulation material as that used in the composite panels, the upstand being bonded to the composite panel beneath. The outer edge of the upstand is sealed and stiffened with a metal strip fixed to the underside of the composite roof panel or the supporting structure beneath. An addi-

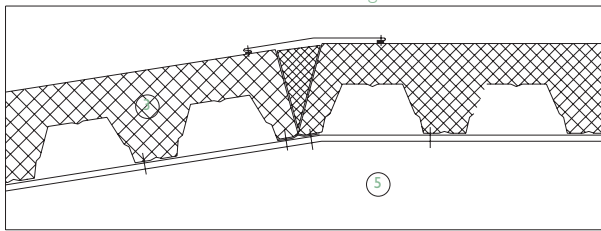
tional length of membrane is then bonded to the top of the upstand and is mechanically fixed or bonded to the top of the adjacent external wall, typically formed in composite wall panels or glazed curtain walling. This parapet flashing is then protected by a folded metal coping set onto it as shown in (A).

Single faced composite roof panels are well adapted to complex roof forms, where a lightweight, well insulated roof can be provided without the need for complex junctions that would be needed with twin wall panels. The use of a separate waterproof membrane on a substrate that is easy to form into a smooth continuous surface allows junctions to be formed easily, particularly around roof penetrations such as duct



Section 1:10. Panel to panel junction at fold

Section 1:10. Panels with rainscreen covering

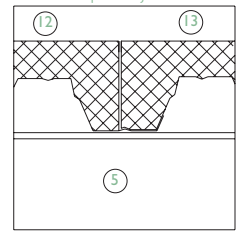


Details

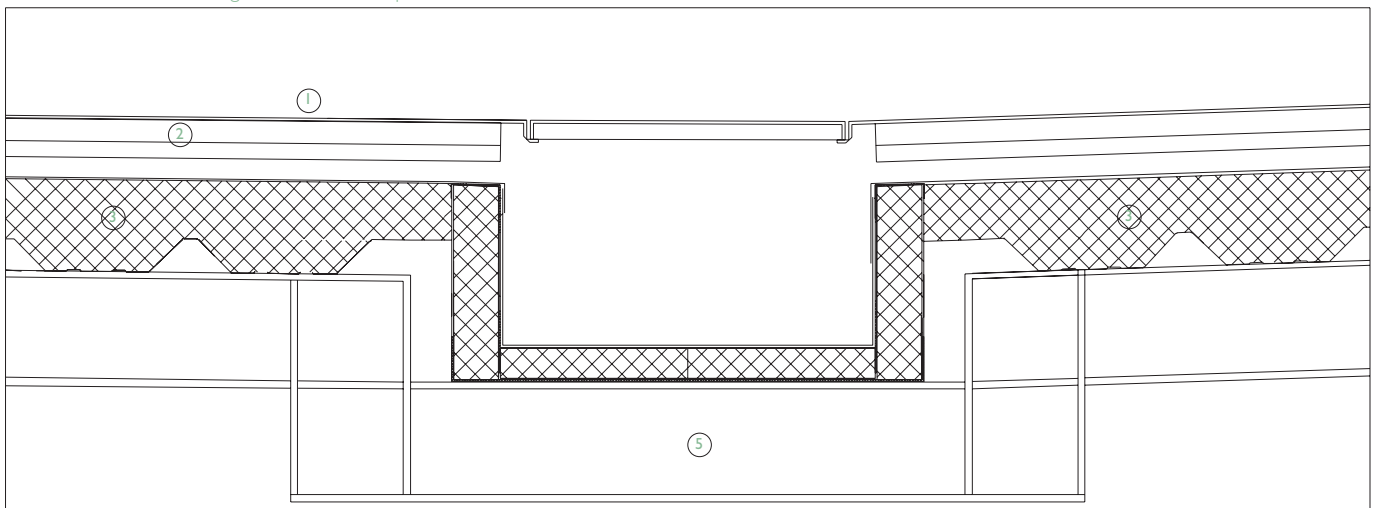
- | | |
|------------------------------|--------------------------------|
| 1. Metal rainscreen panel | 9. Metal fascia panel |
| 2. Single layer membrane | 10. External wall |
| 3. Composite panel | 11. Outer sheet fixing bracket |
| 4. Folded metal coping | 12. Panel 1 |
| 5. Purlin or structural beam | 13. Panel 2 |
| 6. Secondary purlin | 14. Ridge piece |
| 7. Folded metal gutter | 15. Structural frame |
| 8. Folded metal drip | 16. Pipe or duct penetration |

Section 1:10.

Panel to panel junction



Section 1:10. Folded metal gutter set between panels

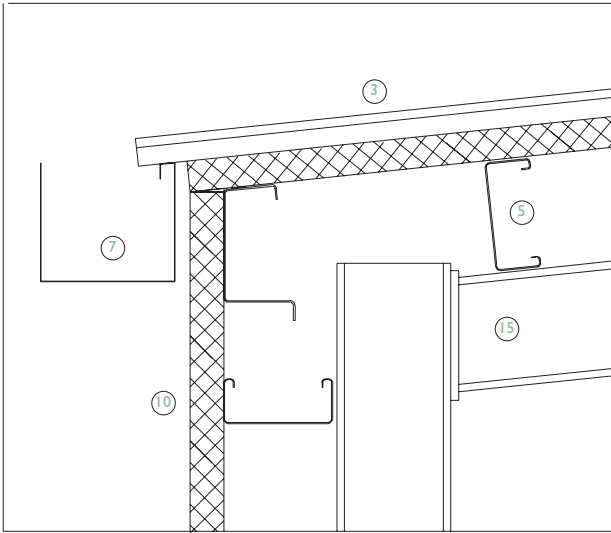


openings and pipe penetrations, where waterproof membranes are well suited due to the ease with which they can be cut, formed and sealed on site. Gutters can be formed by using the rapid site assembly method of setting lengths of composite panel together, while a membrane bonded to the upper surface gives a watertight finish. Composite panels forming a valley gutter or parapet gutter are fixed rigidly to reduce the amount of structural movement that would otherwise damage the membrane, which is typically bonded to the base and edges of the gutter in order to closely follow its shape.

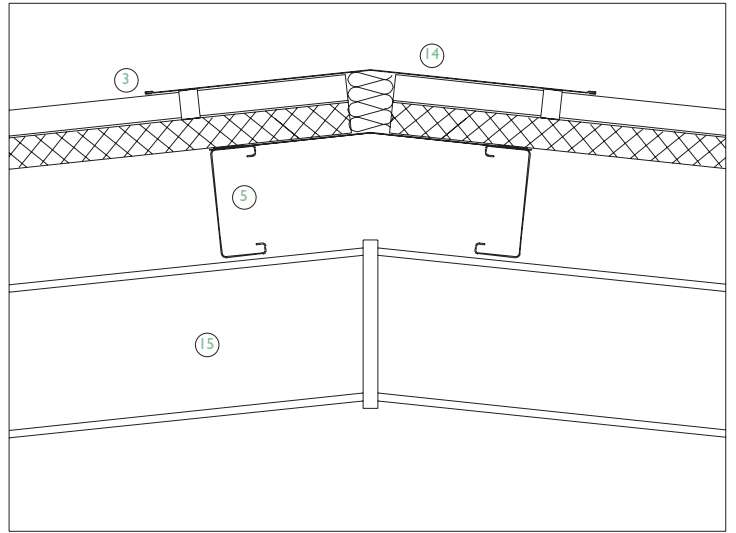
Twin wall panels

This panel type, which combines the separate components of profiled metal sheet has two joint types: a double seam with a cap on top in the manner of standing seam roofing, or a single lap of profile in the manner of profiled metal decking. With the first method, panels have raised edges on their long sides running down the slope. The raised edges are butted together and sealed with butyl tape, as (B). A metal capping is fixed over this joint to provide a weather-tight seal which sheds water onto the panels either side of the joint. This method gives a distinct visual appearance of wider joints. The second method has an uninsulated rib of the outer sheet projecting from the panel on

one long side, as (C), which laps over the adjacent panel. This gives a continuous ribbed appearance to the roof that is visually no different on its outside face to profiled metal roof cladding. Both methods have lapped joints on their short edges, where an uninsulated edge projects down to form a lap joint very similar to that used in profiled metal roofs. These horizontal joints are also sealed with butyl tape to avoid capillary action from rainwater outside, and to prevent the passage of water vapour into the joint from inside the building.

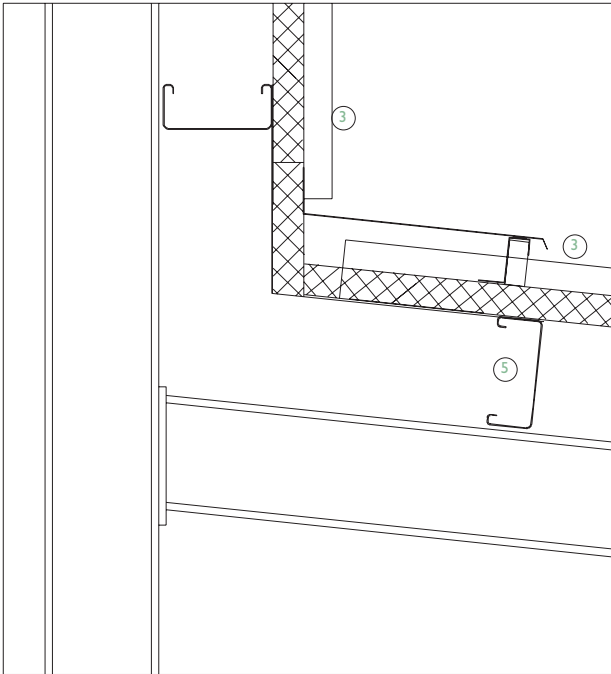


Section 1:10. Eaves with exposed gutter - Detail D

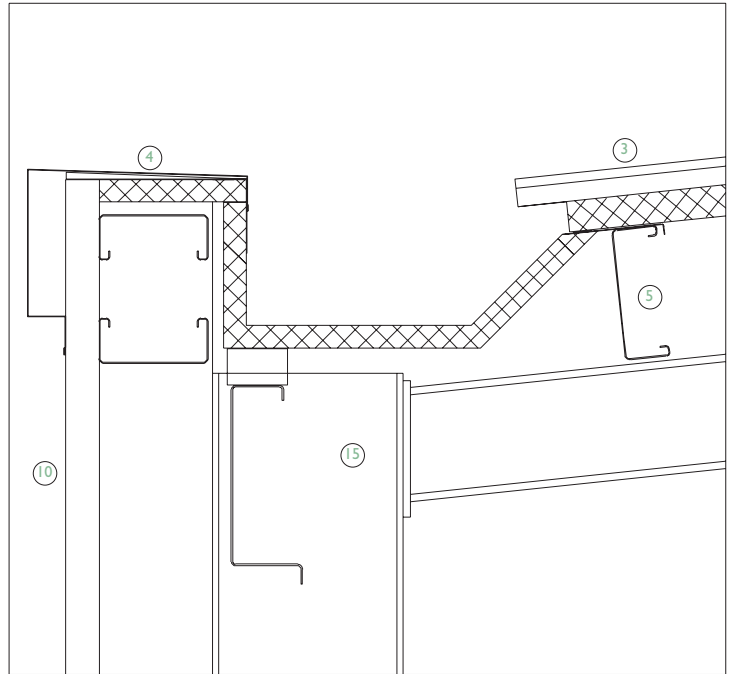


Section 1:10. Ridge with flashing

Section 1:10. Abutment with vertical roof panel



Section 1:10. Parapet gutter



Ridges

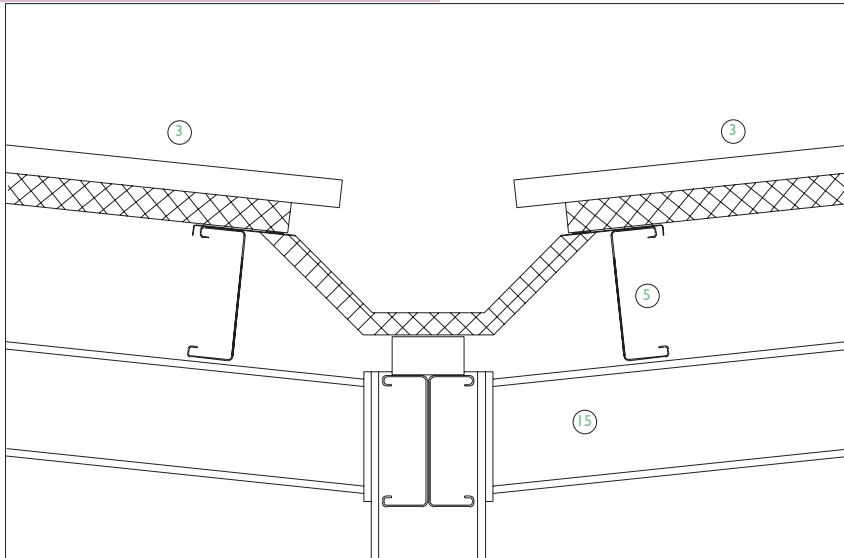
Ridges for twin wall composite panels are formed by fixing a metal flashing over the junction between the panels. The flashing is profiled to match that of the panels onto which it sits. Manufacturers often make these profiles as part of their proprietary system. Alternatively, a flat ridge flashing is used which sits onto the top of the profiled upper sheet. The gaps are then closed with a profiled filler piece as used in profiled metal roof construction. The angle between the meeting panels is closed by adjusting the angle of the fold of the ridge flashing on site, or by folding a flat flashing over the joint to give a smooth curve across the ridge line. The ridge flashing has visible fixings which are difficult to con-

ceal, so that precise positioning is essential to the overall visual appearance of the ridge. The gap between the panels is filled with thermal insulation on site, with either mineral fibre quilt or, more frequently, with the same foam-based insulation used to manufacture the panels. Insulation is injected into the gap to provide a U-value to match that of the adjacent panels.

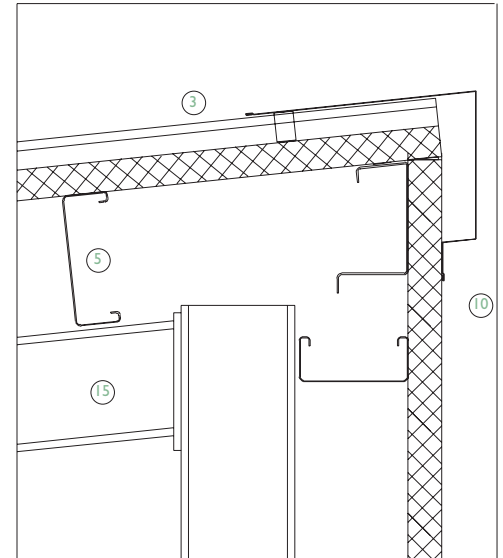
The inner face of the panels forming the ridge is sealed with a folded metal sheet, typically fixed to adjacent roof purlins and sealed against the inner face of the composite panel to provide a continuous vapour barrier. This inner trim is made either flat or profiled to suit the composite panels used.

Verges

Verges between composite panels and the adjacent wall construction is formed with a folded metal closer. Where composite panels form the wall construction, a folded metal strip is sealed to the top of the last 'peak' on the roof panel and is then sealed against the wall panel. Alternatively, a Z-section closer piece is fixed and sealed to profiled sheet and the flashing is fixed to the hip of the closer piece. Where glazed curtain walling is used, the metal flashing is glazed into the top transom of the glazed wall. As with ridges, the gap between the roof panel and the wall construction is filled with thermal insulation, and a folded closer strip is applied to the internal face of the joint to



Section 1:10. Prefabricated valley gutter

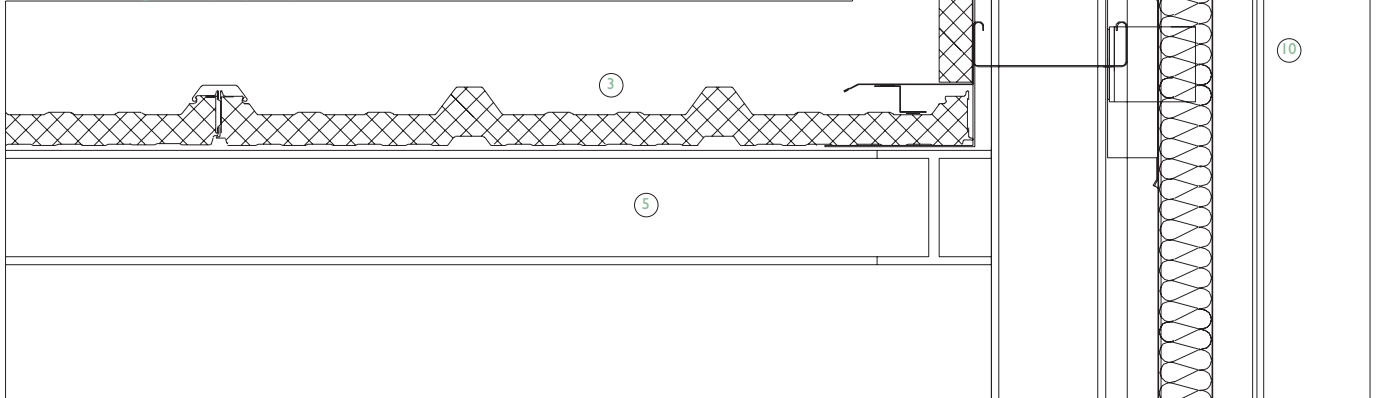


Section 1:10. Monopitch ridge

Details

- | | | |
|------------------------------|--------------------------------|------------------------------|
| 1. Metal rainscreen panel | 7. Folded metal gutter | 13. Panel 2 |
| 2. Single layer membrane | 8. Folded metal drip | 14. Ridge piece |
| 3. Composite panel | 9. Metal fascia panel | 15. Structural frame |
| 4. Folded metal coping | 10. External wall | 16. Pipe or duct penetration |
| 5. Purlin or structural beam | 11. Outer sheet fixing bracket | |
| 6. Secondary purlin | 12. Panel 1 | |

Section 1:10. Verge with parapet upstand



provide a vapour barrier between the insulation and the inside of the building.

If the verge overhangs the external wall instead of meeting it directly, then the void created by the overhang can be either ventilated or sealed. If sealed, then the overhanging verge follows the same detailing principles. If the eaves void is ventilated, then the edge of the verge is sealed to the edge of the roof, while the wall beneath is sealed to the underside of the composite metal roof in order to provide a continuous weather seal without any break in the thermal insulation.

Verges that terminate in a parapet use a flashing that is set behind the vertical panel, or onto it to avoid a thermal bridge, and is folded to be sealed onto the composite roof

panel in the same way as for the eaves detail. The inner face of the joint is sealed with a folded metal closer strip to provide a vapour barrier.

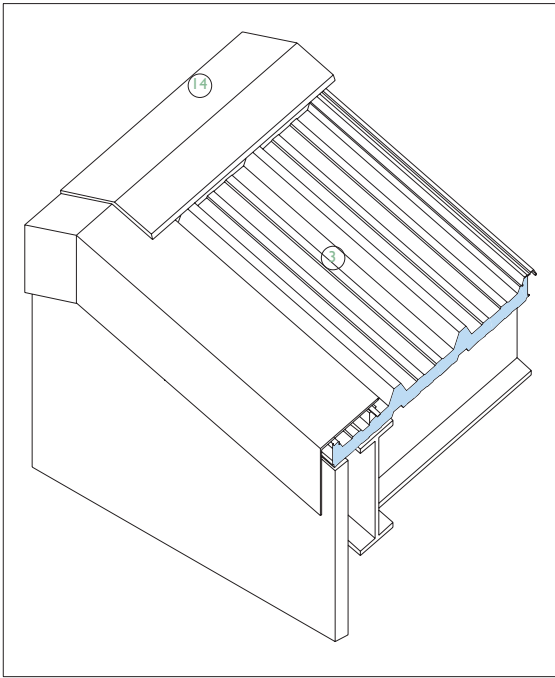
Eaves

These are formed in a similar way to profiled metal panels, by lapping the edge roof panel over a gutter. The gutter is closed against the underside of the composite panel either by folding it outwards and sealing it, as in (D), or by folding the top edge inwards, up the underside of the panel. The gutter is supported by either a bracket beneath the gutter that is fixed back to the primary structure, or by a metal support arm set onto the top of the composite pan-

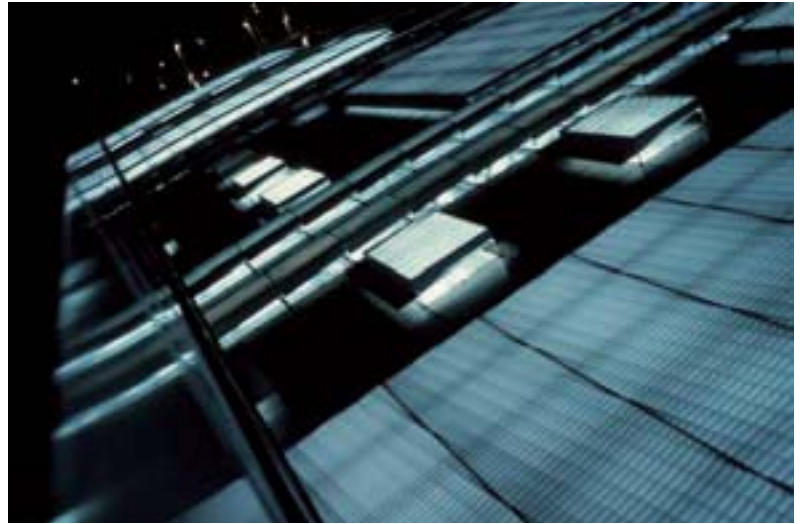
els 'peaks' and cantilevering out to support the top of the gutter. An essential advantage of the metal support arm on the roof is that it does not require any penetration through the wall construction to the supporting structure, but can be fixed through to the roof panels which do not usually require a fixing to pass all the way through the wall panel, thus reducing the risk of any rainwater penetration through the building envelope.

Parapets and valley gutters

Unlike eaves gutters, parapet gutters are thermally insulated, since they form part of the external envelope. The gutter is usually prefabricated to form part of the overall composite panel system. Since an advantage

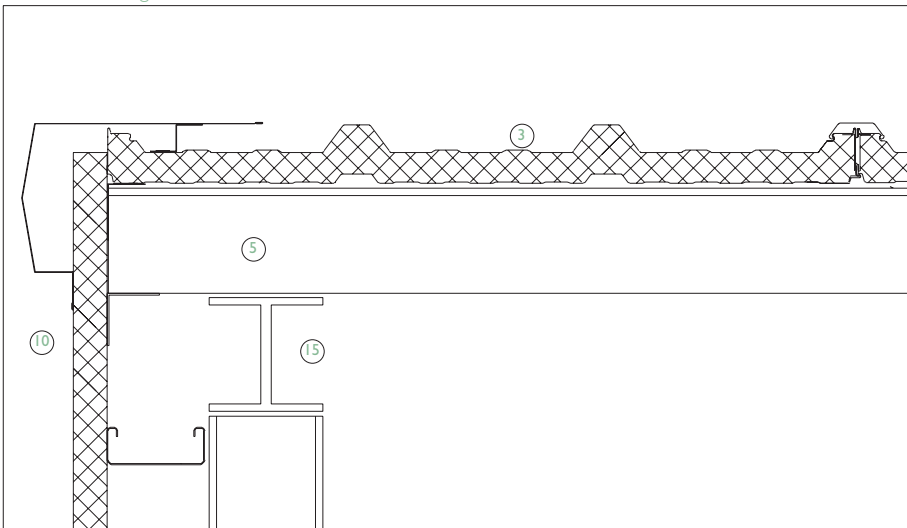


Isometric view of roof assembly

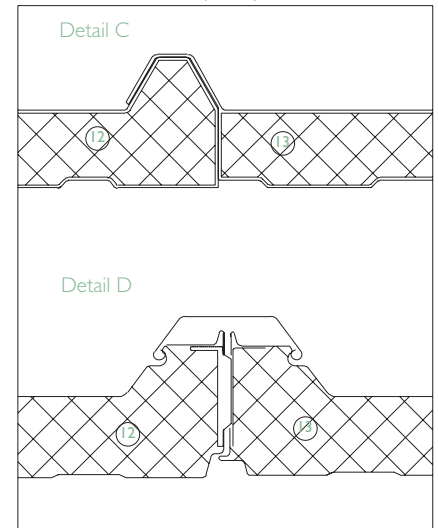


School of Decorative Arts, Limoges, France. Architect: Labfac / Finn Geipel, Nicholas Michelin

Section I:10.Verge



Section I:10. Panel to panel junctions



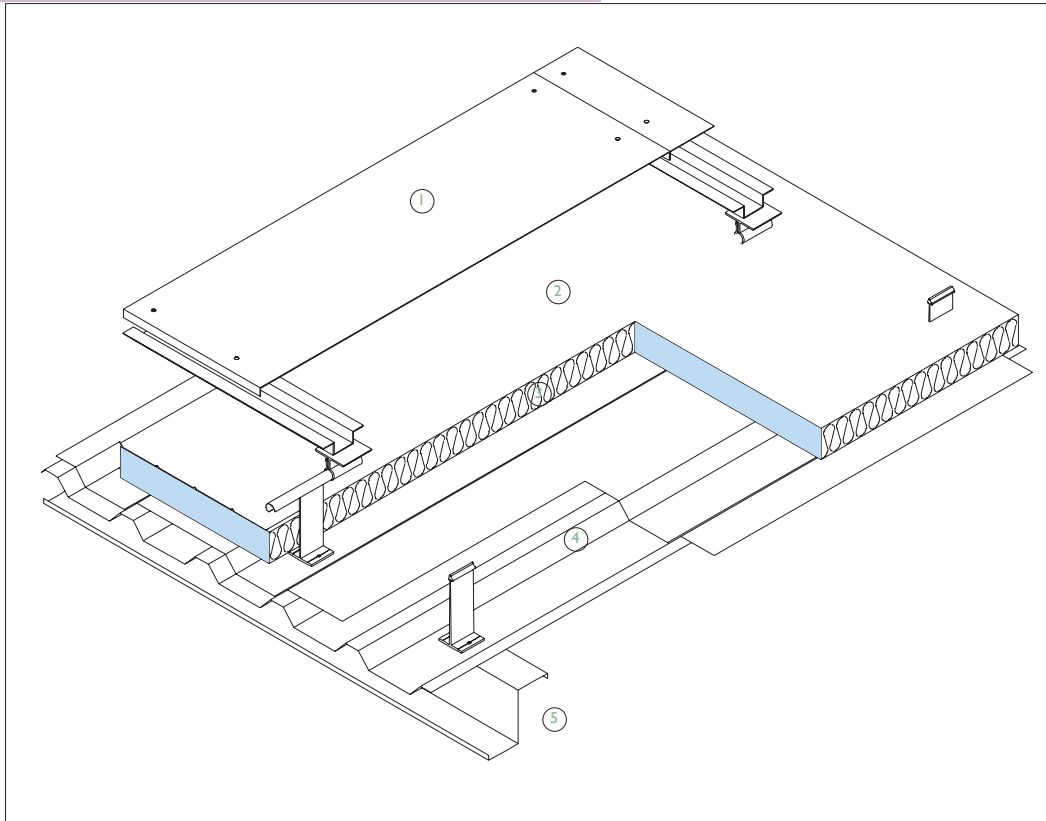
of composite panel construction is the increased speed of construction on site over other metal roofing methods, this advantage would be lost if the gutters took much longer to fix and the panels themselves. The gutter shape, in cross section, is formed to provide continuity in the thermal insulation from roof panel through to the adjacent parapet wall. Seals are provided to avoid any water from penetrating the seals and passing into the building, which might occur in the event that the rainwater outlets become blocked and the entire gutter becomes filled with water up to the level of the outer (top) face of the composite roof panels.

Valley gutters are formed in a similar way, with the seal between roof panel and

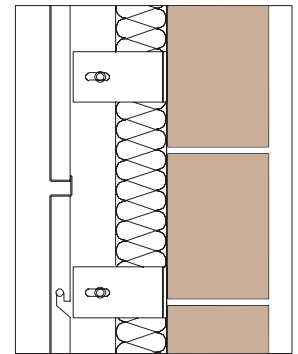
prefabricated gutter being critical to avoid water penetration in the event of the valley gutter being filled to capacity in the event of a blocked rainwater outlet.

The tops of parapets are closed with a pressed metal coping that is folded down over the face of the external wall and the inside face of the parapet to provide a complete weathertight seal. The top of the coping is usually inclined towards the inside face of the wall (into the gutter) to avoid dust, that settles on horizontal surfaces, from being washed down the face of the external wall during rain. The coping is usually made from a minimum 0.7mm thick steel sheet or 3mm thick aluminium sheet. The void immediately beneath the coping is faced with

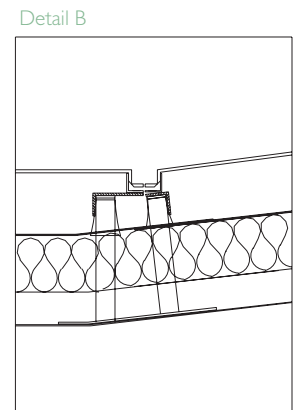
thermal insulation to avoid a thermal bridge occurring through the coping into the air space behind.



Isometric view of roof assembly

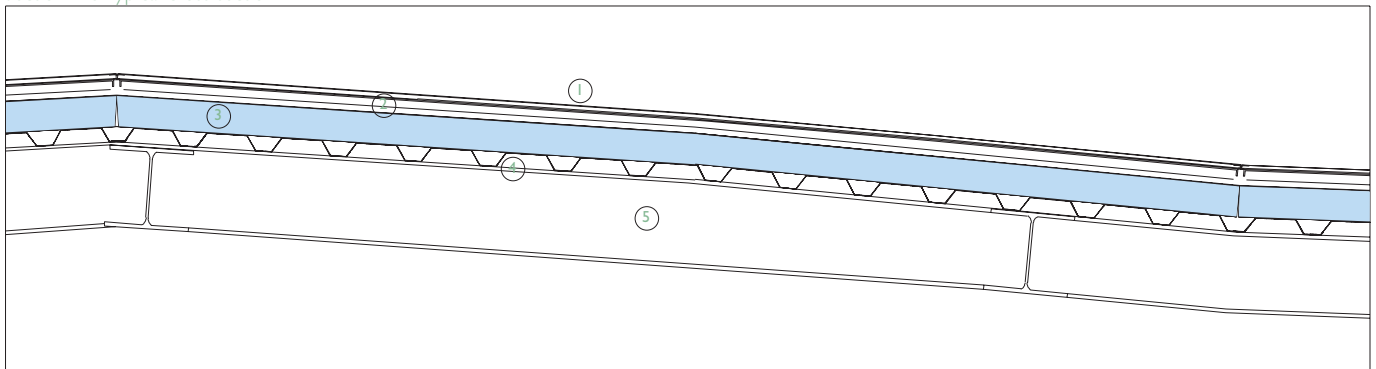


Detail A



Detail B

Section I:25. Typical cross section



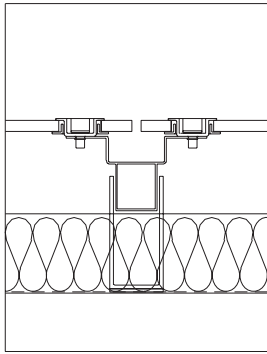
The use of metal rainscreen panels is relatively new in roof construction, and has developed from its use in external walls. In facades, rainscreen panels are used in a configuration that allows most of the windblown rain that reaches a metal panel facade to drain down its face. Joints between metal panels are left open jointed, so that only a small amount of rainwater passes through it. Rainwater is drained away in the cavity behind, the rear face of the cavity being sealed, typically with a single layer membrane on an insulated, lightweight, backing wall. A commonly used alternative is of a bitumen-based paint on a reinforced concrete or concrete block backing wall. Closed cell thermal insulation is usually set on the outside face of

the backing wall, with a cavity between the thermal insulation and the inner face of the metal rainscreen panel, as shown in (A).

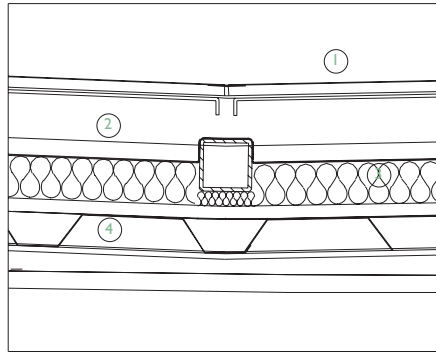
In contrast, metal rainscreens for roofs vary considerably from the configuration used in external walls. Firstly, most of the rain falling onto a metal rainscreen roof is not usually drained away on the outer layer of panels, unless the roof has a relatively steep pitch or curved section. Rainwater is still expected to drain onto the waterproofing layer beneath as if the panels were not in place. The main function of the rainscreen panels on roofs is to protect the membrane from the effects of the sun (heat and UV radiation) as well as from the worst effects of windblown rain. Rainscreen panels pro-

vide a lightweight covering that forms part of the visual language of the external walls. Although smooth pebbles are also used to protect waterproofing membranes on roofs, pebbles and gravel are obviously not suited to sloping or curved roofs. The use of metal rainscreen panels is well suited to these roofs which form a visible part of the design. These panels allow traditional roof elements, which are usually visually dominant, such as gutters, parapets and ridges, to be accommodated within a smooth, continuous finish, allowing roofs to take on the visual characteristics of external walls and become a 'facade' in their own right.

Although metal sheet is used, metal and plastic composites are becoming increasingly



Detail C



Section 1:10. Panel to panel junction

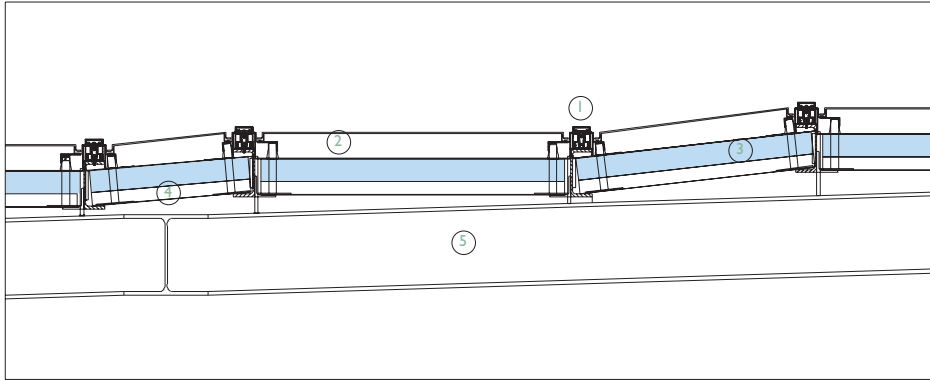
Details

1. Metal rainscreen panel
2. Single layer membrane
3. Closed cell thermal insulation
4. Structural deck
5. Purlin or structural beam
6. Secondary purlin
7. Folded metal gutter
8. Folded metal drip



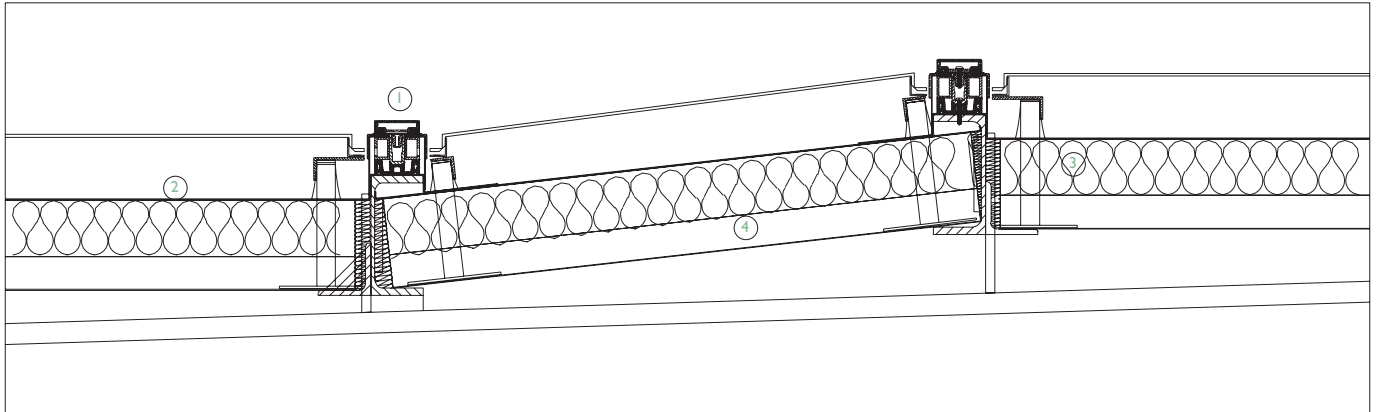
Shimosawa Municipal Museum, Lake Suwa, Japan.
Architect: Toyo Ito & Associates

Section 1:25. Typical long section



9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Panel 1
13. Panel 2
14. Ridge piece
15. Structural frame
16. Pipe or duct penetration

Section 1:10. Panel to panel junction



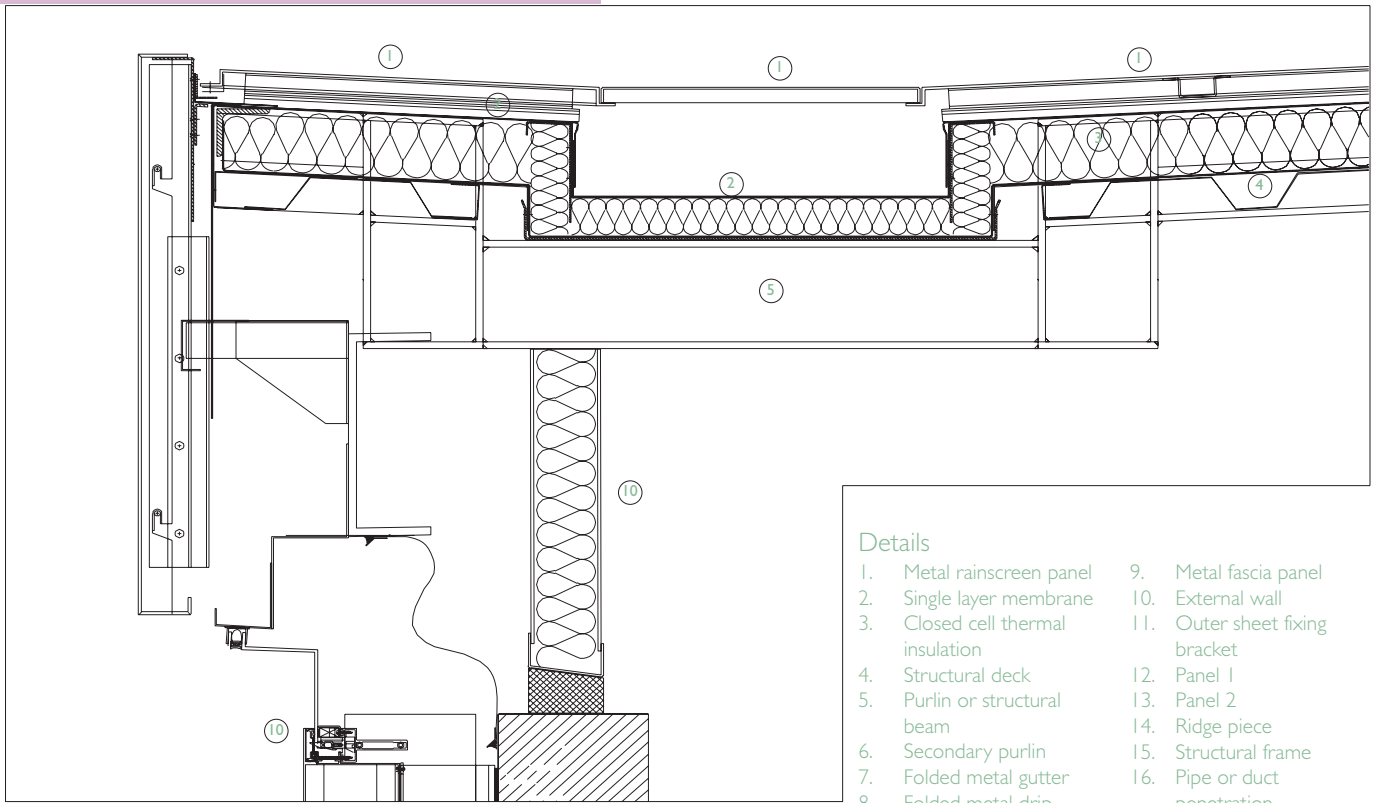
popular, as they are less likely to become dented from foot traffic during maintenance work, which maintains the flatness associated with composite metal materials. The 'oil canning' effect of depressed or dented panels, resulting from regular maintenance access is usually avoided by using these composite sheet materials. In such materials a thin layer of plastic is faced with two thin sheets of aluminium which are bonded to the plastic sheet core. The size of metal rainscreen panels is restricted more by the panel width that can be walked upon for maintenance access than by the sheet size available. The maximum size of metal sheet is usually in a width of 1200mm or 1500mm metal coil. Composite sheets are typically 1000mm to

1200mm wide, in lengths from 2400mm to 3000mm, depending upon the manufacturer. In practice, panels may only be around 600mm wide if they do not have additional supporting framing beneath to stiffen them. Framed panels can reach the maximum sizes already mentioned, but care must be taken to avoid the pattern staining or denting that can reveal the frame behind during the life-cycle of the roof.

Panel arrangement

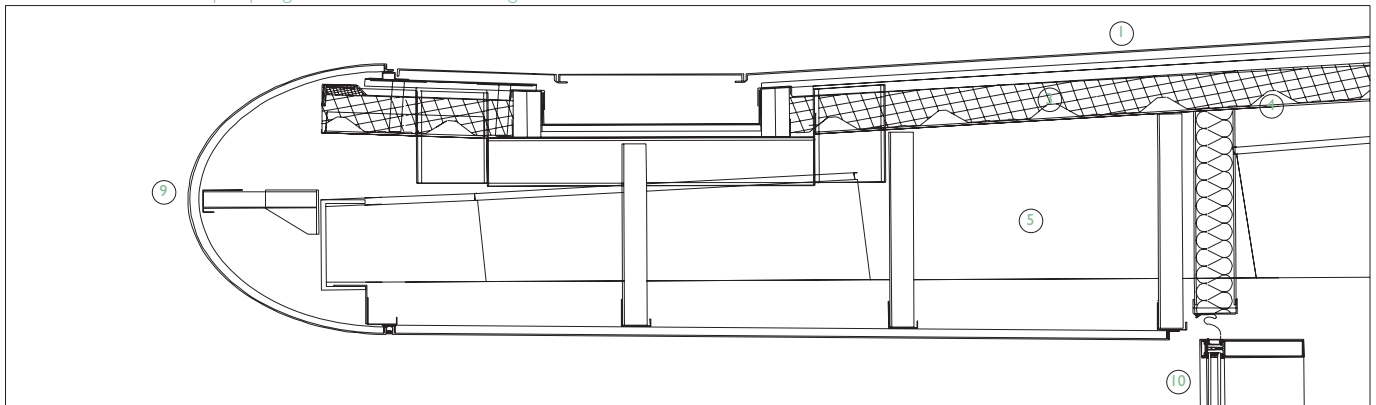
Rainscreen roof panels are typically arranged either as panels laid in a flat grid, or as lapped panels, where the bottom edge is lapped over the top of the panel beneath. Side joints remain open jointed and are set

in the same plane in this configuration. Panels in a flat grid are set onto metal Z-sections, which are either bonded to the top surface of the waterproof membrane to avoid any risk of water penetration through mechanical fixings, or are set above the membrane on support pads. These pads are usually covered with a waterproofing membrane to reduce the number of fixing penetrations through this layer. The rainscreen panels are then screw fixed to the Z-section with brackets that avoid the screw fixings being seen at a distance where this is a visual requirement. Unlike rainscreen panels for walls, roof panels cannot be secured easily on a hook-on type support system while being set near a horizontal plane. Since pan-



Section 1:10. Concealed parapet gutter Detail D

Section 1:10. Concealed parapet gutter with cantilevered edge



els must have the ability to be removed easily and regularly for maintenance access, screw fixings in all panel corners are most commonly used. Concealed fixings are more difficult to accommodate, though such systems are likely to appear over the next 10 years as demand for this roof system increases.

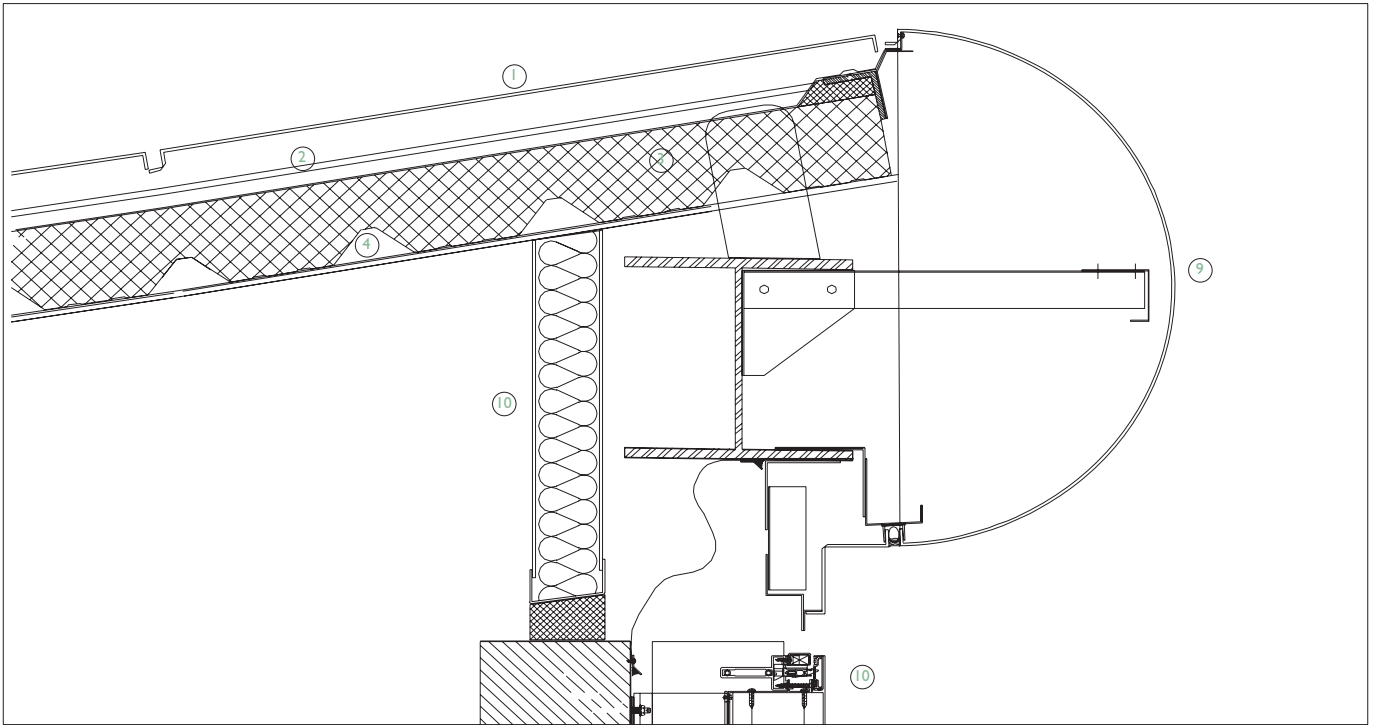
Panels are made usually by folding the edges down to form a tray, then outwards to form a rim around the panel, as shown in (B). Holes are drilled at the corners to allow access to screw fixings beneath. Short lengths of bracket are bonded or riveted to the sides of the tray beneath the projecting panel rim. The panels are then screw fixed at the brackets to the supporting rails or Z-sections by passing the screw through the hole in the

rim. This allows the screw fixings to be concealed from view, while allowing each roof panel to be removed without affecting adjacent panels.

An alternative fixing method for panels is to set screws in each corner of the face of the panel onto a support rail system, as shown in (C). Screw heads are difficult to coat in a colour that matches the panel, and even if this is achieved, then scratching of the panel is likely as a result of removing panels for maintenance access. Screws are usually left as a self-finish, and have a particular appearance when viewed as a complete set of roof panels. Countersunk screws have the least visually obtrusive appearance.

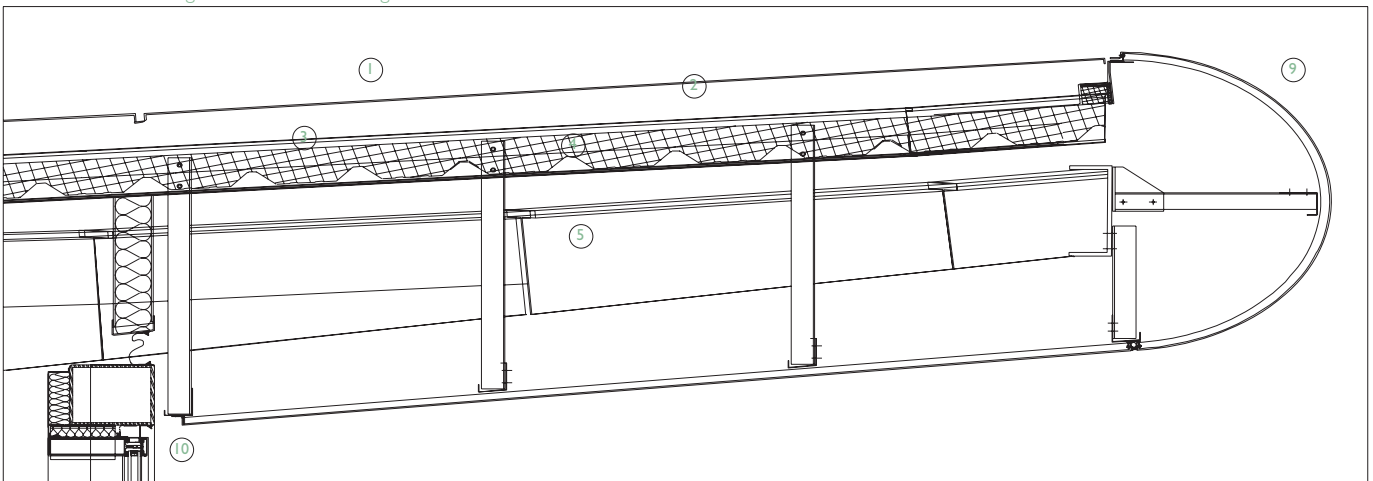
Parapets

An advantage of rainscreen panels for parapets is that the gutter and upstand can be made without either element being visible. Consequently, eaves, monopitch ridges and verges can have a similar outward appearance of an uninterrupted panel layout extending from roof down to the external wall. Parapets are formed only by a gutter that also provides the necessary upstand height for the parapet itself. A coping is then formed by using the same rainscreen panels as elsewhere on the roof in order to provide a continuity of appearance. The waterproof membrane beneath is then sealed against the wall construction or against the side of the sealed roof deck, which is closed off with



Section 1:10. Monoridge with curved fascia panel Detail E

Section 1:10. Monoridge with cantilevered edge



a folded metal strip, in the case of profiled metal sheet or composite metal panels being used.

The depth of the roof construction is then finished with another rainscreen panel, set vertically, which is fixed in front of the parapet. Unlike parapets in profiled metal or composite panels, the vertical fascia panel can extend up to the top of the wall in order to conceal the coping flashing. In other types of metal roofing, the coping extends over the top of the wall, resulting in a thin visual edge to the top of the wall. This coping line can be concealed from view in rainscreen roof panel construction. The external wall beneath is typically sealed up to the underside of the roof deck.

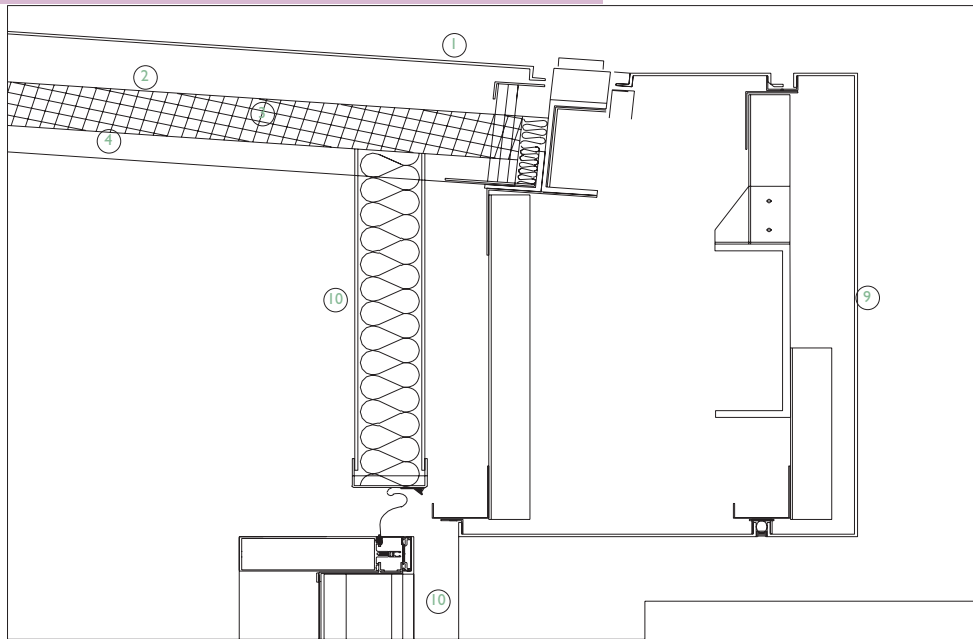
The parapet gutter can be covered with a perforated or slotted metal cover in the same material and finish as the adjacent rainscreen panels. Since rainwater runs off each panel at its edges onto the membrane below, there is no need to leave the gutter uncovered, as is the case with other metal roof systems. Water running down the membrane is drained directly into the gutter, and water underneath the gutter cover drains through slots or perforations.

Monopitch ridges and verges

These ridge types, as shown in (D) are formed by sealing the waterproof membrane against the side of the roof deck to provide a watertight enclosure that is con-

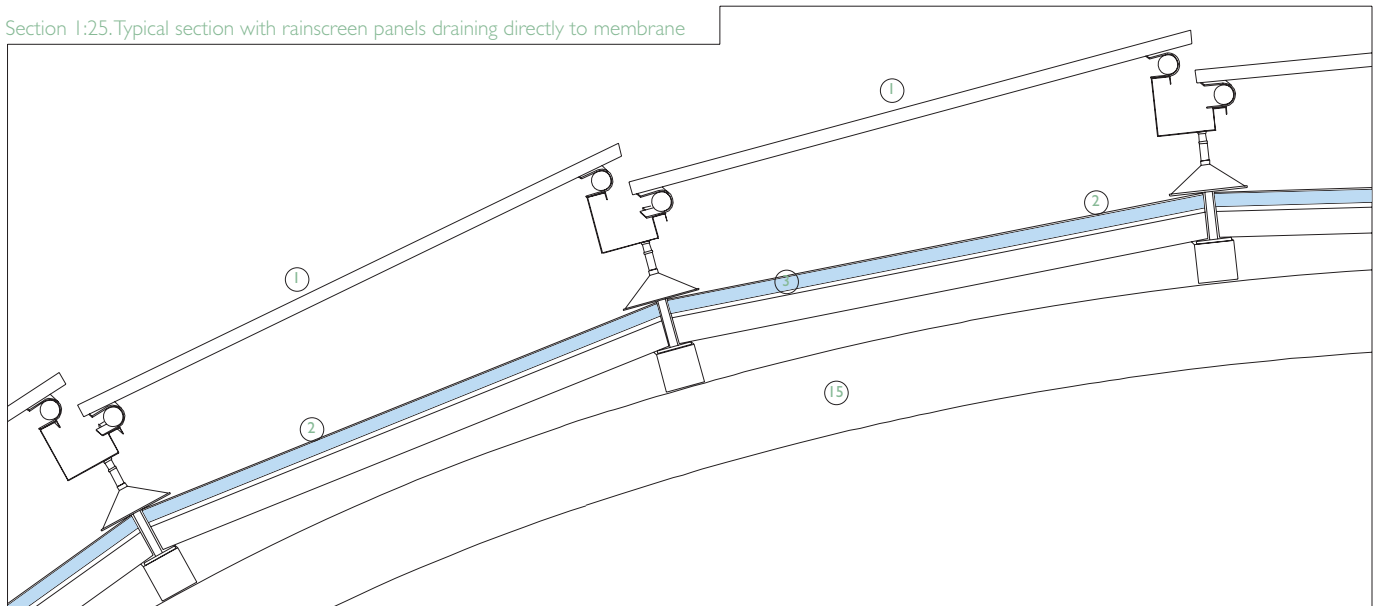
tinuous with the external wall beneath. The rainscreen panel at the edge of the roof is linked directly to a fascia panel. In (E) a curved panel is shown which is structurally independent of the external wall beneath. This allows the roof deck to deflect and move under normal structural loading without affecting the wall beneath. If wall and roof were rigidly fixed together, the wall would deflect with the roof, to amount that would be too much for curtain wall systems, whose movements are very restricted. This is a common detail for roofs where the expected structural movements are higher than the modest movements allowed with curtain wall facades.

A seal between the external wall and



Section 1:10. Verge with projecting fascia panel

Section 1:25. Typical section with rainscreen panels draining directly to membrane



Details

1. Metal rainscreen panel
2. Single layer membrane
3. Closed cell thermal insulation
4. Structural deck
5. Purlin or structural beam
6. Secondary purlin
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Panel 1
13. Panel 2
14. Ridge piece
15. Structural frame
16. Pipe or duct penetration

the underside of the roof is provided by two layers of EPDM sheet with flexible insulation quilt set between them. Folded metal sheet can also be used, but is less flexible in the longitudinal direction (along the length of the roof) than EPDM sheet.

Verges are similar to monopitch ridges, but differ in that they require an upstand at the roof edge to prevent rainwater from spilling off the roof. The upstand can be low if the verge is flat, and if relatively small amounts of rainwater are flowing along this edge of the roof. If large amounts of water flow are expected then the roof can be angled upwards slightly to avoid an upstand that extends above the line of the rainscreen roof panels, as shown in (F). An alternative

solution is to introduce a gutter at the edge of the verge to give greater height to the verge upstand without it becoming visible, and without breaking the continuous line of rainscreen panels.

Roof geometry

An advantage of rainscreen panels is their ability to form complex geometries from flat panel components. Since the panels are not required to be waterproofed, they do not require any joints between panels that would become difficult and expensive for roofs with complex geometries. Flat panels can be fixed down at their corners on a curved roof to create a set of gently curved panels that are turned in either one or two

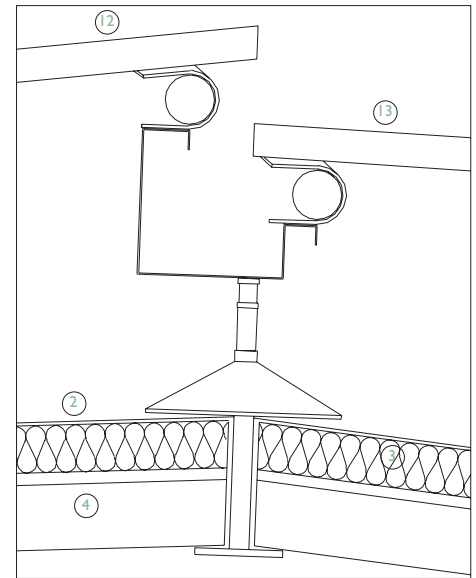
directions. Panels are increasingly being twisted in two directions in order to create genuinely curved roof finishes. Alternatively, panels can be set flat but with each panel set at different angles to create a faceted roof section.

Although the drawn examples here show lightweight roof configurations to suit the lightweight nature of the metal rainscreen panels, any compatible roof substrate can be used, from reinforced concrete slabs to timber shell structures.

Although most rainscreens are set at around 100mm above the membrane, some can be up to 1000mm above the roof deck in order to accommodate mechanical plant equipment and duct outlets for mechanical

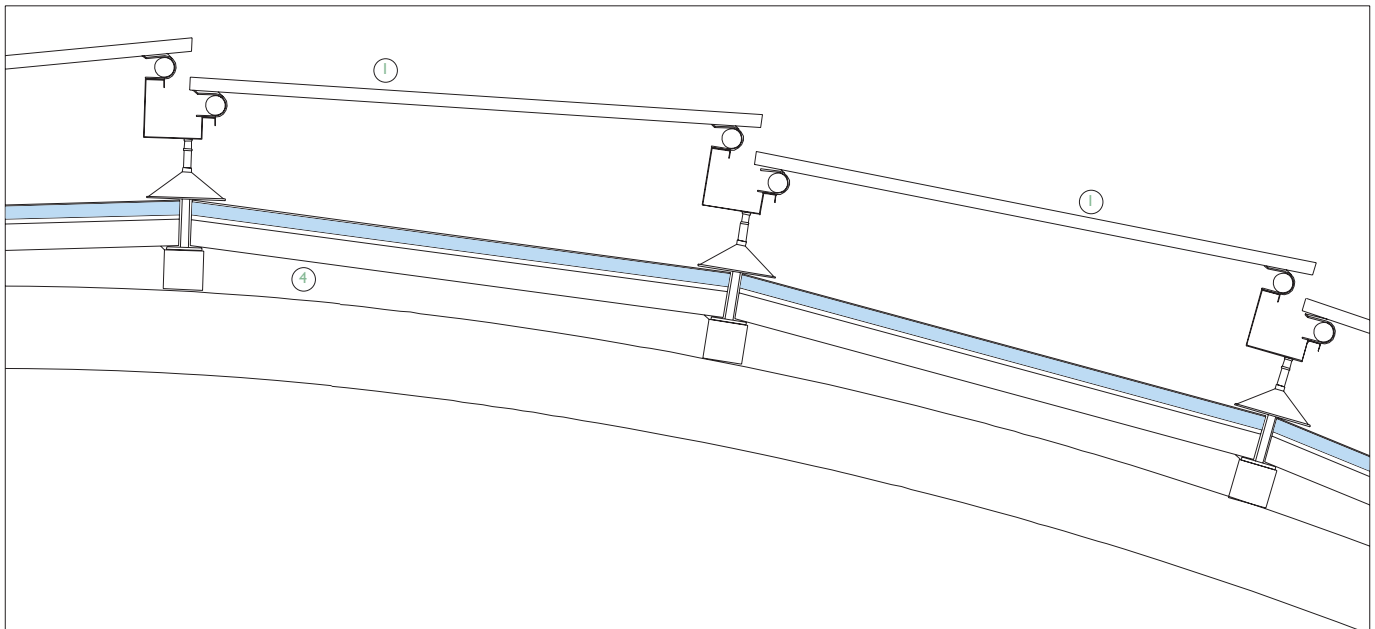


Shimosuwa Municipal Museum, Lake Suwa, Japan. Architect: Toyo Ito & Associates



Section I:10. Panel fixing

Section I:25. Typical section with rainscreen panels draining from panel to panel



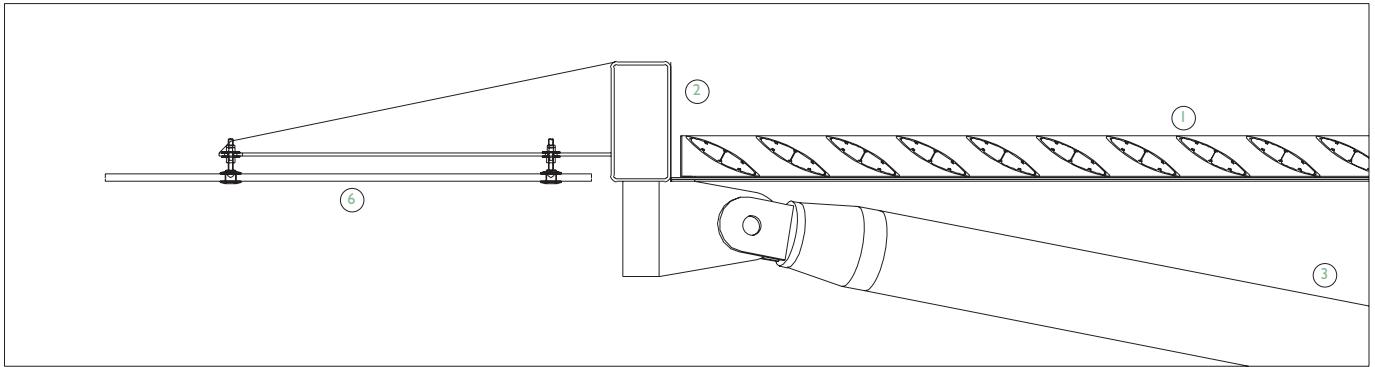
ventilation within the building. This allows rainscreen panels to provide weather protection for equipment as well as a visual screen to these items, which can have a considerable visual impact on a roof. Rainscreen panels set 1000mm above the roof are fixed to a secondary support framework, typically of cold formed steel sections or aluminium extrusions. The framework is fixed at its base to pads or Z-section profiles in the same way as the rainscreens set close to the roof membrane.

Roof soffits

Metal rainscreen roof panels can also be used as soffits panels to either an overhanging eaves or parapet, or alternatively to form

a complete soffit to the underside of a roof. When mixed with perforated or slotted panels and louvres, a roof can become a single visual entity, set above its external walls as a separate and distinct element. This can be achieved without the need for an expensive structure, or for an expensive waterproofing layer, since the membrane is concealed from view and is chosen for its performance rather than for its visual qualities. The easy removal of panels for maintenance access both on the roof, and into the ceiling void from the soffit panels beneath, make it an economic and easy to use system for roofs of complex geometry. The range of colours for composite sheet and for coatings to sheet metal have increased considerably

in the past 10 years, making this a roofing method set for new developments.

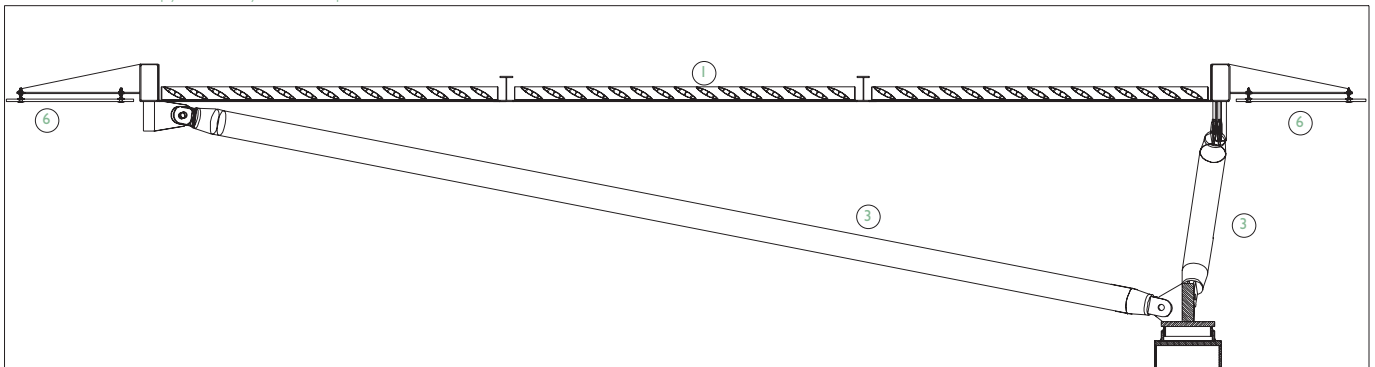


Section 1:25. Canopy edge

The Giovanni and Marella Agnelli Art Gallery at Lingotto, Turin, Italy. Architect: Renzo Piano Building Workshop



Section 1:80. Canopy assembly Example B

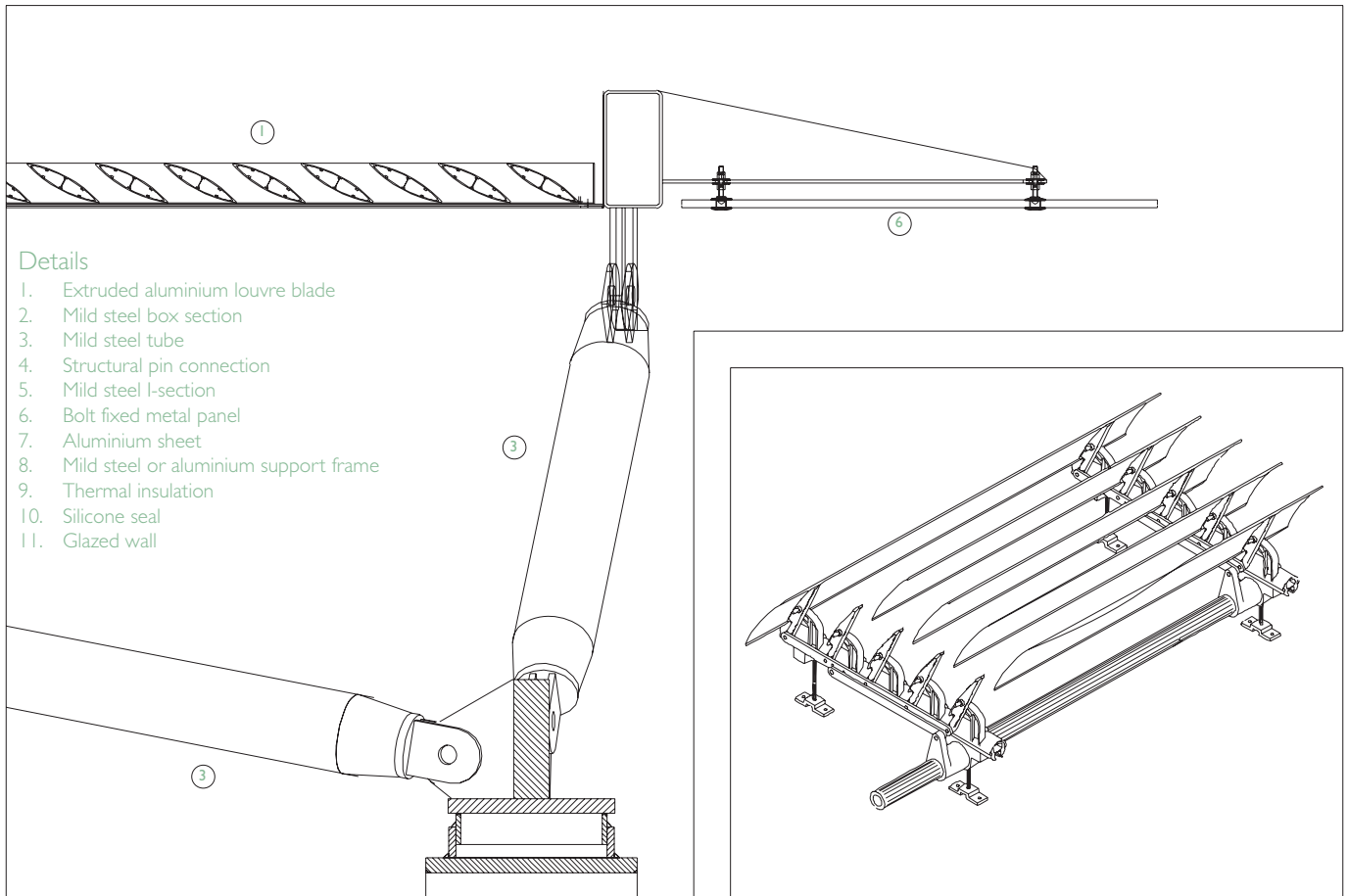


Metal canopies use all the techniques available to metal: standing seam, profiled sheet, composite panel and rainscreen panels with a membrane beneath. However, the preferred technique for metal canopies is usually none of these, but instead a method suited to small-scale construction of complex geometry. This method uses metal panels with folded edges, sometimes called cassettes, the joints between panels being sealed with silicone sealant. Panels can be individually folded to different shapes to form a canopy of complex geometry. There has been a gradual move towards larger metal panel sizes, even a complete form made from metal coil, which imitates the homogeneous forms found in GRP membranes and tent struc-

tures, but with the more durable finishes associated with metal panels. In common with other canopy types, metal canopies are expected to be fully watertight. The generic example here follows this principle.

In generic example (A) the metal canopy also serves as a sealed roof to part of a glazed wall. An inclined glazed wall meets a metal canopy at mid-height which might form part of an entrance, or may serve as solar shading to a facade. The sealed outer layer of the canopy comprises metal panels which are folded to form an overall curved profile, each panel being made from metal sheet which is folded at its edges to form a tray. The folded edges form the surface to which the silicone sealant adheres. An alter-

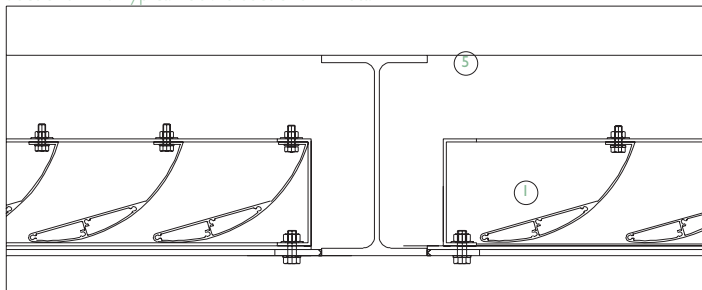
native method of joining metal panels together is by riveting them together, leaving a hairline joint between the sheets. This is done either by butting flat sheet together and riveting the two sides together as (C), or by folding the sheets down and riveting the underside as (D). In (C), the sheets are fixed with countersunk rivets fixing the edges of each sheet in place. A compressible polymer sheet is set beneath the sheets to provide a weathertight seal. In (D) a similar sheet material is set between the riveted panels to provide a seal. In practice, seals (C) and (D) are difficult to achieve where a high weathertight performance is required. Instead, the seal (E) used in the generic example shows silicone seal around 10mm wide between



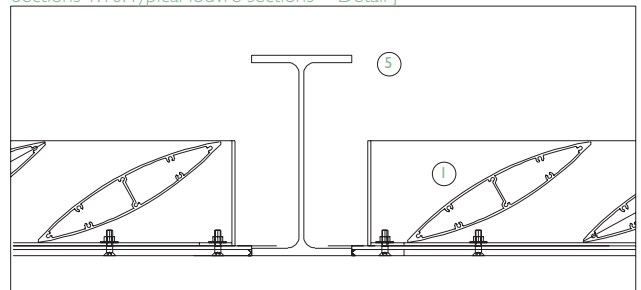
Section I:25. Canopy edge and support

Isometric view of assembly: Electrically operated louvres

Sections I:10. Typical louvre sections Detail H



Sections I:10. Typical louvre sections Detail J



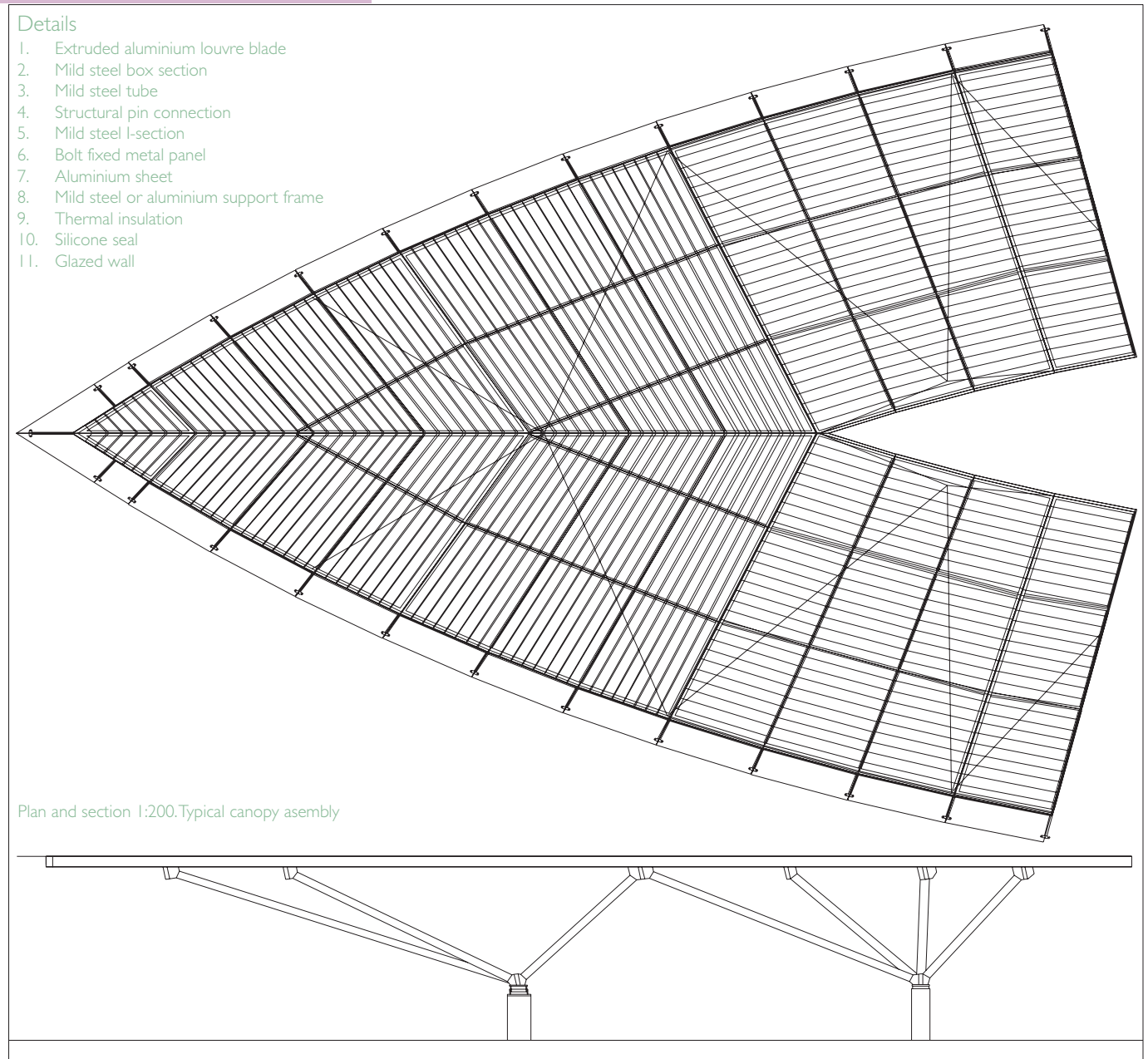
panels which are fixed with brackets back to a supporting structure. This provides a reliable seal that maintains its weather tightness in the long term.

The supporting structure is made from either mild steel or aluminium sections. Aluminium sections are usually preferred for their durability but mild steel is often used for its greater rigidity. Mild steel is galvanised, painted, or both, while aluminium, with its greater durability, can be natural, anodised or cromated (similar to anodising) depending on the individual application. Metal panels of large size, made from 1200mm x 2400mm sheet, can result in a gentle oil-canning effect around their edges. This gives panels their characteristic soft edge, but they look

smooth and consistent, and this is usually accepted visually as part of their appearance. If much thicker sheet is used, there is a disadvantage in increased cost as well as a greater difficulty in working the sheet to form smooth shaped pressed panels. Aluminium panels are typically either PVDF coated or polyester powder coated, while steel sheet is usually polyester powder coated only. The use of anodised aluminium as a finish on sheet has increased in recent years as a result of greater reliability of the finish, which until recently has suffered from uneven colour consistency. In generic example (B) the silicone used to seal the joints can be applied in a variety of monotone tints, ranging from white, to greys, to black. Some sil-

ver-grey colours match well with silver coloured panels to give an overall appearance of a single colour for the complete canopy, particularly when recessed joints are used between panels, shown in (B). Flush joints in silicone tend to give the canopy surface an homogenous appearance, giving it more the appearance of concrete than of metal. This can detract from the crisply fitted assembly of panels which is characteristic of metal and also one of the advantages of the material.

Metal panels can bring together the full set of assembly techniques available to the material within a single assembly. With folded panels, the edges are welded and ground smooth, and the complete panel is coated to



a single consistent colour. The use of countersunk screws, painted on site in a colour matching that of the panels, enhances the overall appearance.

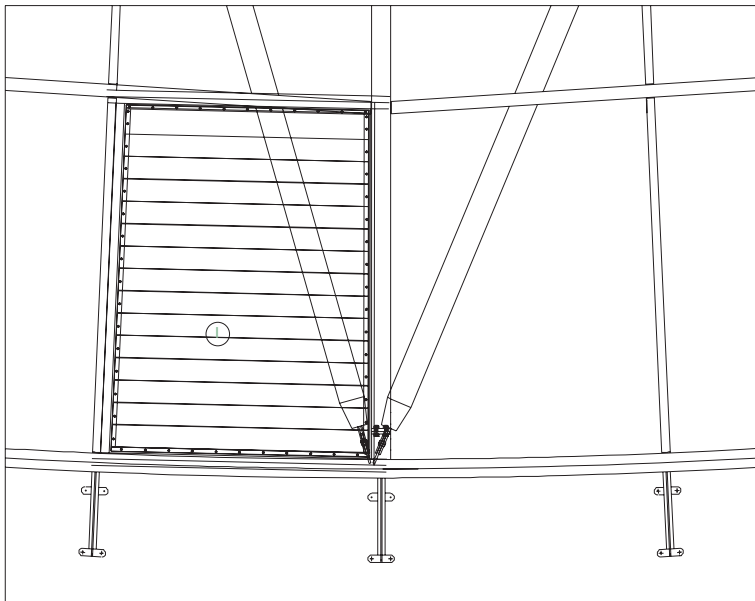
In generic example (B) the glazed wall above the canopy is sealed to it by extending the metal sheet forming the external gutter up into the bottom transom (horizontal glazing bar) of the glazing system to form a continuous seal with the glazed wall above. The thermal insulation within the canopy is continued in order to meet the thermally broken transom where it forms a continuity with the double glazed units above. The metal sheet forming the top of the canopy on the internal side of the wall is lapped up the internal face of the glazed wall framing where it is

folded under the bottom transom. The metal sheet forming the top of the canopy becomes a vapour barrier on the internal side of the wall, rather than the full weather barrier used on the external face of the canopy.

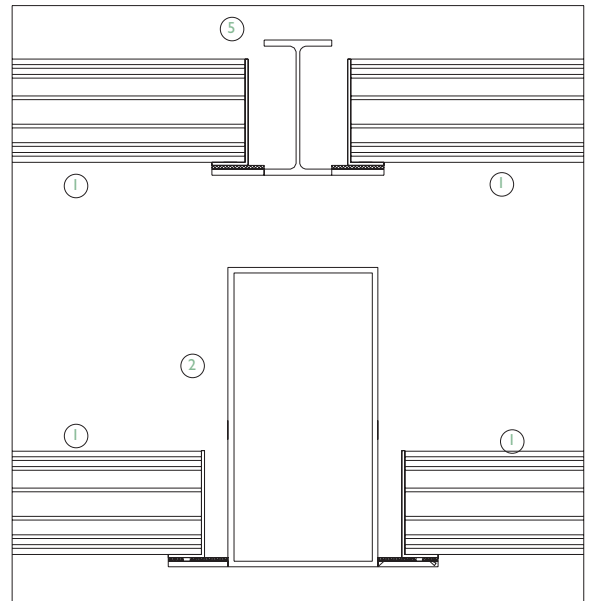
The glazed wall on the underside of the metal coping is joined in a way that disturbs the line of the canopy as little as possible as it passes it from outside to inside. The metal sheet on the exterior face of the wall is glazed into the top transom of the wall below. Any excess rainwater that is blown into the joint drips off the top of the transom pressure plate and capping. Small amounts of rainwater that find their way into the transom are taken away through the

ventilated internal drainage system of the glazed wall framing. The metal sheet forming the underside of the canopy on its internal face is taken as close to the glass as possible before being folded back to align with the transom.

Metal canopies are increasingly using a single seal between panels to form a weathertight joint. This method uses the application method of bolt fixed glazing, where a reliable silicone seal between double glazed units is the norm. However, where a foam-based backing rod is used to support the silicone applied from the outside, workmanship on site must be of the highest quality to ensure a durable weathertight seal. Where this is difficult, as where the edge of the



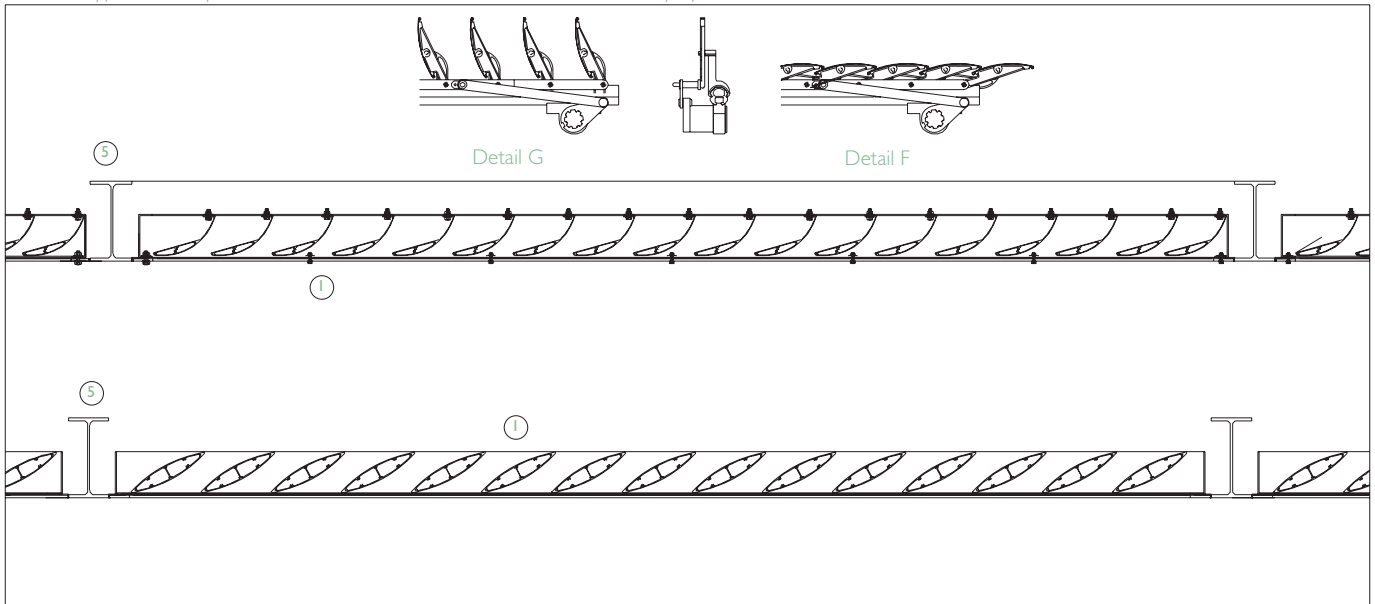
Section 1:25. Typical louvre panel



Section 1:10. Junction of louvre panel and frame. Detail K

Plan 1:80. Typical louvre panel

Electrically operated louvres



panel has a small edge return, or where panels are not able to be very rigid due to their geometry or manufacturing method, a second line of defence for weather tightness is provided by an elastomeric or thermoplastic waterproofing membrane. The ends of the waterproofing sheet at their top and bottom ends are fixed into the glazing system above and below where small amounts of water that penetrate the outer silicone seal are allowed to drain to the outside.

Bolt fixed panels

Metal panels can be bolt fixed, as shown on the canopy edges in generic example (A). With flat panels, such as minimum 3mm thick aluminium sheet, and metal / compos-

ite sheet can be bolt fixed using proprietary systems destined for use in point fixed glazing. The use of oversized holes or slotted holes in the metal panel ensures that the metal panels can move with thermal expansion without bowing or bending.

Gutters and rainwater outlets can be formed in sheet metal as shown in (B). The rainwater outlet can be finished to match the adjacent metal finishes so as not to detract from the overall visual form of the canopy.

In (B) the canopy forms part of a glazed wall, and is thermally insulated. The insulation usually follows the form of the outside of the canopy to keep the voids within the structure at a similar temperature to the internal

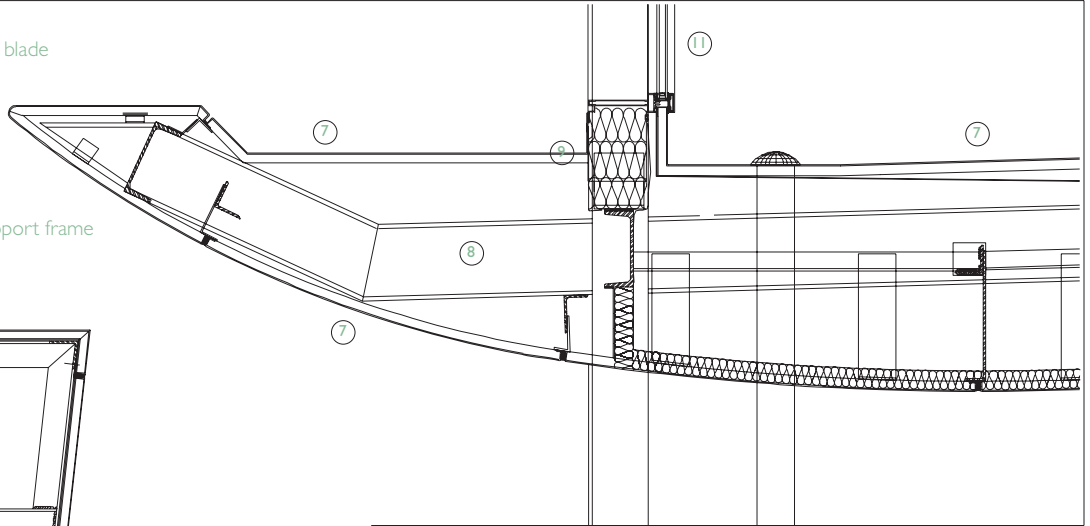
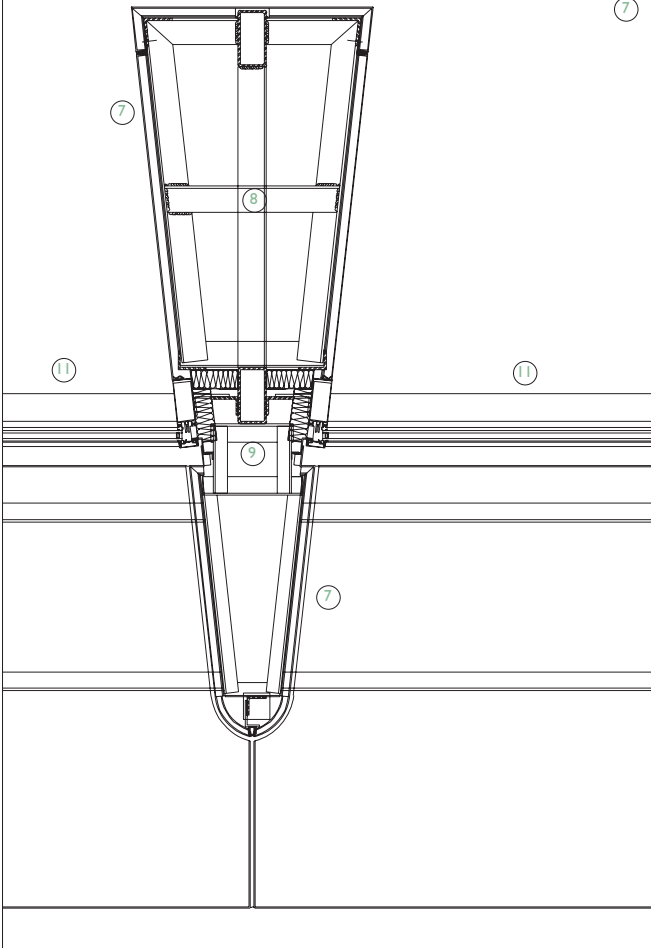
temperature of the building. An alternative is to form the insulation with the shortest distance between the glazed walls above and below, so that the structure and void are at the external temperature. The warm roof solution is usually preferred.

Fixed metal louvre canopies

Arrangements of metal louvres are used as canopies to provide solar shading while still allowing daylight to pass through the canopy. Louvre blades are set typically at 45° to the vertical in order to block the passage of direct sunlight but allow the light to be reflected off its surfaces down to the space beneath the canopy. Louvre sections are created from folded strips of aluminium or mild

Example A Details

1. Extruded aluminium louvre blade
2. Mild steel box section
3. Mild steel tube
4. Structural pin connection
5. Mild steel I-section
6. Bolt fixed metal panel
7. Aluminium sheet
8. Mild steel or aluminium support frame
9. Thermal insulation
10. Silicone seal
11. Glazed wall



Plan and section 1:20. Typical metal canopy Example A

The Giovanni and Marella Agnelli Art Gallery at Lingotto, Turin, Italy. Architect: Renzo Piano Building Workshop



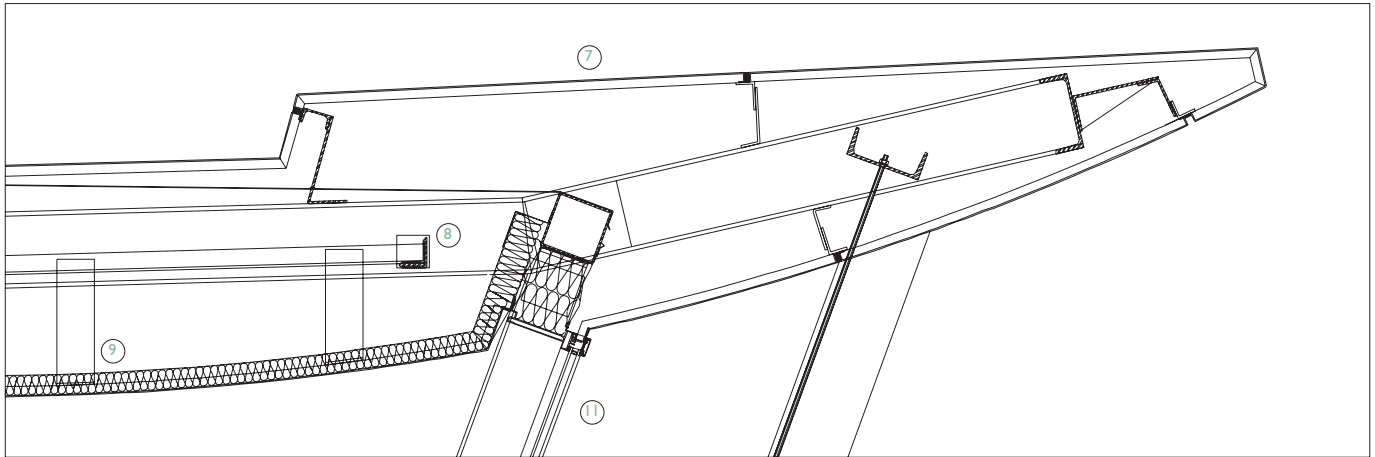
steel sheet, but these have limited stiffness and stability, requiring restraint along their length to hold their straightness in length. Greater stiffness is provided by extruded aluminium sections, where the elliptical section is most commonly used, mainly for its ability to reflect daylight in a way that reveals its 3-dimensional form, enhancing its appearance. Sections are either a half ellipse as (H) or a full ellipse as (J). Flat louvre arrangements provide much less visual vibrancy when viewed from below. Extruded aluminium sections require end caps, usually for visual reasons, and these are either fixed with countersunk screws into the wall of the section, or are welded and ground smooth. Where end caps are screwed to the ends, the aluminium

profile has screw ports that form part of the extrusion, into which the screws are fixed, as shown in (K). Aluminium extrusions can be made in lengths up to around 6000mm, and are supported at centres to suit their structural depth. An elliptical section will span typically 1500mm for a 75mm to 100mm deep section while a 250mm deep section will span 2500mm, depending upon design wind speed and related loads. When fixed at their ends, as shown in generic example (B), a fixed louvre assembly can be made without visible fixings.

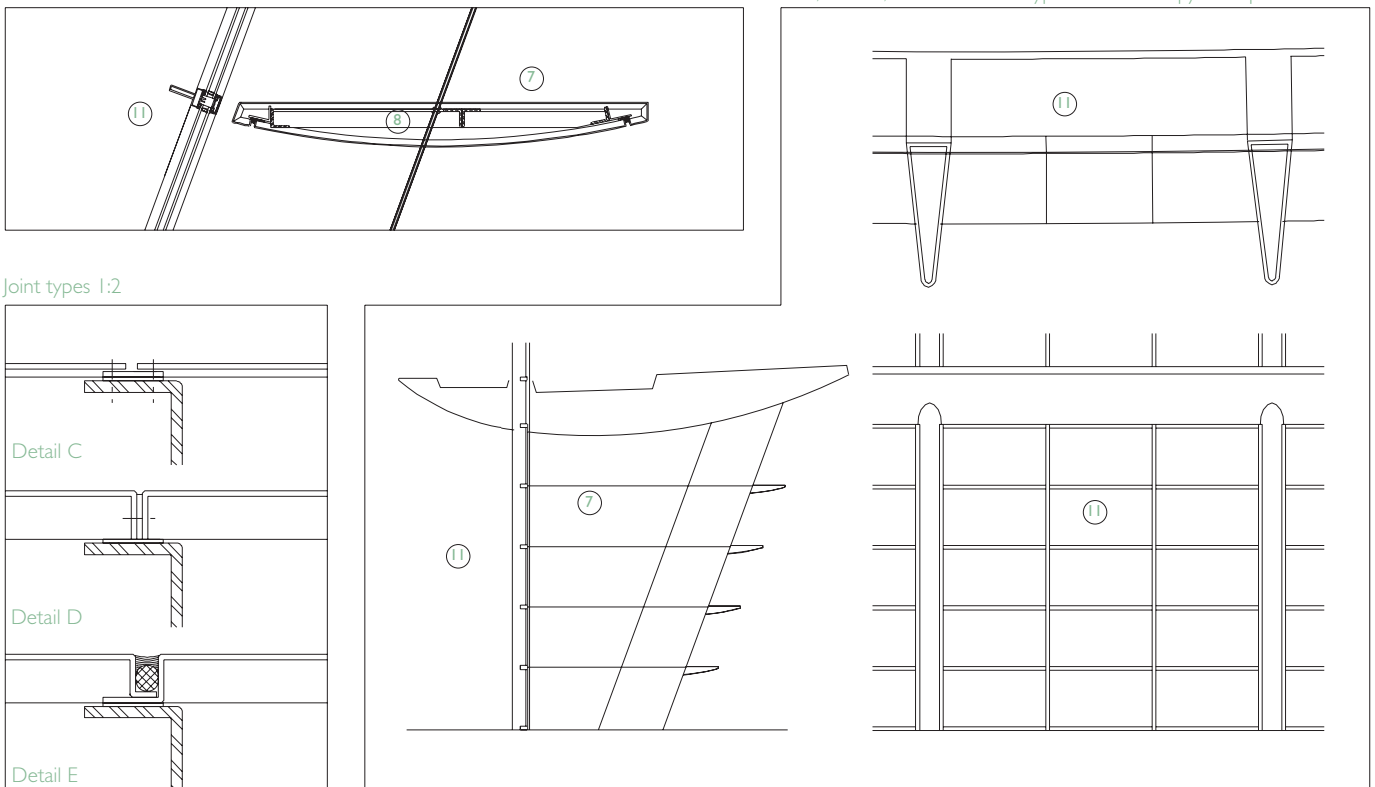
The supporting structure in (B) comprises a mild steel frame fabricated from box sections, supported by tube sections that spring from points below the roof. The box

sections are shown bolted together to form a flat frame structure, into which are set louvre panels, prefabricated and finished in a factory, then fixed to the supporting mild steel frame on site. The steel tubes are fixed to the flat frame with pin connections. Two flat plates are welded to the ends of the tubes, and a single plate forming a cleat is fixed to the underside of the flat frame and the base support below the roof. The fork ends of the tubular supports and the support cleats to which it connects are fixed together with face-mounted or countersunk bolts to form a visually crisp connection. The tubes have tapered ends shown which is typical of this type of steel construction. The aluminium louvre panels are fixed to the

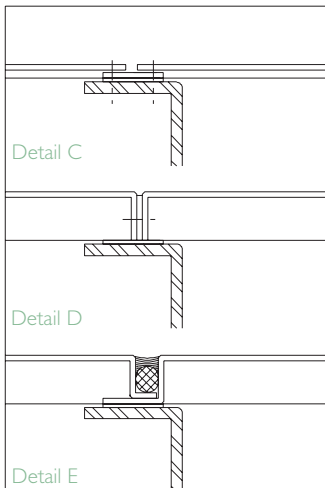
Plan and section 1:20. Typical metal canopy Example A



Plan, section, elevation 1:100. Typical metal canopy Example A



Joint types 1:2



supporting flat frame with brackets that are welded to the sides of the bottom flange of the steel I-section. The aluminium louvre panel is supported on these brackets, with a nylon spacer between them to allow for thermal movement. The louvre panel is fixed to the cleat bracket with a countersunk bolt.

Electrically operated louvres

Louvre canopies are also used for horizontal and inclined glazed roofs, excluding up to 90% of solar heat gain when set at a 45° angle. Louvre blades are 75mm-100mm in typical proprietary systems but blades up to 300mm wide can be made as a single extrusion. Nylon sleeves and washers are used at the connection of moving parts, rather than

metal, to avoid the need for regular lubrication. Louvres can be solid or perforated to different percentages of solid to void, from around 10% void to a maximum of 50%, though the latter is difficult to fabricate.

Louvres are fixed by steel pins into a sliding aluminium section at each end of the profile, as shown in (F) and (G). The louvres are also fixed at their centre in section. As the sliding aluminium rod moves, the aluminium louvres move together, opening and closing together. The sliding rods are connected at each end of the louvres are fixed to a supporting frame of aluminium I-sections. The single tube is powered by an electric motor, and as it turns, the sliding arms move through the arrangement of gears, shown in

the two diagrams of (F) and (G).

Louvres are typically a maximum of around 6000mm long for those 75mm to 100mm deep, requiring support at 1000mm to 1500mm. Sliding arms typically support up to a 6000mm length of louvre blades, giving an overall square shape (in plan) to each set of controlled louvres of 6000mm x 6000mm size which are fixed into the supporting I-section frame. A 100mm deep I-section will span typically 1000mm - 1500mm between supports depending on the design of the glazed roof below. The distance between the moveable louvre panels and the glazed roof below is made sufficient to allow for access for cleaning the glass below and the louvre assembly itself.

2

GLASS

(1) Greenhouse glazing and Capped glazing

Greenhouse glazing

Modern roof glazing

Capped systems

(2) Silicone-sealed glazing and Rooflights

Junctions

Use of capped profiles

Rooflights

(3) Bolt fixed glazing

Generic structural

support methods

Supporting brackets

Bolt fixings

Arrangement of bolt fixings

Glazed units

(4) Bolt fixed glazing: Pitched roofs and rooflights

Base of glazed roof

External and internal folds

Small glazed rooflights

Larger rooflights

(5) Bolt fixed glazing: Twin wall roofs

(6) Bonded glass rooflights

Generic conical rooflight

Generic rectangular rooflight

Generic monopitch rooflight

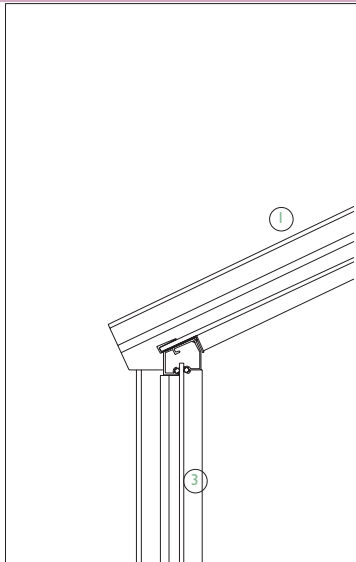
Glass roof decks

(7) Glazed canopies

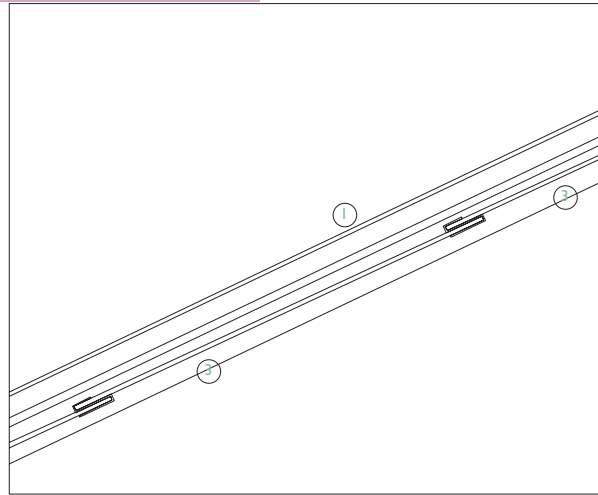
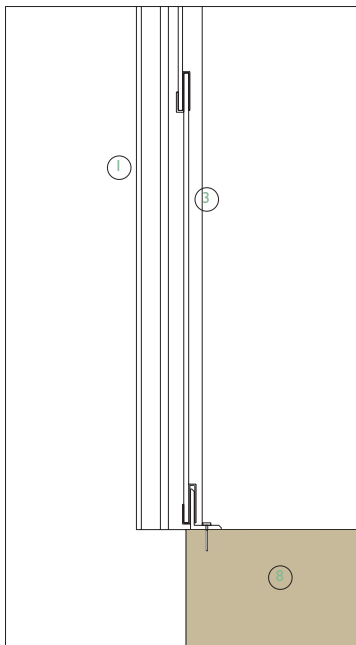
System assembly

Four edge restrained canopy

Bonded glass canopies

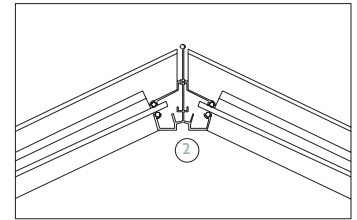


Section I:25. Greenhouse glazing. Typical cross section.

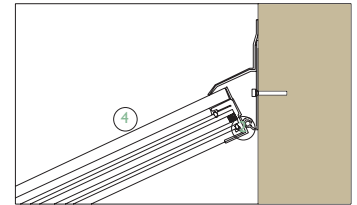


Section I:25. Greenhouse glazing. Typical section. Detail A

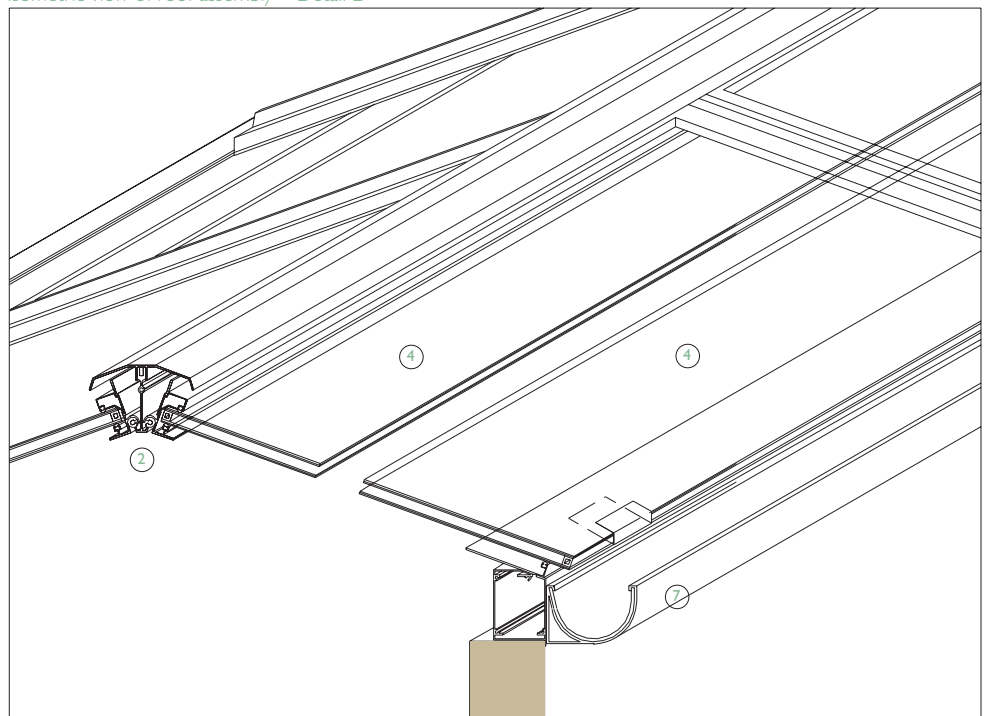
Isometric view of roof assembly Detail D



Section I:25. Greenhouse glazing. Typical ridge section.



Section I:25. Greenhouse glazing. Abutment.



Greenhouse glazing

Curtain walling principles used in external walls have been adopted, over the last 20 years, as a reliable method of constructing glazed roofs to replace earlier systems developed from greenhouse glazing. Traditional greenhouse glazing used thin steel or cast iron sections to support glass sheets on their vertical edges to form a pitched roof. Since rainwater needs to run down the slope without being impeded by glazing bars, a method of lapping glass sheets over one another was used, as shown in (A). Traditionally, the glass is lapped with no seal, with glazing bars set at around 600mm centres in order to keep the glass as thin as possible, with glass thicknesses from 4mm to 6mm

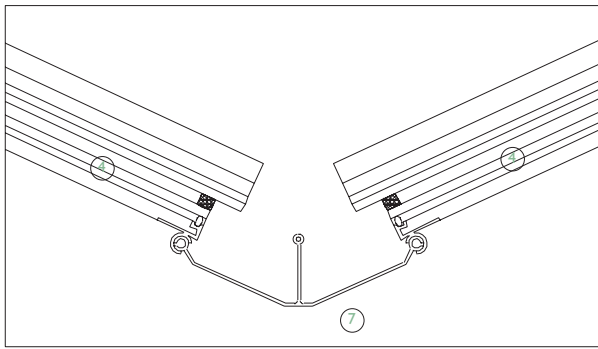
thicknesses being used typically. The lapped glass results in water being drawn up between the sheets by capillary attraction, which can cause water leaks and staining. However, complete weather tightness is a secondary issue in greenhouses, this design being a very neat and economic solution for its purpose.

The glazing can be used in a pitched roof as well as a vertical wall to form the traditional greenhouse enclosure. For large greenhouses an additional aluminium or steel frame is used to support the glazing. A typical structure is of lightweight metal trusses, used to support the glazed roof, are set on steel or aluminium box section columns that also support the glazed wall. Trusses are

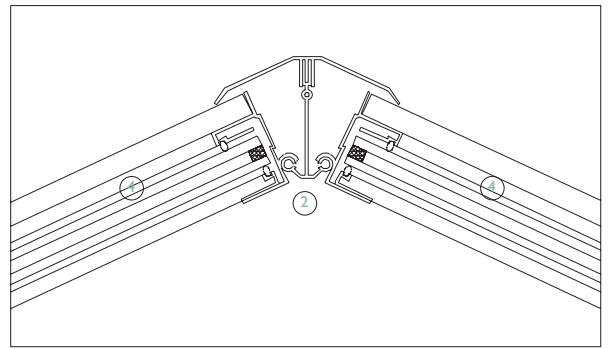
set typically at 3000mm centres with purlins running between them to support the glazing bars at 600mm centres.

This glazing system is still used in greenhouses for agricultural activities, but has poor thermal insulation, since their purpose is to absorb the heat from the sun rather than excluding it. The use of single glazing, with no thermal breaks and high air infiltration rates (by curtain walling standards), make it ideal for agricultural use, but very poor for the use in general building construction. However, the concept of greenhouse glazing has been developed into the highly insulated, air sealed and watertight glass roof systems used in contemporary buildings.

An essential component of greenhouse

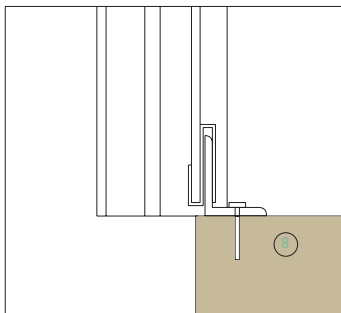
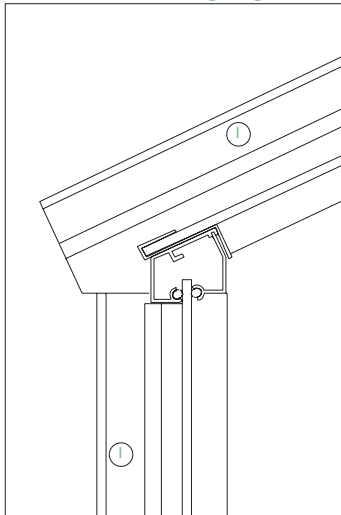


Section I:5. Greenhouse glazing. Valley Detail F



Section I:5. Greenhouse glazing. Ridge

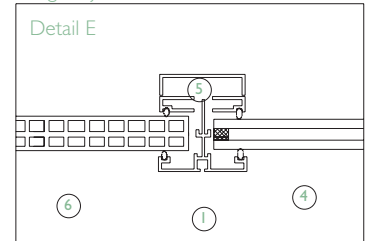
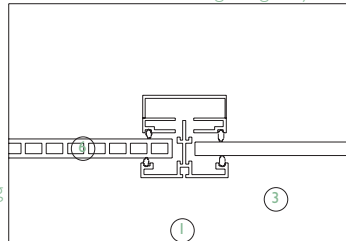
Section I:5. Greenhouse glazing. Eaves



Greenhouse details

1. Extruded aluminium glazing bar
2. Extruded aluminium sections
3. Single glazed sheet
4. Double glazed unit
5. Aluminium clip-on capping
6. Polycarbonate sheet
7. Aluminium gutter
8. Concrete base

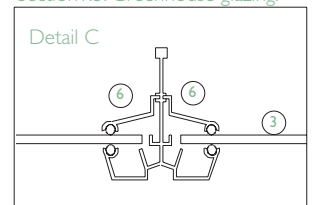
Section I:5. Greenhouse glazing. Polycarbonate to glass junction



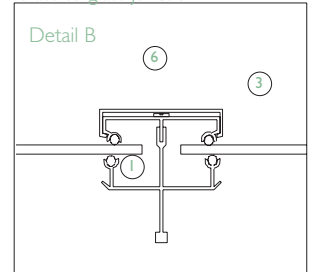
Amazonian House, Stuttgart. Architect: Auer und Weber



Section I:5. Greenhouse glazing.



Glass to glass junction.



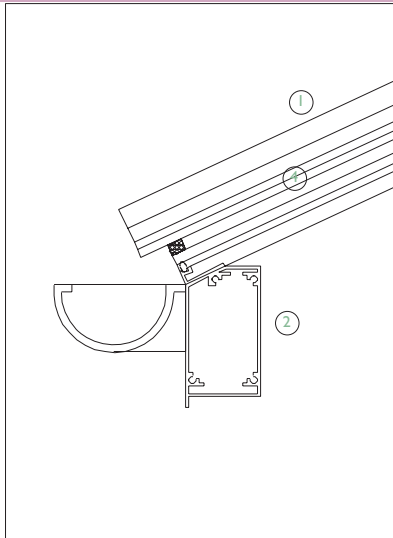
glazing that has been retained in modern glazed roofs is the glazing bar; which corresponds to a mullion in glazed walls. The greenhouse glazing bar has a condensation channel beneath of the glass to drain away water that passes through the outer seal during rain. The condensation channel also serves as a drain for moisture inside the building that has condensed within the framing. Condensation channels are either open at the edges, as (B), or are enclosed as (C). Modern greenhouse glazing is made from extruded aluminium sections with no thermal break, since high thermal insulation is not required, but includes the condensation channels to avoid water from dripping below.

The horizontal joint between lapped

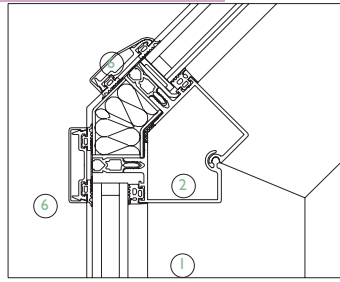
glass sheets is sealed with either a clear coloured seal, typically silicone sealant, or with continuous aluminium clips. Some greenhouse systems still have lapped glass with no seal between the glass sheets, making it very economic, but not very airtight, which suits certain agricultural applications.

Ventilation in greenhouse glazing is provided at the eaves and at the ridge, while opening lights are used for more closely controlled ventilation. Single glazed sheets are held in place on their sides by supporting them on the glazing bars and securing them in place with continuous aluminium clips that snap onto the glazing bar. The aluminium sections are separated from the glass by extruded rubber-based seals which

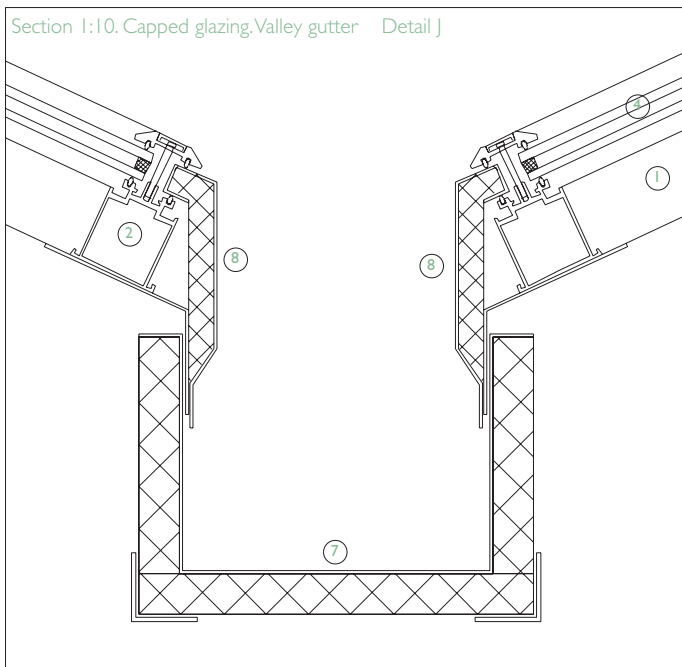
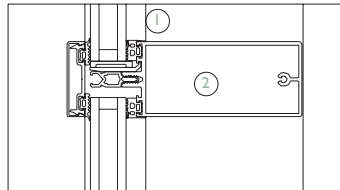
are held in place on the aluminium glazing bars and which press against the glass to provide both a cushion for the glass as well as a water and air seal. The strength and stiffness of the glazing bar is provided by the central flat bar that extends beyond the glazing line either inside or outside the glazing. Unlike curtain walling based systems, where the structural mullion extends on the inside face of the glass, with a pressure plate on the outside, greenhouse glazing has only clips either side of the control bar, allowing it greater freedom to extend both inside and outside the face of the glass. The rubber seals are deep enough and soft enough to allow the bottom of the glass sheet to lap over the top of the sheet below on the hori-



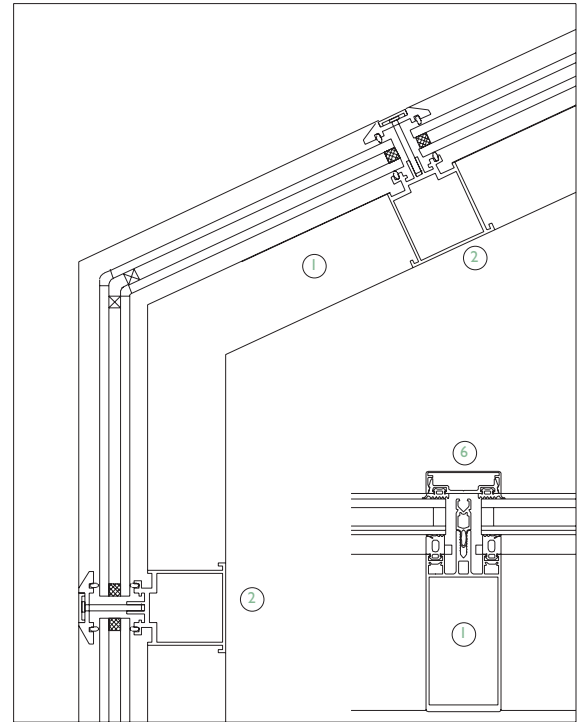
Section 1:10. Capped glazing. Eaves gutter



Section 1:10. Capped glazing. Eaves with glass to glass fold

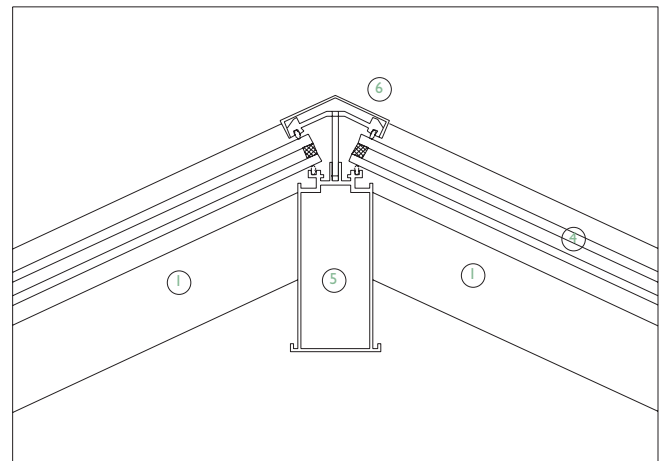


Section 1:10. Capped glazing. Valley gutter Detail J



Section 1:10. Capped glazing. Eaves with profiles at fold

Section 1:10. Capped glazing. Ridge



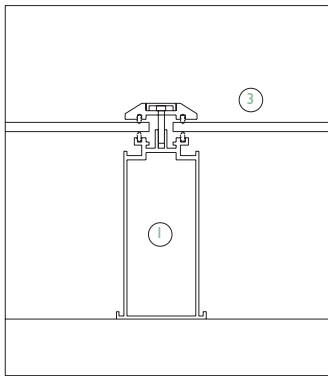
zontal joints. Greenhouse glazing can accommodate double glazing units, as shown in (D). The main reason for this is usually to provide greater control of the internal temperature for agricultural buildings. Thermal breaks are still not required, but there is a larger provision for slot ventilation at the ridge and eaves locations to encourage natural cross ventilation. The increased weight of double glazed units over single glazed sheets results in bigger glazing bars to support them, but the system remains essentially the same. The snap-on glazing clips or screw-on types in use usually have a stepped profile to accommodate the increased glass depth, while short length aluminium clips are used along the horizontal joints to hold the lapped units in place. These

horizontal joints are usually sealed with silicone to provide an air seal. Greenhouse systems can also accommodate both flat polycarbonate sheet and the multi-wall type. A twin wall sheet has thicknesses with are similar to those of double glazed units, ranging from around 24mm to 32mm, allowing the same aluminium profiles to be used for both double glazing and polycarbonate sheets, as shown in (E).

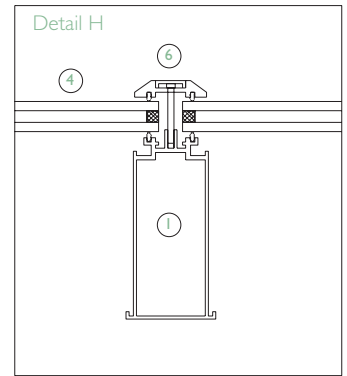
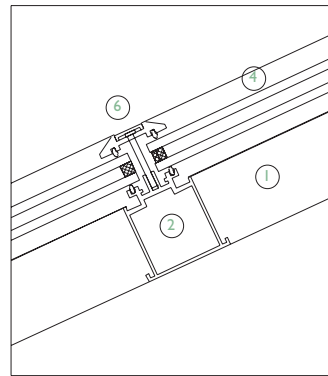
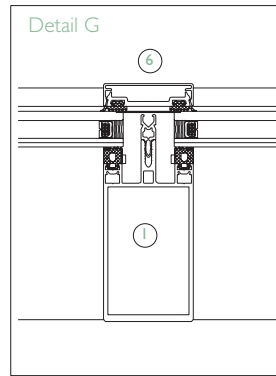
Ridges are formed by special extruded aluminium sections that hold the glass with the same clips used for the glazing bars which meet at the ridge. Since each ridge extrusion can suit only one roof pitch, manufacturers offer ridge profiles to suit a limited range of roof pitches, typically 22°, 30° and

45°. A condensation channel set into the glazing section is drained either into the glazing bars that intersect with it, which drains down the slope of the roof to the eaves, or is drained at its gable ends if the ridge can be set level to allow the water to drain freely.

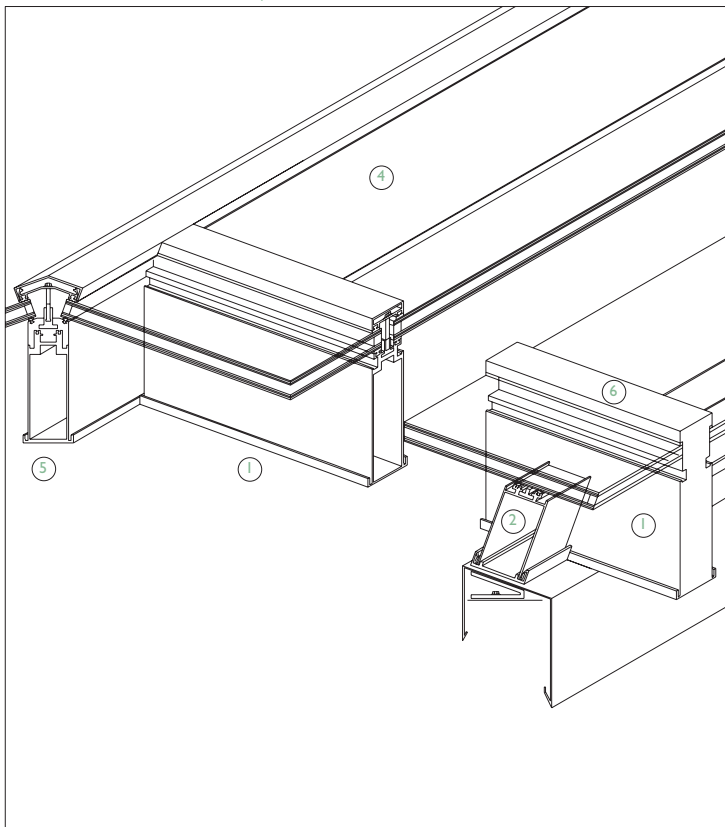
Gutters are formed by fixing gutter profiles to a box section used at junctions beneath it. The glass simply overhangs the edge of the roof to drain rainwater into the gutter. At ground level, the glass often overlaps the concrete ground slab, where a finished floor is provided. Where the greenhouse glazing has no floor, as is the case in many agricultural applications, a brickwork or concrete blockwork edge is provided to ter-



Section I:10. Capped glazing. Typical profiles



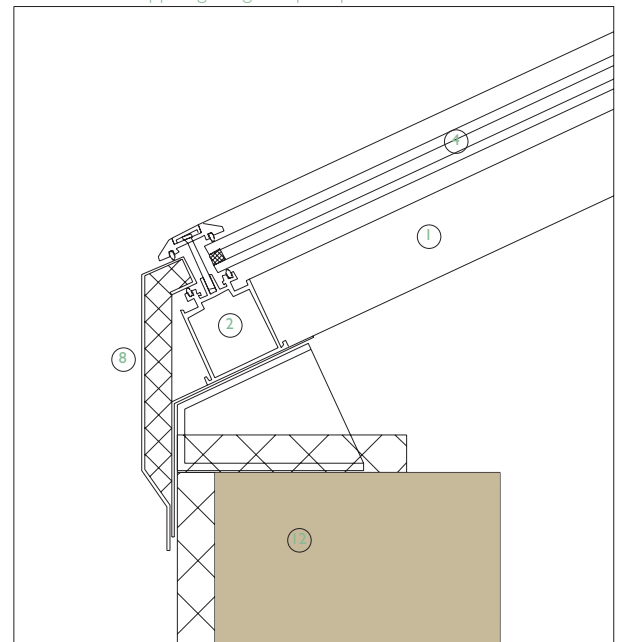
Isometric view of roof assembly



Capped glazing details

- | | |
|-----------------------------------|----------------------------|
| 1. Extruded aluminium glazing bar | 7. Insulated gutter |
| 2. Transom | 8. Insulated flashing |
| 3. Single glazed unit | 9. Rooflight |
| 4. Double glazed unit | 10. Thermal insulation |
| 5. Ridge bar | 11. Pressed metal flashing |
| 6. Pressure plate and capping | 12. Concrete base |
| | 13. Pressed metal trim |

Section I:10. Capped glazing. Parapet upstand. Detail K



minate the glass above ground level, where it could otherwise be susceptible to damage.

Valley gutters, which occur typically where glasshouse roofs are set next to one another, are also formed from extruded aluminium sections, with the glass being secured in the same way as the glazing bars, as shown in (F). An additional upstand is often added to the aluminium section for increased rigidity. Gutters in other roof systems are usually insulated, where the depths of insulation, together with the inner lining, provide a rigid gutter. With greenhouse glazing, with no thermal insulation provided, an upstand or downstand formed within the gutter extrusion performs the same function of providing sufficient stiffness to bear the

weight of a gutter filled with rainwater.

Although not useful for most applications in general building construction, greenhouse glazing is useful for the reader for two reasons: to understand how glazed roofs have evolved from a simple mass produced system, as well as for applications where a glazing system is required that is minimal in both its components and its overall assembly as well as where an uninsulated glass structure might be required, without the need to use thermally broken glazing systems which are designed for much larger glass units.

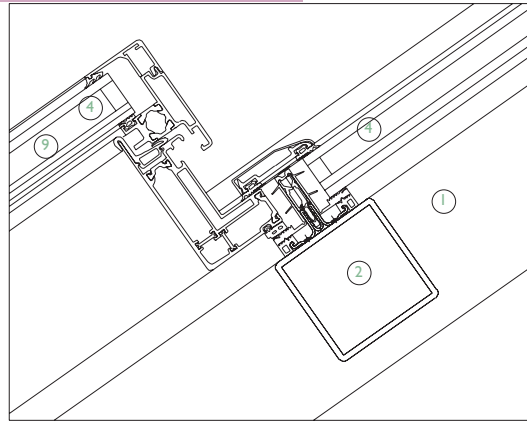
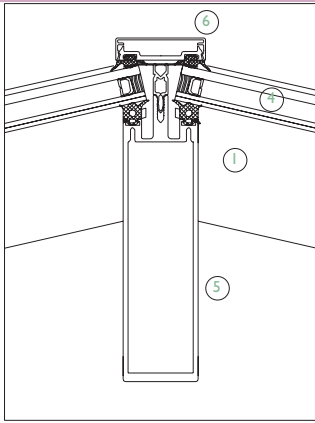
Modern roof glazing

Systems for glass roofs use the principles of greenhouse glazing, but incorporate the

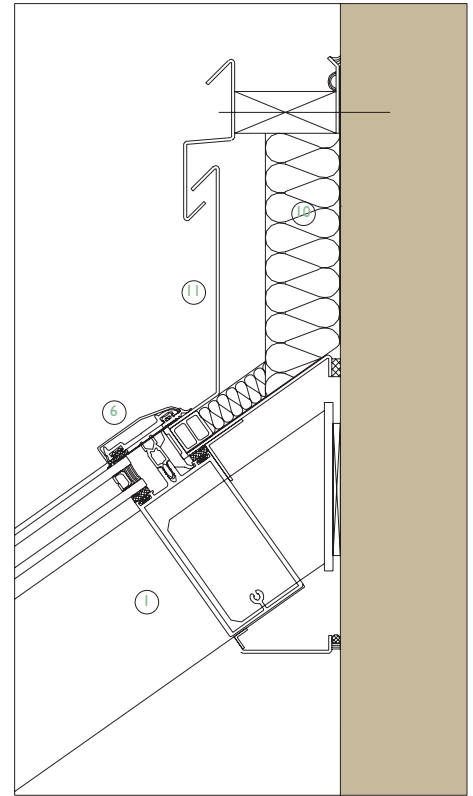
principles of glazed curtain walling. Drained and ventilated systems are used, with thermal breaks and double glazed units. Pressure plates rather than clips are used to hold large glass units in place in capped systems, and toggle-type plates are used to provide flush joints in silicone based systems. This latter type is discussed in the next section of this book, while this section focuses on pressure plate based, or 'capped' systems.

Capped systems

The system shown in (G) comprises glazing bars which are assembled on site in a grid of members that resemble the mullions and transoms of stick glazed curtain walling. The base of the curtain wall, at the bottom



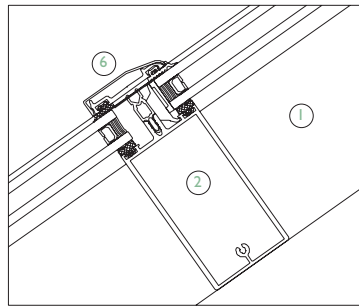
Section 1:10. Capped glazing. Junction with rooflight



Section 1:10. Capped glazing. Abutment

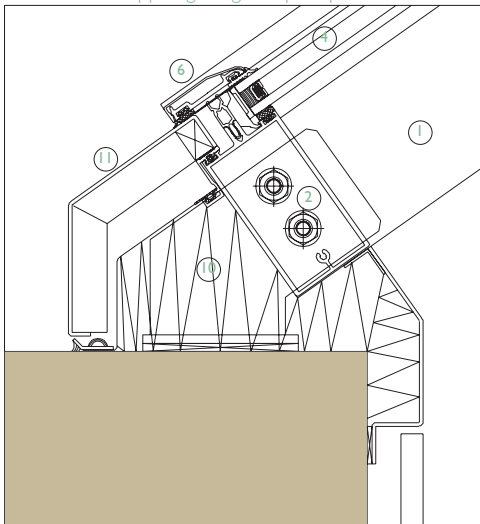
Capped glazing details

- | | |
|-----------------------------------|----------------------------|
| 1. Extruded aluminium glazing bar | 7. Insulated gutter |
| 2. Transom | 8. Insulated flashing |
| 3. Single glazed unit | 9. Rooflight |
| 4. Double glazed unit | 10. Thermal insulation |
| 5. Ridge bar | 11. Pressed metal flashing |
| 6. Pressure plate and capping | 12. Concrete base |
| | 13. Pressed metal trim |

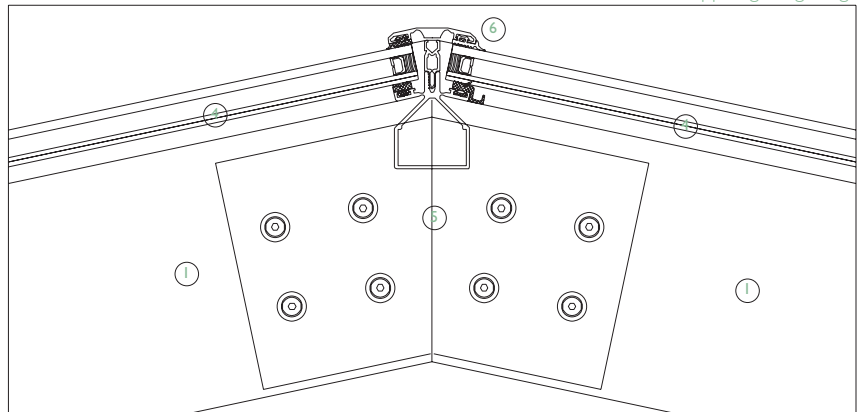


Section 1:10. Capped glazing. Typical profiles

Section 1:10. Capped glazing. Parapet upstand



Section 1:10. Capped glazing. Ridge



of the extruded profile, may have an additional condensation channel, as shown. This provision can also be made by setting the condensation channels immediately beneath the glass, as shown in (H). The glass is set onto rubber-based air seals fixed to the glazing bar and is secured with a continuous pressure plate of extruded aluminium. A strip of extruded EPDM is set between the pressure plate and the glass to provide a weathertight seal. As with glazed curtain walling, the glazing bars are drained and ventilated, or pressure equalised, internally. Water that is able to find its way through the outer seal drips into an internal channel where it is drained away safely to the bottom of the roof, typically at the eaves. In smaller roofs

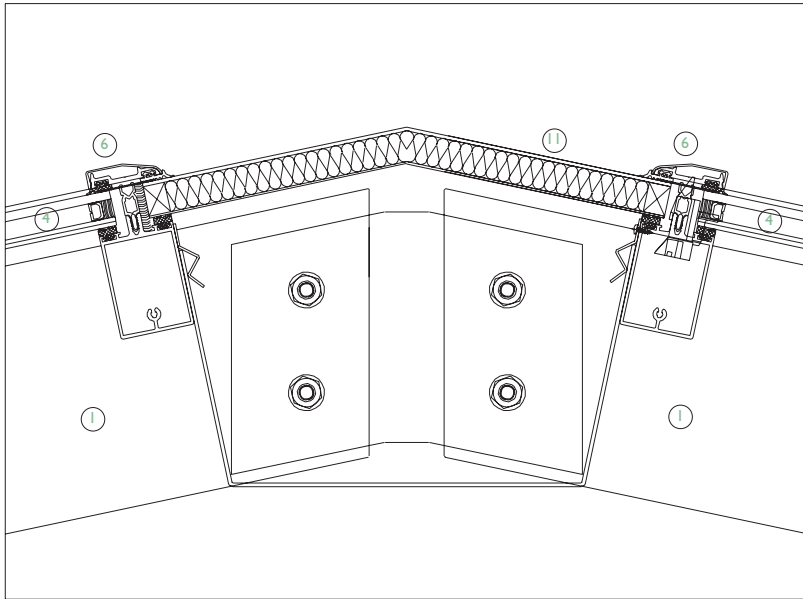
without eaves, where the roof angle changes from pitched to vertical wall, rainwater is allowed to run on down the wall to the base of the roof. At the 'fold' point of the roof the internal drain in the glazing bar is continuous with the vertical wall, and the system is drained at the base of the wall, which could be a reinforced concrete slab at roof level.

While glazing bars running down the roof project above the surface of the glass, those running along the roof, holding in place the top and bottom edges of the glass, require a method of allowing the water to run over the junction. Some systems use a step at this point, without a pressure plate on top that would otherwise impede the passage of water down the roof. Other sys-

tems use a pressure plate and cover capping with chamfered edges that allows rainwater to pass over it easily. A small amount of water is left trapped on the top edge of this horizontally-set glazing bar, but this is soon blown away by the wind or else evaporates. Any water that penetrates the outer seal is drained away through the internal drain in the glazing bar.

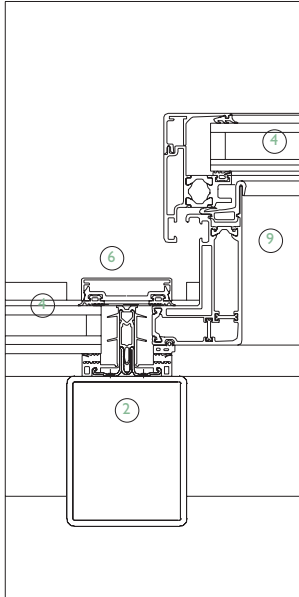
Ridges, like glazing bars, follow the main principles of greenhouse glazing. The box section, or chosen profile of the typical glazing bar is usually made deeper to take the higher structural loads of the ridge. Glazing bars that intersect with the ridge profile are notched at the top to allow the drained and ventilated inner chamber to drain water

Section I:10. Capped glazing. Ridge

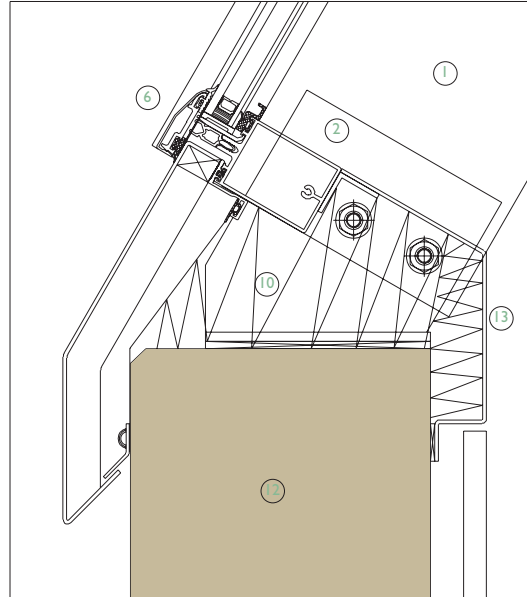


Amazonian House, Stuttgart. Architect Auer und Weber

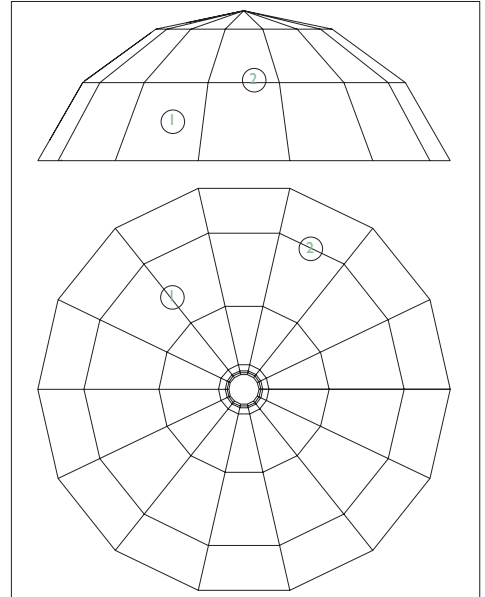
Section I:10. Capped glazing. Junction with rooflight



Section I:10. Capped glazing. Parapet upstand



Plan and section 1:100. Capped glazing. General principle



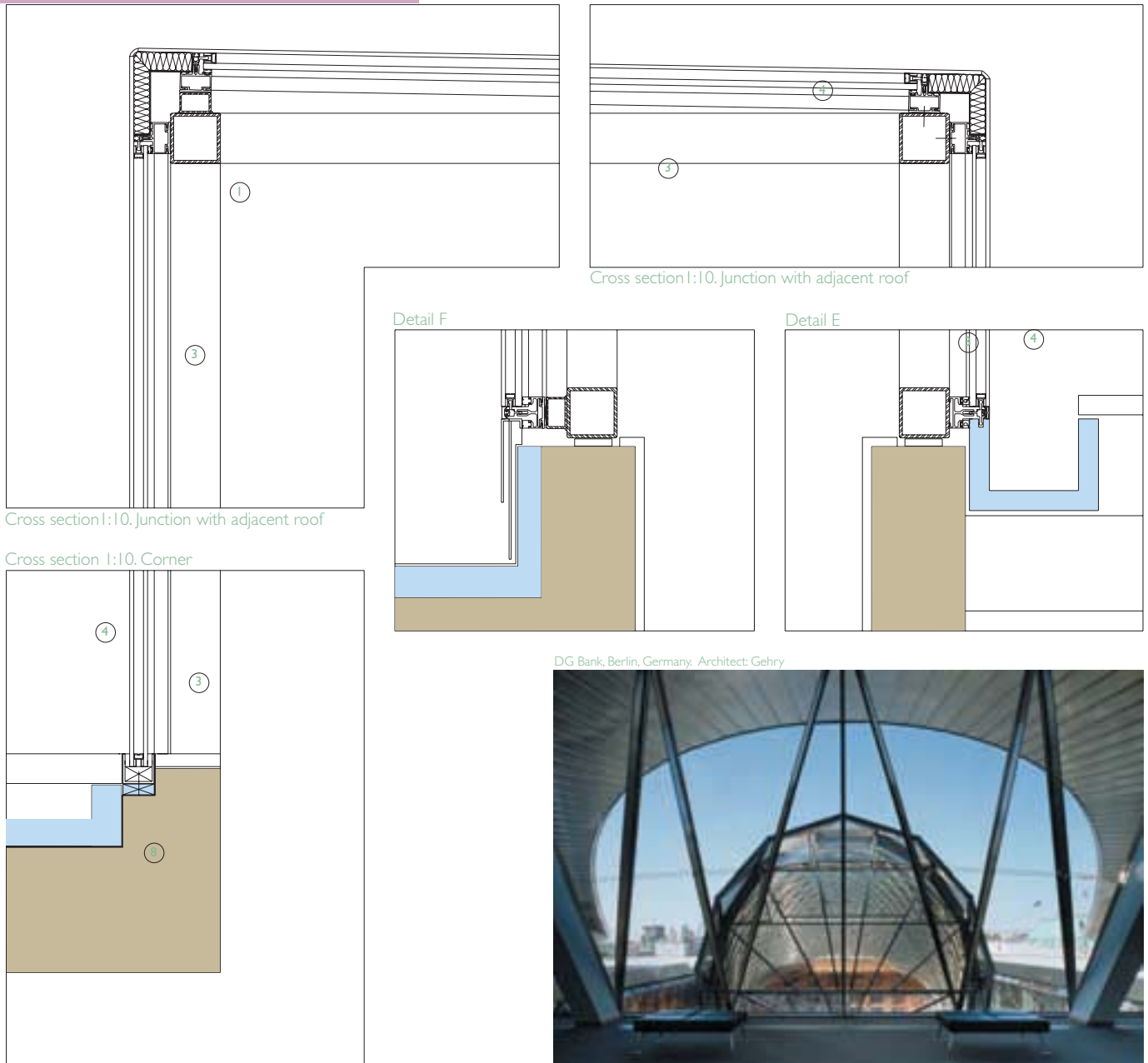
internally down the glazing bars that follow the slope down the roof. A specially made V-shaped continuous pressure plate is used to secure the glass at the ridge, with a similar shaped cover cap set on top. While cover caps are not an essential part of glazed roofs, as is the case with curtain walling, their function is to conceal the drainage slots and screw fixings in order to provide a consistent visual finish to the glazing bars.

Gutters, at both valleys and eaves, are very different to greenhouse glazing. Instead of lapping the glass into the gutter, the gutter profile (or downstand flashing) is clamped into one side of the horizontally-set glazing bar at the base of the pitched roof, as shown in (J). An insulated gutter is used to maintain

the relatively high level of thermal insulation and to avoid a thermal bridge across the system. If a downstand flashing is used to separate the roof from the gutter, to make it easier to install the gutter, then two layers of flexible membrane seal are used between the downstand insulated flashing and the insulated gutter. This seal is required to be fully watertight if the gutter becomes blocked and water in the gutter fills to the top of the gutter during a storm, for example.

Regular downstand flashings, shown in (K), are insulated in order to provide a continuity with the thermal insulation of the adjacent construction at the base of the roof in order to avoid a thermal bridge. Glazing bars

that terminate at flashings and gutters allow the internal drain to release water at these points. Drops of water that find their way into the drainage chamber are drained out onto the outer (top) surface of the downstand flashing.



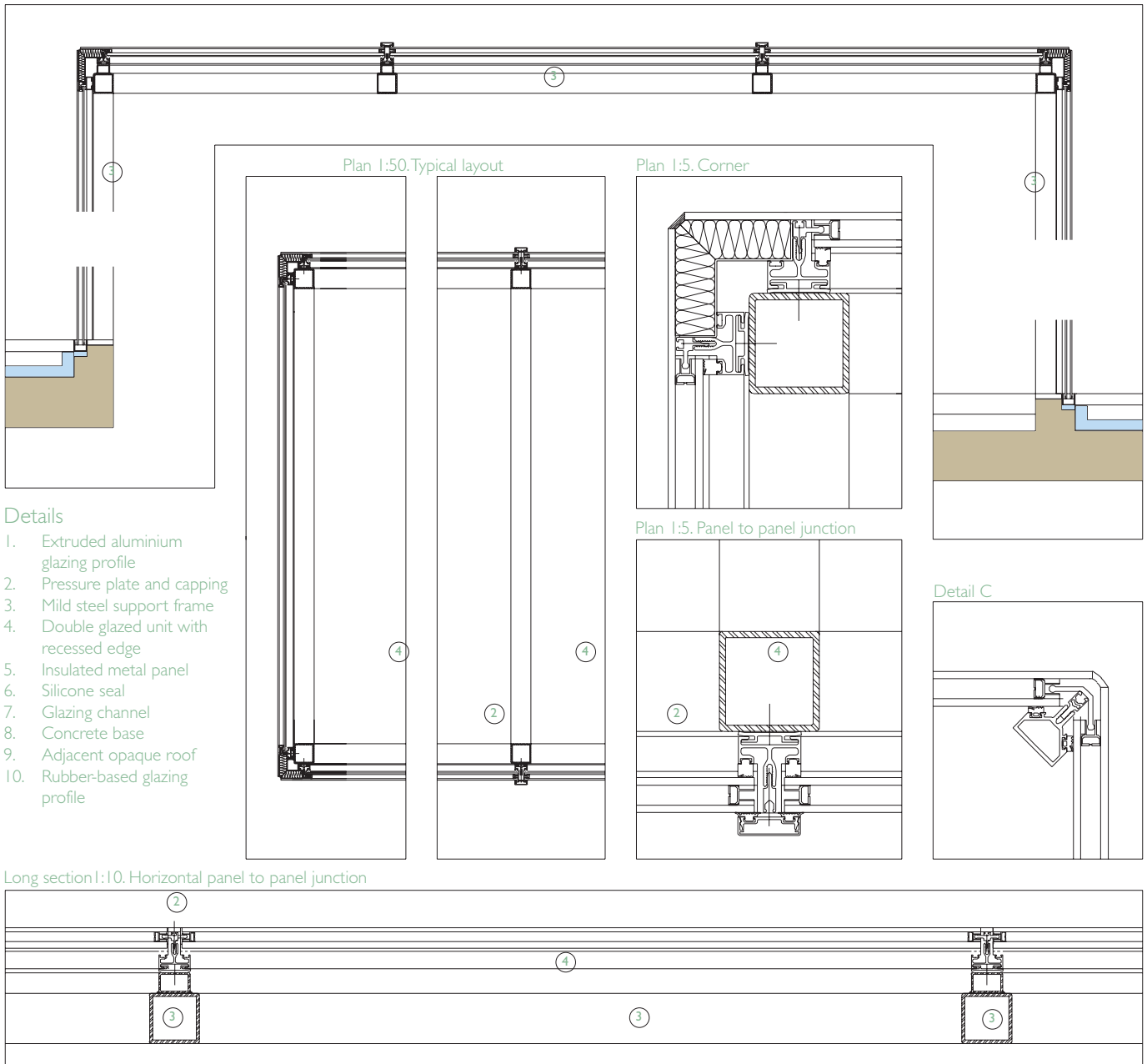
Silicone-sealed systems

While capped systems, described in the previous section, suit pitched roofs, they cannot reliably be used on (nominally) flat roofs, where the roof pitch is usually 3° to 5° . This is mainly because the rainwater running down the roof cannot pass the horizontal glazing bars which project above the surface of the glass. The smooth, continuous finish required for flat glazed roofs is achieved with a silicone seal between glass panels that is set flush with the surface of the glass. The glass is clamped in place with short lengths of pressure plate that are recessed below the outer seal. The recessed plates are secured to an aluminium channel which forms an integral part of the double glazed unit and which is

continuous around its perimeter. The extruded aluminium channel is recessed into the gap at the edge of the unit usually used to bond the unit together and to seal the edges of the double glazed unit both keeps the glass at a fixed distance apart as well as having desiccant within it to absorb any residual moisture within the sealed cavity between the glass sheets. The recessed aluminium channel is bonded to each glass sheet and also provides the edge seal to the completed unit, as in a regular double glazed unit. The short lengths of pressure plate are then set into the gap formed by the recessed channels of abutting glazed units, and are clamped to the glazing bar with self tapping screws, typically

at 300mm centres. The gap between the glazed unit is sealed with silicone, typically 15mm to 20mm wide, and with a backing strip or 'backing rod' behind it to form a back edge to the silicone seal.

In (A) the glazing bar has its structural box or fin removed in order to fix it directly to a steel support frame. Square hollow sections are shown here. Alternatively, an all-aluminium glazing bar can be used, as shown in (B). As with capped systems, small amounts of rainwater that pass through the outer silicone seal are drained away in the condensation channels set below the glass, within the glazing bar. In practice, silicone seals are very reliable but are dependent upon good workmanship on site, so the condensation chan-



nel is often not used in practice but serves as a secondary chamber to support the inner air seals. Silicone-sealed glazing bars can be used in all directions across a roof, unlike capped systems, since the glazing bars present no barrier to the passage of water.

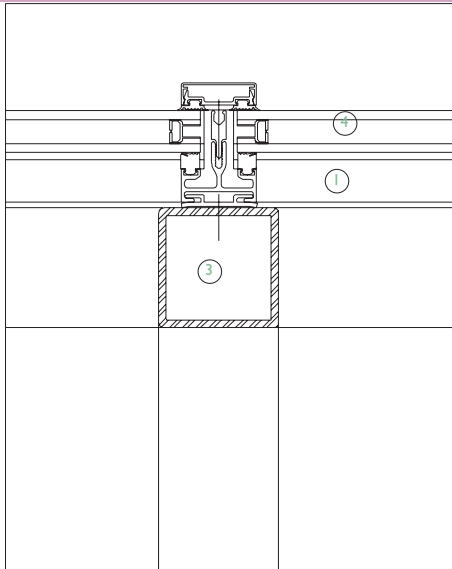
Junctions

Since the advantage of silicone-sealed systems is of continuous glazed surfaces uninterrupted by visible glazing bars, ridges and valleys are treated as simply folds in the surface of the glazing, since rainwater runs across the complete sealed surface of the glass rather than being directed into gutters across its surface. The short lengths of pressure plate can be folded in the factory to the

required angle, while the glazing bar forming the ridge is the same as that used elsewhere on the roof, with some modifications to the angle of the clips that hold the inner EPDM seal in place. The edges of roofs are also treated as folds, with rainwater usually allowed to run off the edge into a gutter; either just below the roof, or down to the base of the glazed wall below the glazed roof. An advantage of this system is the ability of the roof to be continuous with a glazed wall in the same system with a simple 'fold', without reducing its weather tightness. Typically the wall is not very high, forming part of a larger glazed roof. Dust that is carried down off the roof during rain is washed down the vertical glazing, rather than being

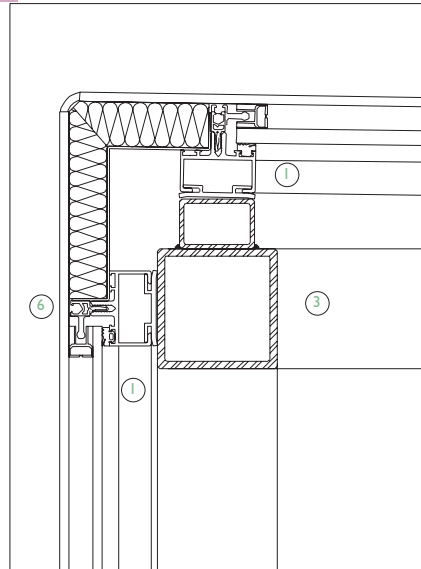
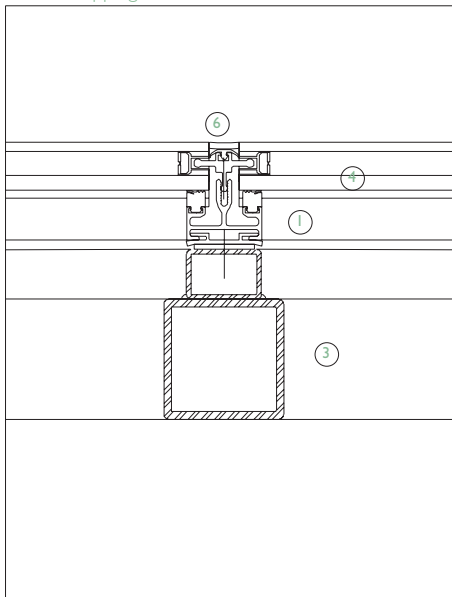
carried away in a gutter, but in practice glazed rooflights require regular cleaning to maintain their crisp appearance.

The folded corner is formed with either a single specially formed glazing bar, as (C), or with two glazing bars meeting as shown in (D). In (C), the recessed lengths of pressure plate are folded to form the required angle, and the silicone is chamfered to form a flat surface between the two meeting glass panels. Silicone is rarely used to make a sharp angle between the two double glazed units as it is very difficult to achieve a straight line without the assistance of an additional metal angle bedded into the silicone. The alternative method of forming a roof edge, as (D), requires the edge of the double



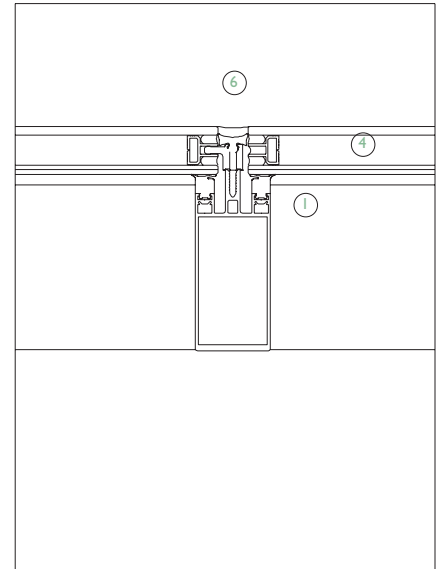
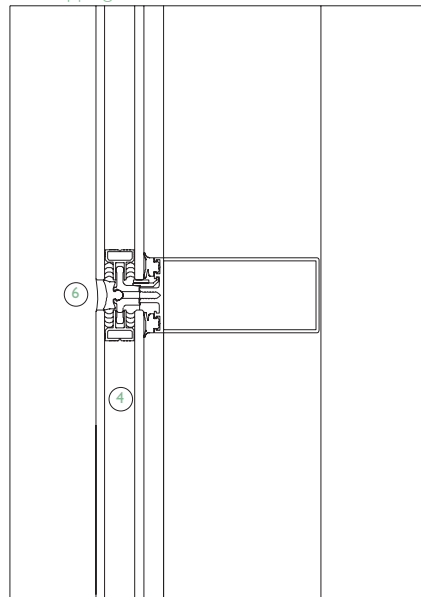
Section 1:5. Horizontal panel to panel junction with capping - Detail A

Section 1:5. Horizontal panel to panel junction without capping



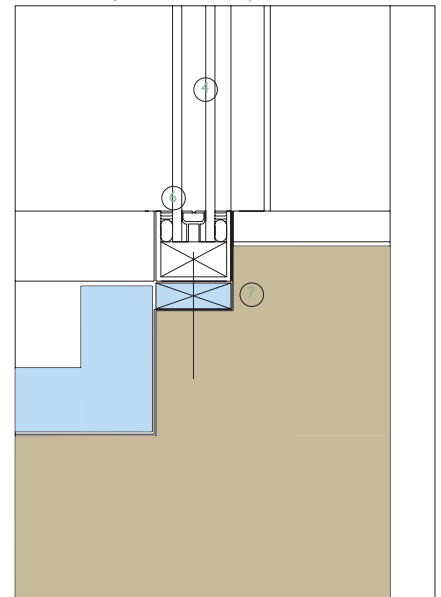
Cross section 1:5. Corner - Detail D

Section 1:5. Vertical panel to panel junction with capping



Section 1:5. Horizontal panel to panel junction without capping - Detail B

Section 1:5. Junction with adjacent roof - Detail G



glazed unit to be coated or 'opacified' to avoid the frame behind being visible through the glass. This is often achieved by stepping the glazed unit, with the outer glass extending to meet the corner, while the inner glass stops at the glazing bar to allow the recessed aluminium angle to be bonded in its usual position adjacent to the glazing bar. The glass unit is secured in the same way, with a recessed length of pressure plate, while the outer glass is cantilevered to meet the adjacent glazed unit at the corner. Thermal insulation is bonded to the outer glass along the cantilevered edge to form a continuity of thermal insulation, and avoiding a thermal bridge that will result in condensation occurring in temperate climates. The inner face of

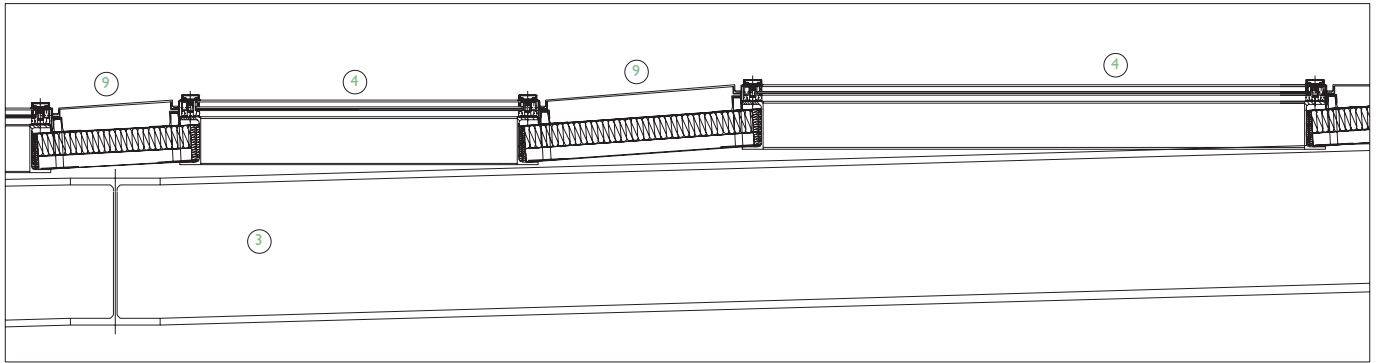
the thermal insulation is lined with a vapour barrier; typically a 3mm thick folded aluminium sheet. The opacifying of the glass is done by screen printing on the internal face of the glass. While black is often the preferred colour, in order to match with the silicone seals, other colours and patterns are increasingly being introduced in glass manufacture.

Where a gutter is required, an insulated gutter is fitted to the glazing bar as shown in (E). Prefabricated gutters are used where they are seen from the underside, inside the building. They can be glazed into the system following the line of the internal face of the double glazed units. Where the gutter is required to be separated from the glazing structures, typically for structural reasons,

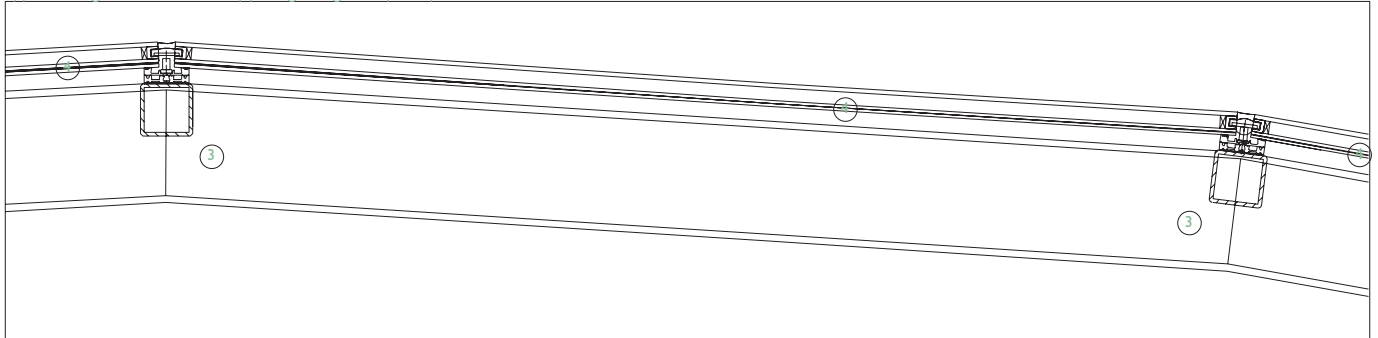
then a separate flashing can be used, fixed to the glazing bar but independent of the gutter. The gutter is still sealed to the glazing bar with a flexible EPDM gasket to provide a continuous seal, as in (F).

The base of the glazed roof that terminates in a glazed wall can meet an adjacent concrete roof slab with either a metal glazing channel, as (G), or in an upstand and flashing as (F). Where a glazing channel is used, the double glazed unit sits in a profile formed from extruded aluminium, stainless steel or painted mild steel. The glass is levelled on metal shims (short lengths of metal strip) then sealed with silicone. The advantage of the glazing channel is that it can be set flush with the finished internal level to provide a

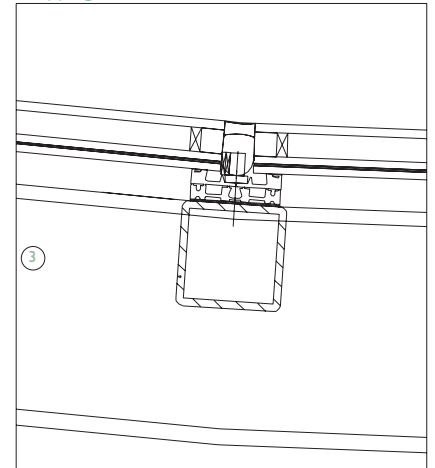
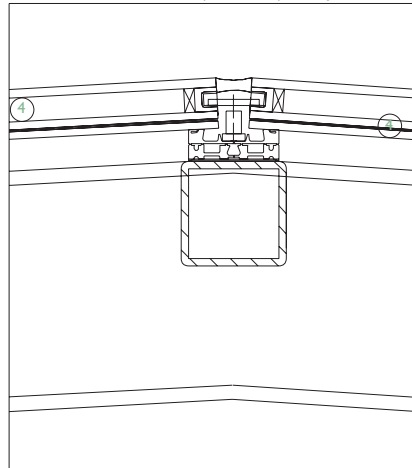
Typical cross section 1:25. Capped glazing. Typical profiles



Typical long section 1:25. Capped glazing. Parapet upstand



Section 1:5. Horizontal panel to panel junction without capping Detail H



Details

1. Extruded aluminium glazing profile
2. Pressure plate and capping
3. Mild steel support frame
4. Double glazed unit with recessed edge
5. Insulated metal panel
6. Silicone seal
7. Glazing channel
8. Concrete base
9. Adjacent opaque roof
10. Rubber-based glazing profile

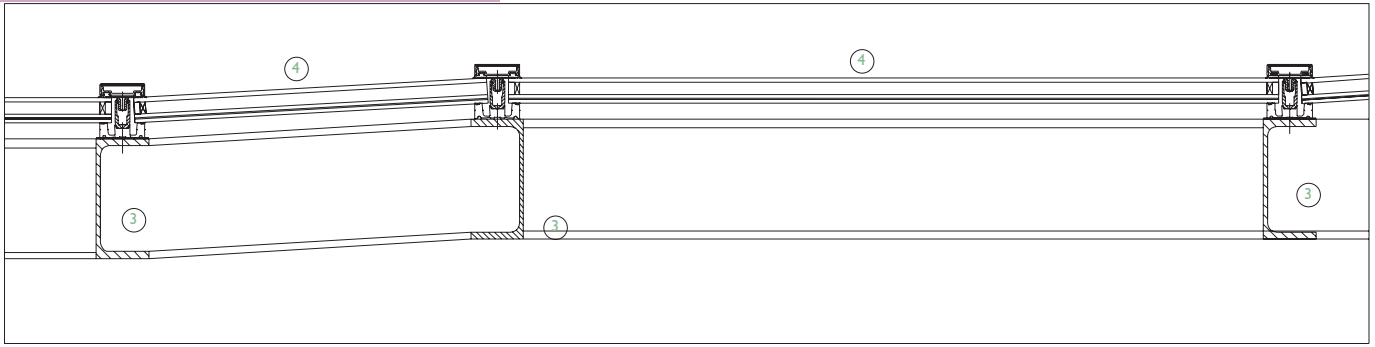
junction with no visible horizontal glazing bar. Alternatively, the glazing can terminate in a horizontal glazing bar, to which an aluminium flashing can be fixed. A downstand flashing is more easily fixed to a horizontal glazing bar than a glazing channel. The vertical glazing bars (forming the mullions) are fixed to brackets that are secured to the upstand. A concrete upstand is shown in (F) with external insulation and a single layer membrane. The metal flashing extends down the face of the upstand to protect the joint. As with gutters, an EPDM membrane extends down from the horizontal glazing bar where it is bonded to the membrane. The roofing membrane and the EPDM are always checked for compatibility, but in practice this

rarely presents any difficulty.

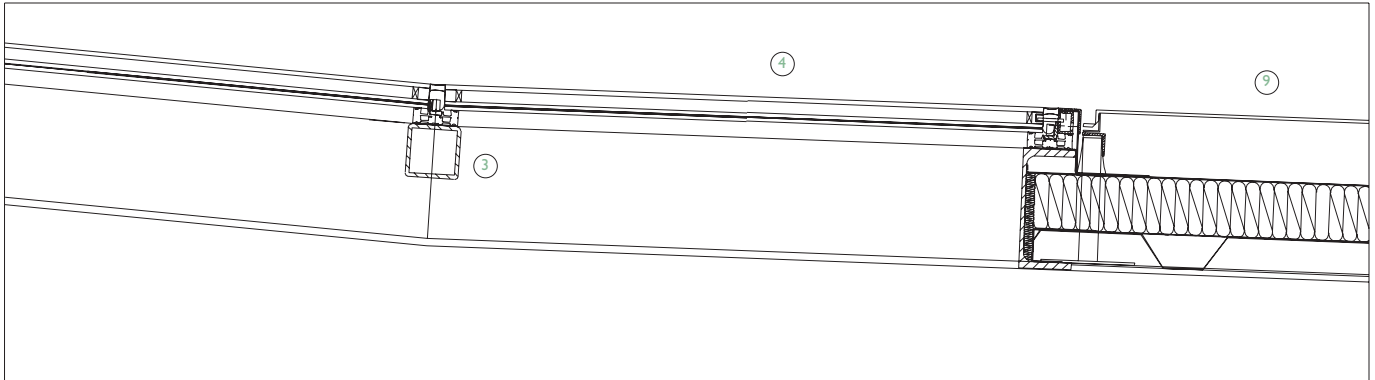
Use of capped profiles

An advantage of silicone sealed glazing over fully bonded glazing (discussed in the next section) is its ability to be mixed with capped glazing. Since both systems are drained and ventilated (pressure equalised), the same glazing bar can be used in a mixed roof system of flush silicone joints and capped profiles. Although this mix is done often for visual reasons, it does allow for easily formed junctions with adjacent areas of roof in different materials, and for a mix of metal panels and glazed panels in a single roof using a reliable drained and ventilated system.

The most common application of this method is where capped profiles are used for the vertically-set glazing bars running down the slope of a roof, while silicone-sealed glazing is used on horizontal joints to allow rainwater to pass down it unimpeded by any projecting glazing bars. Junctions in silicone sealed glazing such, as edges of roofs and ridges, are formed in the same way, while the capped system follows the folds with continuous pressure plates that are mitred and sealed at the folds. Butyl tape is used as an extra seal at folds, set between the pressure plate and the outer EPDM gaskets. Cover caps are also mitred to give a crisp appearance.

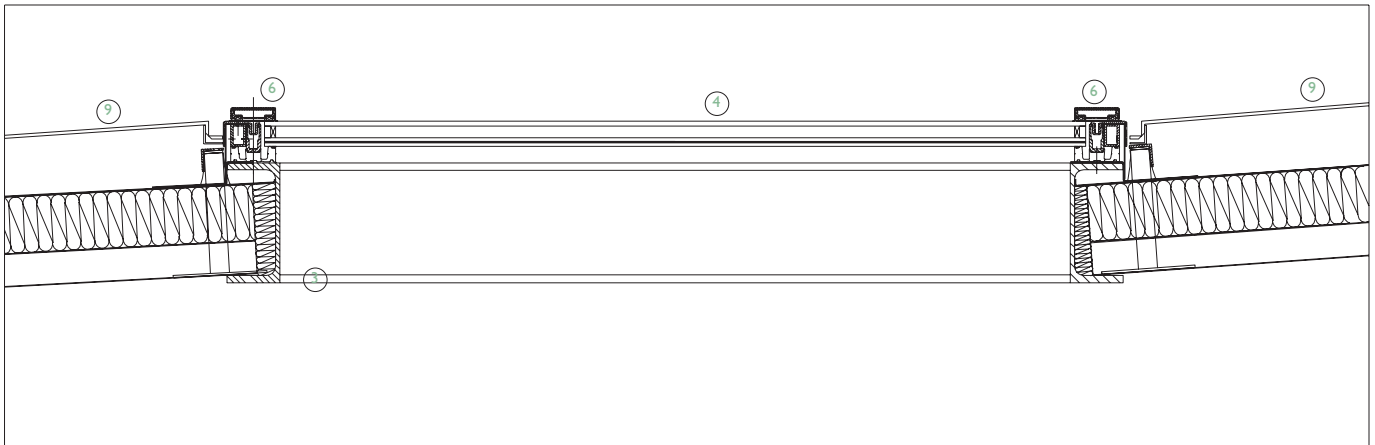


Long section 1:10. Edge of rooflight



Cross section 1:10. Edge of rooflight.

Long section 1:10. Typical profiles



The internal drainage of the mixed glazing system works in the same way, with any water that penetrates the silicone sealed glazing being drained along the internal condensation channels before draining into the profiles of the capped system and onwards down to the base of the roof. The condensation channel and inner air seal can also be formed in a single EPDM extrusion, as shown in (H), without the use of any aluminium extrusion, but with a supporting structure behind. In this case, the short lengths of pressure plate holding the glass in place are secured by self tapping screws that are secured to a supporting structure behind. A hollow box section is shown in (H). The EPDM gasket, combined with a steel sup-

porting structure, is used as an alternative to the extruded aluminium glazing bar, usually for larger glass panels where the supporting fin or box profile to the aluminium extrusion would be visually too deep or too wide.

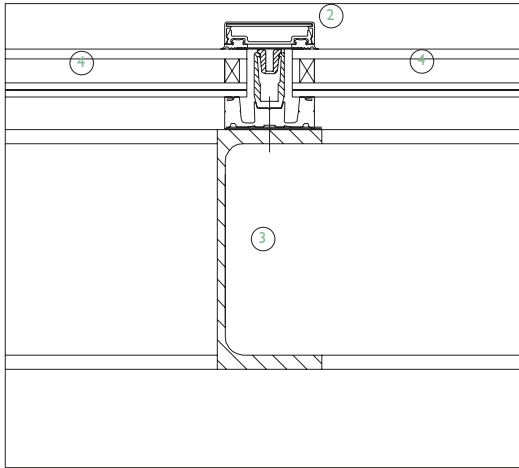
Rooflights

A useful application of combining capped and silicone sealed glazing is in sealed rooflights, where strips or bands of glazing are combined with a roof in a different material. Traditionally, individual rooflights are formed in upstands that sit high above the level of the adjacent roof. Large numbers of these traditional individual rooflights lack the visual elegance of continuously glazed roofs. In recent years this has changed with

the increased use of the combination of single layer membranes and rainscreen panels with capped and silicone sealed to provide individual rooflights that are visually integrated into adjacent areas of opaque roof. In (J), a single layer membrane roof is sealed into the edge of a capped glazed rooflight by clamping the membrane into the glazing system. In (J), a metal rainscreen is shown, completely independent of the rooflight, but set onto the membrane to both protect it and give a visual continuity to the rooflights across the roof.

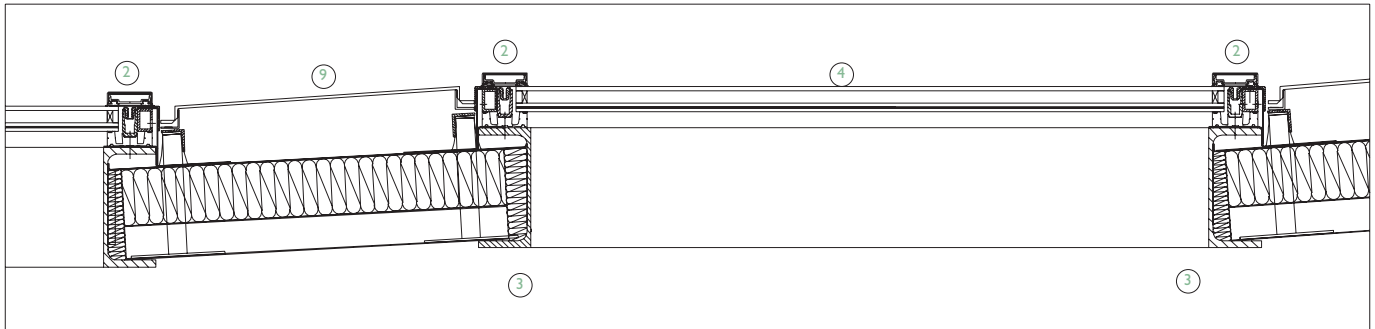
The edge of the rooflight is formed with a capped glazing profile, while the joints within the rooflight, running across the rooflight (at 90°), as shown in (H), use a sili-

Section I:5. Horizontal panel to panel junction with capping

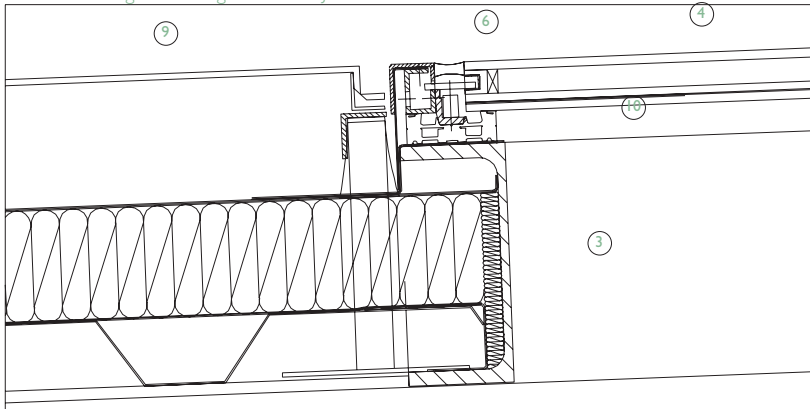


DG Bank, Berlin, Germany. Architect: Gehry

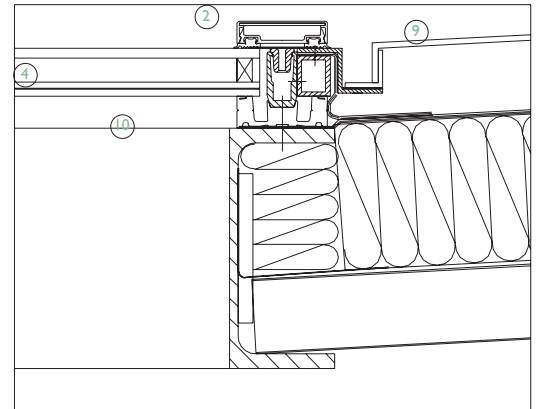
Cross section I:10. Junction of 2 rooflights with opaque roof



Section I:5. Edge of rooflight Detail J



Detail K

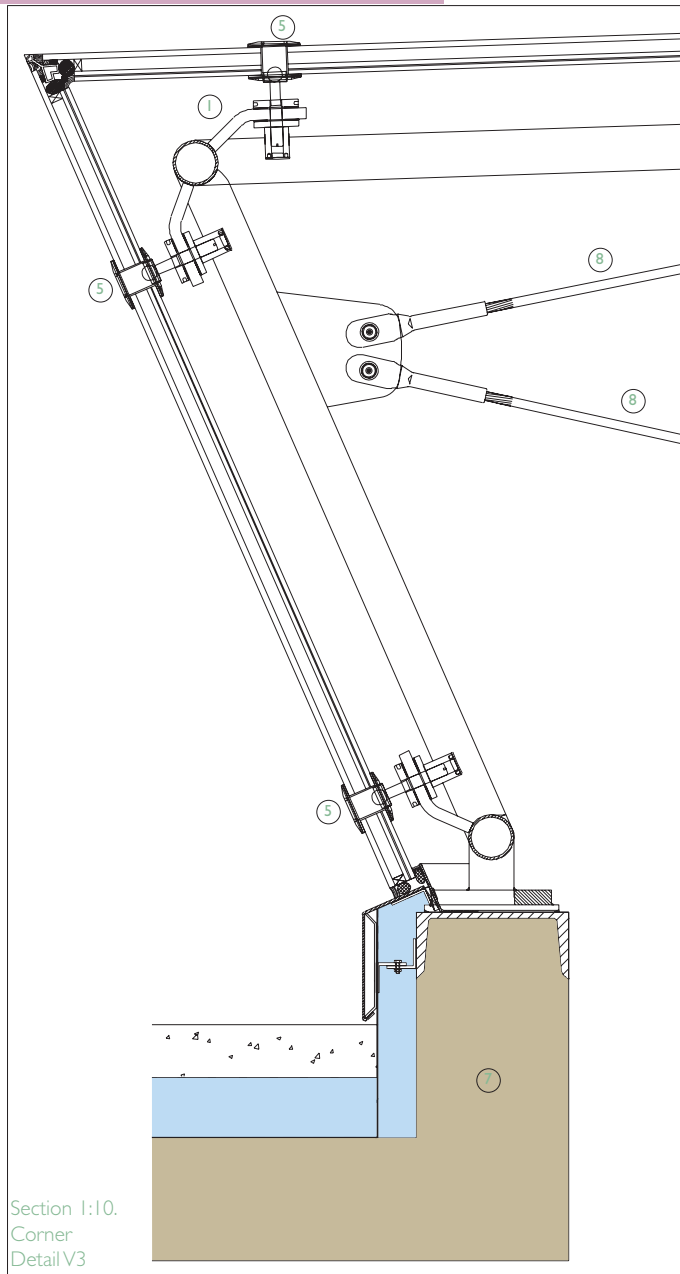


cone-sealed profile to allow water to run down to the bottom edge of the rooflight shown in (J). This lowest edge of the rooflight has a silicone sealed edge with a drip flashing glazed into the edge of the profile to drain water off the edge. The single layer membrane is tucked under this flashing and is clamped down with the pressure plate that extends the full width of the rooflight. The top edge of the rooflight (running parallel with the roof slope) has a capped profile to allow water to drain around the sides of the rooflight as shown in (K). The condensation channels in all profiles are set at the same level to ensure that any water that passes through the outer seal is drained through a set of linked channels to the bottom edge of

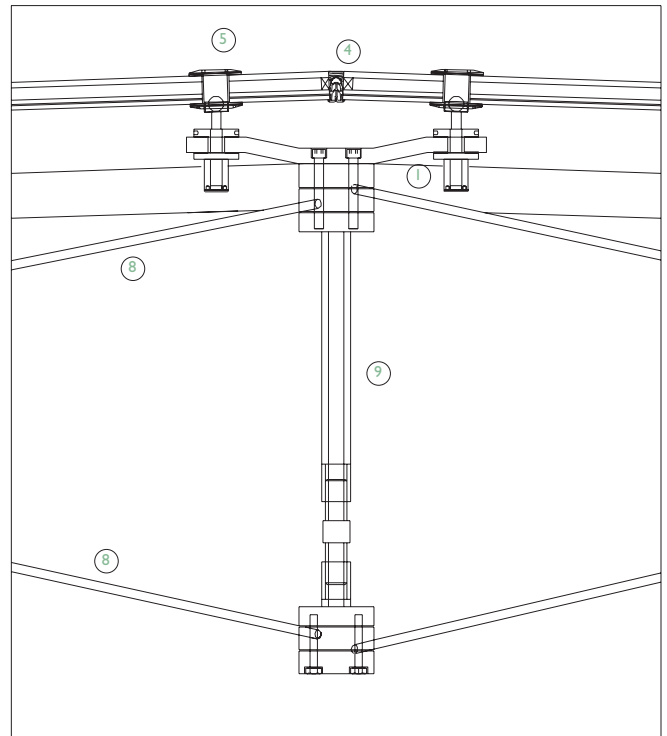
the rooflight where it is released above the roof level of the adjacent membrane. Openable rooflights, as shown in the previous section on capped glazing systems, can be incorporated easily, with the use of an additional sub frame, into which the openable light is set.

Details

1. Extruded aluminium glazing profile
2. Pressure plate and capping
3. Mild steel support frame
4. Double glazed unit with recessed edge
5. Insulated metal panel
6. Silicone seal
7. Glazing channel
8. Concrete base
9. Adjacent opaque roof
10. Rubber-based glazing profile



Cross section 1:10. Horizontal panel to panel junction Detail V2



Hydrapijper, Haarlemmermeer, Netherlands. Architect: Asymptote.



This method of glazing for roofs has been adapted from the technique used for glazed walls, where glass is fixed at points with specially designed bolts rather than with a frame supporting the perimeter of the glass. Bolt fixed glazing for facade construction developed from patch plate glazing in the 1960's, where single glazed sheets of glass are bolted together with mild steel brackets. Glass fins are used to stiffen the glazed walls to replace the aluminium mullions. The L-shaped patch fittings bolt the fins and glass together, as well as bolting the glass to the supporting structure at the top and bottom of the wall. While this glazing method has been developed and is still in use, the idea of frameless glazing has evolved further into double glazed units

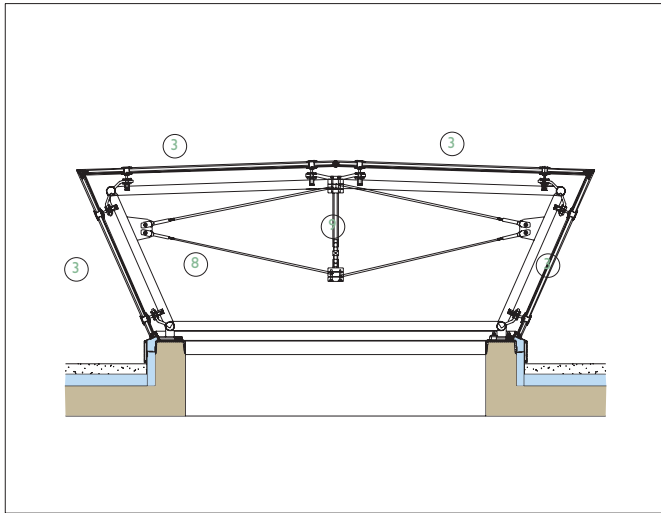
being bolted directly to a supporting structure without patch fittings at all. This further enhances the essential concept of frameless glazing which is to provide greater visual transparency than an equivalent framed system.

The patch plate method of frameless glazing is not used very often in roofs, since the glass fins become glass beams in such applications. While glass beams have been used in modest rooflight applications, there is uncertainty surrounding the difficulty of replacing cracked or damaged beams once the roof is completed. This has limited the use of glass beams to modest applications in glass roofs. In contrast to this, bolt fixed glazing has become increasingly popular for

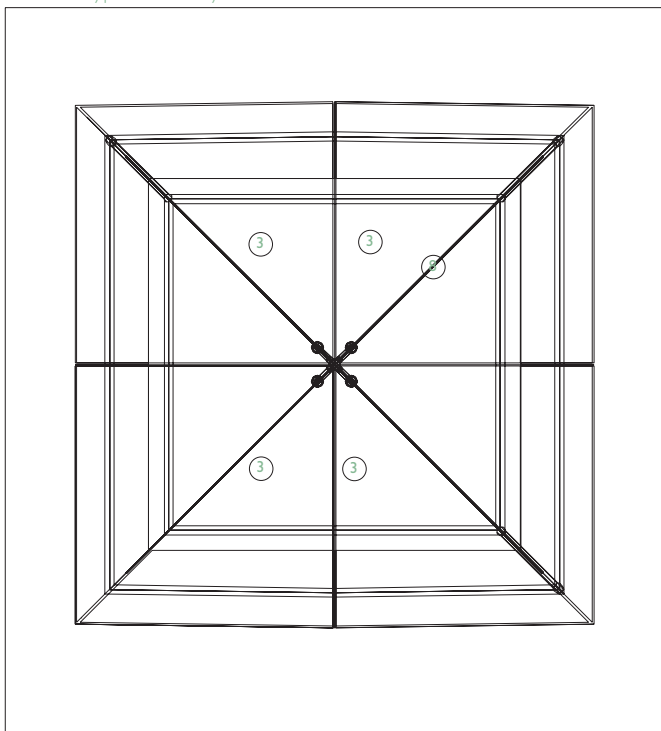
glazed roofs in mainly commercial and public buildings.

During the early 1990's doubts were raised over the reliability of the waterproof silicone seals between glazed units, but these were soon overcome with a mixture of laboratory testing and a better understanding of the workmanship required with silicone jointing. While manufacturers offer proprietary systems for walls, which can include a supporting structural system such as cable trusses, roof glazing systems are usually designed for individual applications.

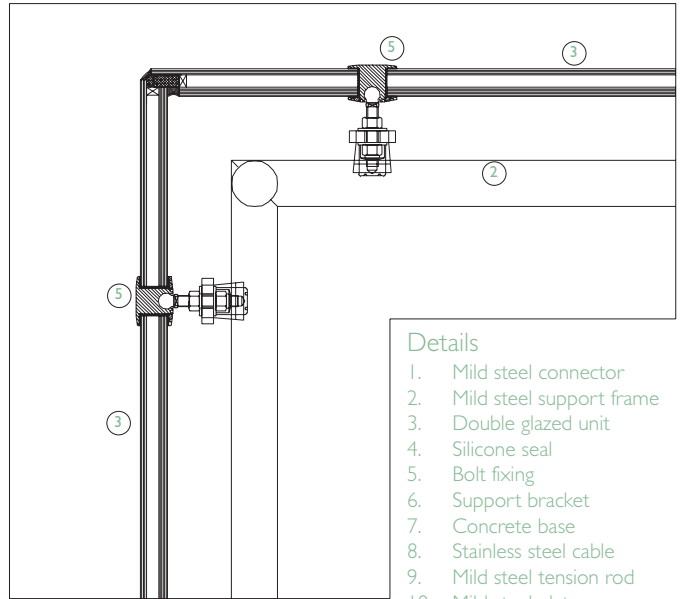
Section I:50. Typical assembly Detail VI



Plan I:50. Typical assembly

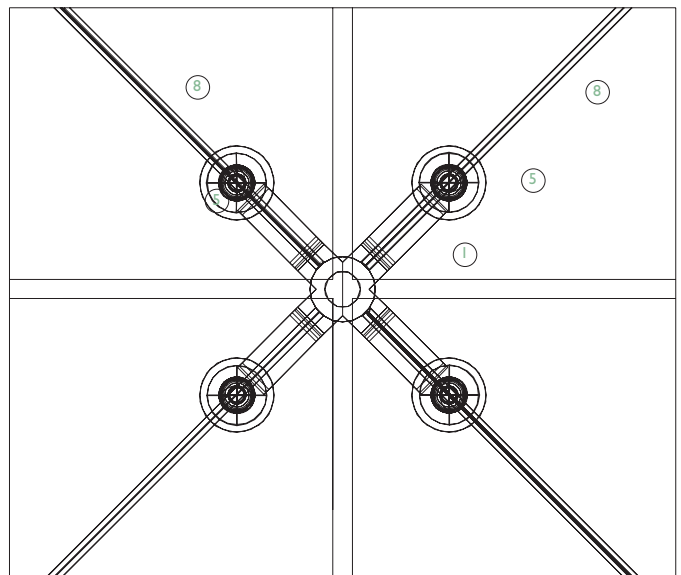


Plan I:10. Vertical panel to panel junction Detail V4



- Details
1. Mild steel connector
 2. Mild steel support frame
 3. Double glazed unit
 4. Silicone seal
 5. Bolt fixing
 6. Support bracket
 7. Concrete base
 8. Stainless steel cable
 9. Mild steel tension rod
 10. Mild steel plate
 11. Adjacent external wall

Plan I:10. Bolt fixing



Generic structural support methods

Where glazed walls are usually structurally supported by either top hung or bottom supported methods, the support of glazed roofs is by trusses, steel sections or purlins that span across the roof opening. For (nominally) flat roofs, the most common arrangement of supporting beams is as shown in (A) and (B). In (A) a supporting beam is set under each glass joint, so that bolts are supported on each side of the beam by a short bracket. In (B), only half the number of beams are required to support the same three panels of glass. This is achieved by setting the beam in the middle of alternate glass panels. Brackets are can-

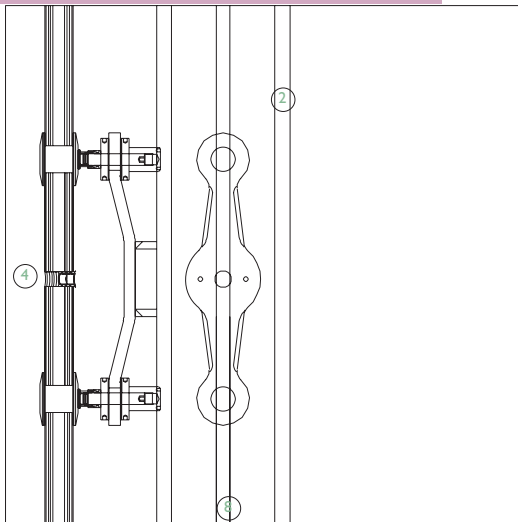
tilvered from the beam to support the edge of the panel above as well as one side of the panel next to it. This method provides greater visual transparency than (A) but requires larger brackets, which in practice detract little from the increased effect of transparency.

The single tube section shown in the diagrams would suit only a short span, as in a rooflight, but large span roofs require deeper beams, usually formed as open trusses in order to maintain the sense of transparency at oblique viewing angles. Triangulated trusses, as (C), provide both structure and support for the glass, but tend to be visually heavy. Cable trusses, as (D), are often preferred, but they require a ring beam around

the edge of the glazed roof to form a tensile supporting structure like a tennis racquet. The cable trusses, always in tension, require an equivalent surrounding structure in compression to transfer the loads to the main building structure.

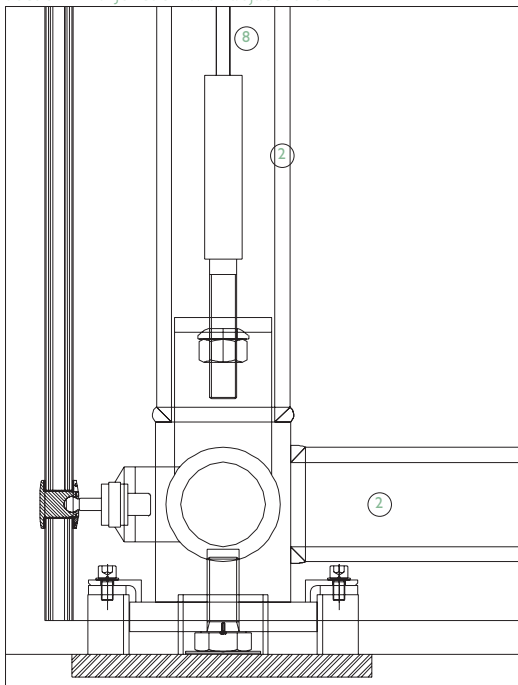
Supporting brackets

All these supporting structures require brackets to which the bolt fixings are attached. In the case of a short bracket attached to a beam, a mild steel bracket can be welded to each side of the tube shown in (E). Because the bracket is welded, the adjustment for tolerance between fixing of the supporting structure and the glass panels is taken out in the position shown in (E) at



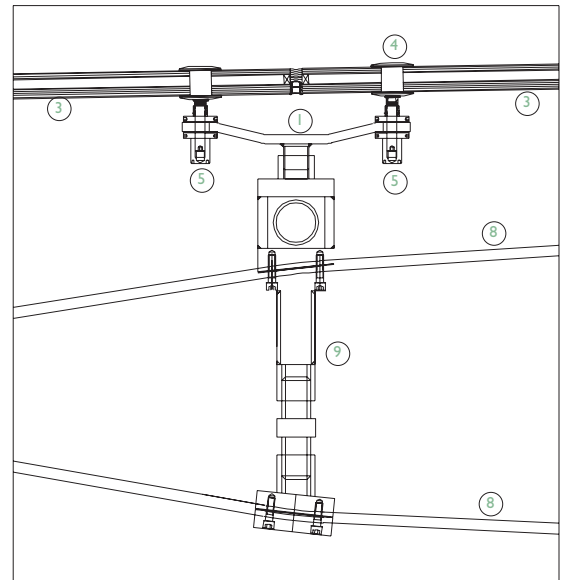
Section 1:10. Vertical panel to panel junction

Section 1:10. Junction with adjacent roof



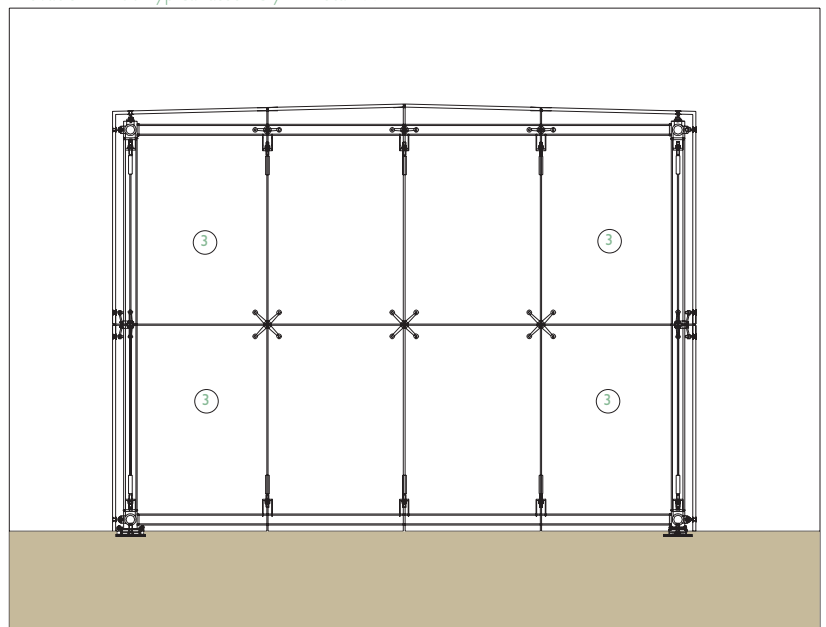
Details

1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall



Section 1:10. Horizontal panel to panel junction

Elevation 1:100. Typical assembly Detail W1



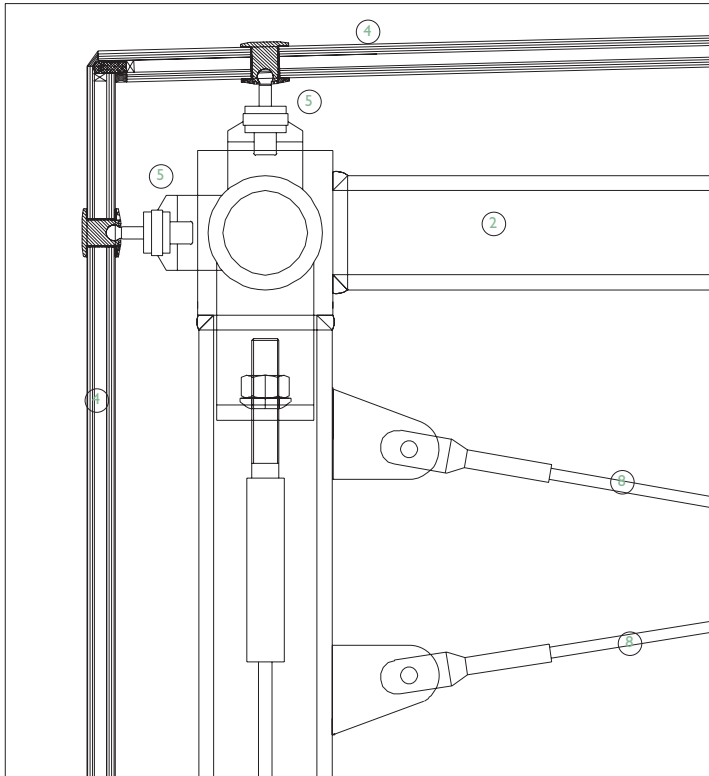
the connection between the bolt and the bracket. A slotted or oversized hole is cut into the supporting bracket and the bolt supporting the glass is fixed to it. The bolt may be off-centre from the bracket, and each bolt may be in a different position in relation to its neighbour. This can produce an awkward appearance when seen from below the roof, but this is certainly one of the most economic solutions. In (F) a channel-shaped bracket is welded to the top of the beam. A single bracket, typically mild steel plate, is bolted to the channel bracket. An oversized hole in the bracket is used to make the adjustment for tolerance. The bolts supporting the glass are set at each end of the bracket. In (G) the flat bracket is replaced by a casting, usually in

either mild steel or aluminium. The casting for this application would be made from a steel mould which is expensive to manufacture, so a large quantity of cast brackets are needed to make this method economic. Adjustment is made in the same way as (F). In (H) the beam becomes a cable truss, where a supporting bracket in either mild steel plate or a casting is clamped to the cable. Here the adjustment for tolerance is made in two places; at the junction of the bracket and the bolt fixing, as well as at the junction of the bracket and the cable clamp. There are, of course, many variations on these types, but these are the most commonly used bracket support methods.

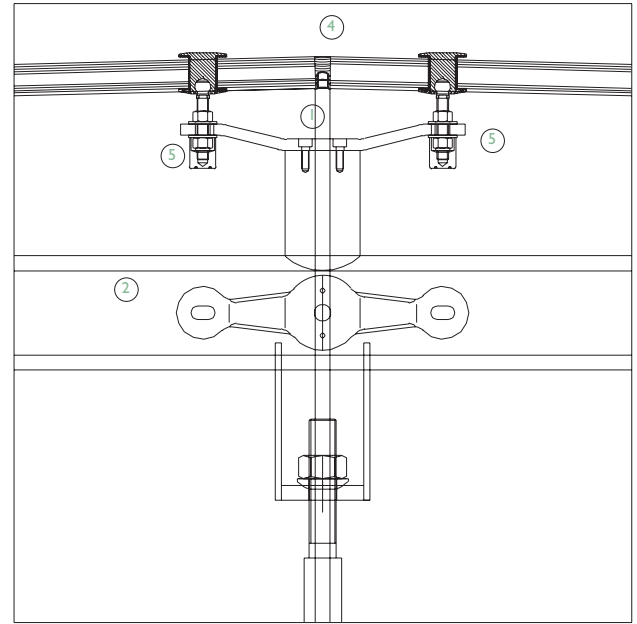
Bolt fixings

The essential component in this glazing method, the bolt fixing, is made typically in stainless steel, and consists of several components that form the complete assembly. The part that passes through the glass has either a disc on each side of the glass to clamp the glass or double glazed unit together, or alternatively is angled to form a countersunk device within the depth of the double glazed unit. The countersunk fitting is set flush with the outer face of the glass, and the face fixed disc type is set forward of the face of the glass. A polished stainless steel finish is mostly used on the outside in order to make it easy to clean and maintain. In the face fixed type, which is currently the most com-

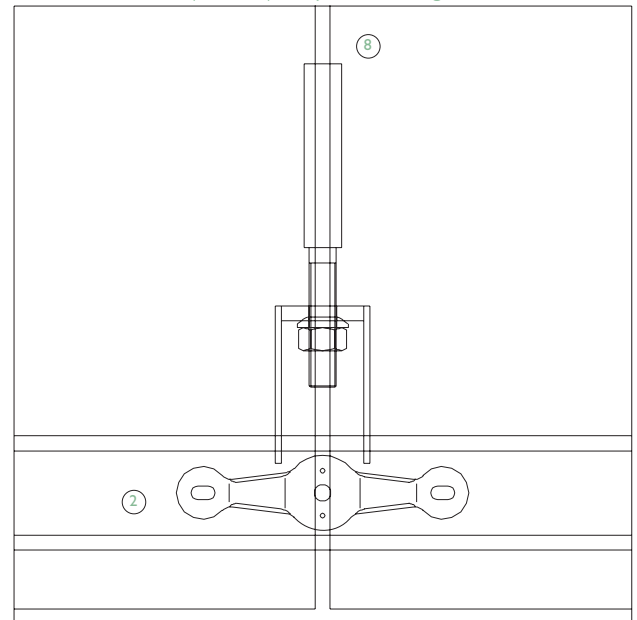
Section I:10.Corner Detail W4



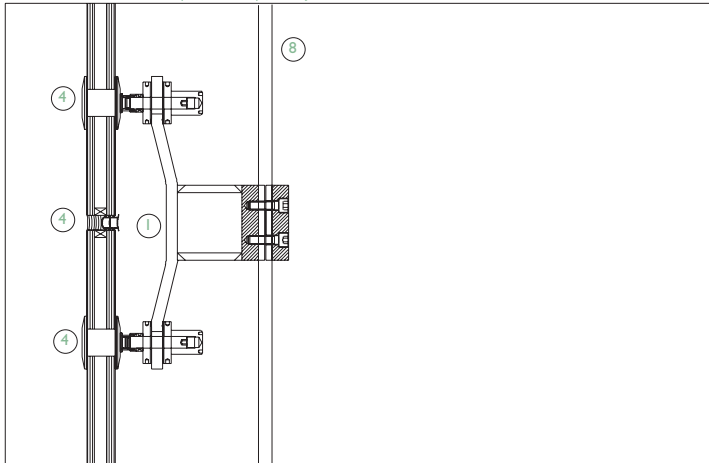
Section I:10.Horizontal panel to panel junction



Plan I:10.Horizontal panel to panel junction at edge



Section I:10.Vertical panel to panel junction Detail W3



monly used fixing, the inner disc screws over the threaded shank that forms part of the outer disc until it is tight up to the inner face of the glass. The threaded shank projecting into the building is able to rotate about a ball bearing where it meets the inner face of the double glazed unit. This allows the double glazed unit to rotate up to around 12° under wind load and associated structural deflections. This swivel joint is essential in avoiding the over stressing of the glass under full wind load that would otherwise result in breakage of the glass unit. The threaded shank is then used to clamp the complete bolt fixing to a support bracket with either threaded discs or nuts, as in (J). The visible thread in the shank can be either left

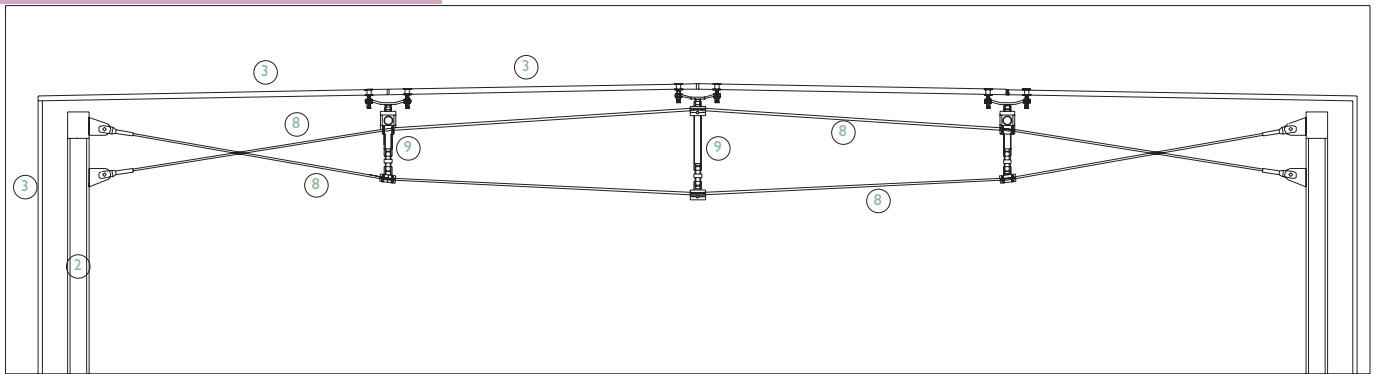
exposed, or be covered with threaded sleeves and stop ends, as shown in (J). This bolt type is used regardless of the orientation of the roof, whether flat or pitched.

Arrangement of bolt fixings

The arrangement of brackets for bolt fixed roofs is dependent upon the position of the fixing bolts. In (K), rectangular shaped double glazed units are arranged with supporting beams set in the direction of the long side of the panel. Bolts are positioned in a way that reduces the span of the glass by pushing them away from the edge. The reduced glass span allows the glass thickness to be thinner; making it more economic, particularly given that the material cost of glass

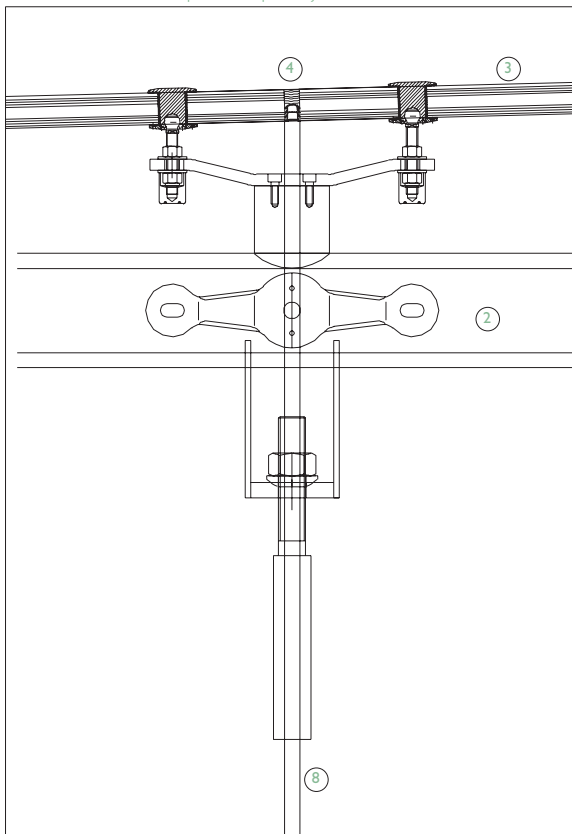
increases dramatically with the increase of thickness (the relationship between glass thickness and cost is not linear). With bolt fixings in these positions, the most economic position of support brackets is as shown in (K). Flat plates can be used, subject to structural requirements.

Where the glass fixing bolts are equidistant from the edges of the glass as in (L), a cross-shaped bracket allows four glass connections to be made with a single bolt connection between this support bracket and the beam beneath. The cross-shaped bracket is carrying a high load of glass to a single point on the beam. Stiffening fins are usually needed on the underside of the cross-shaped bracket. These can be individually



Section 1:50. Typical assembly

Section 1:10. Vertical panel to panel junction



Hydrapij; Haarlemmermeer, Netherlands. Architect: Asymptote.



welded and ground, but it is often economic to make them as castings, which have a more reliably refined appearance. Mild steel brackets require painting; stainless steel brackets can be buffed or polished to the preferred visual finish.

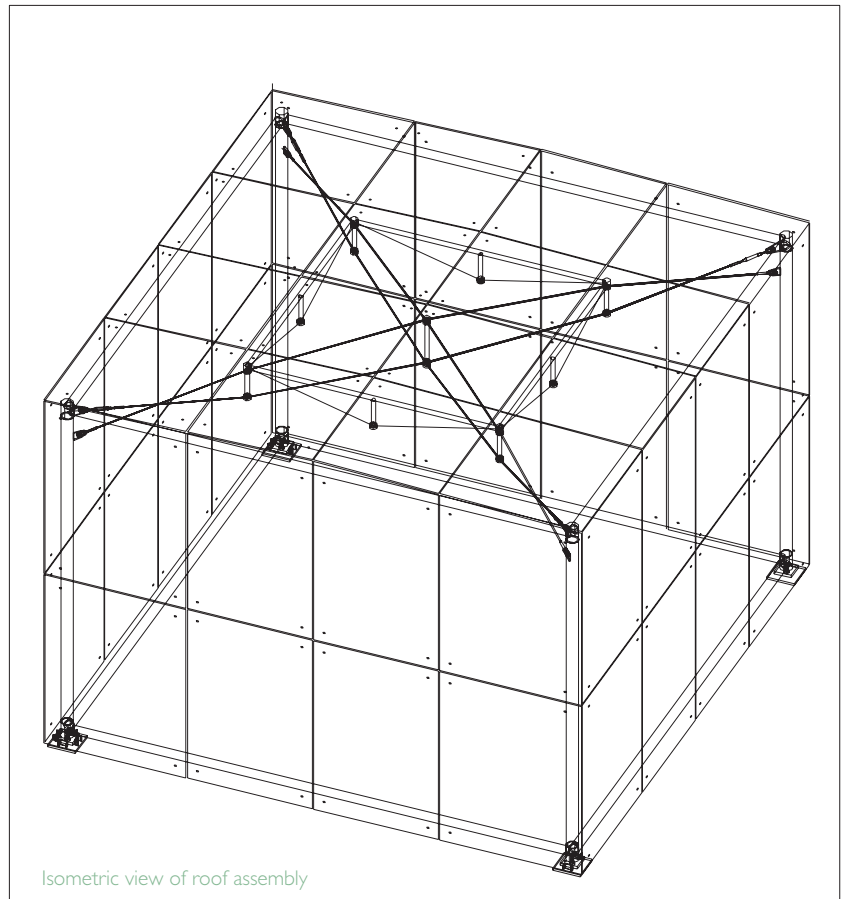
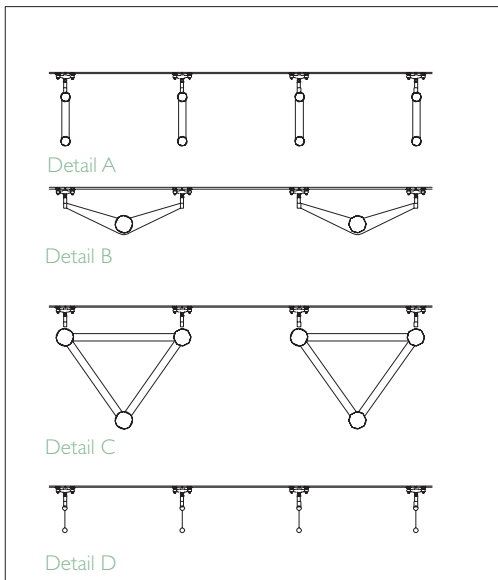
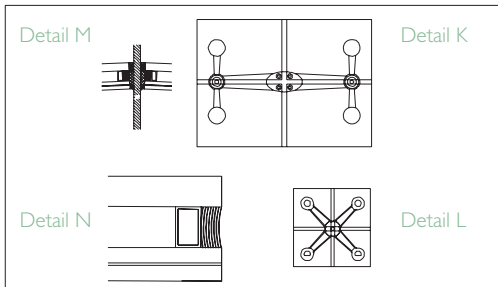
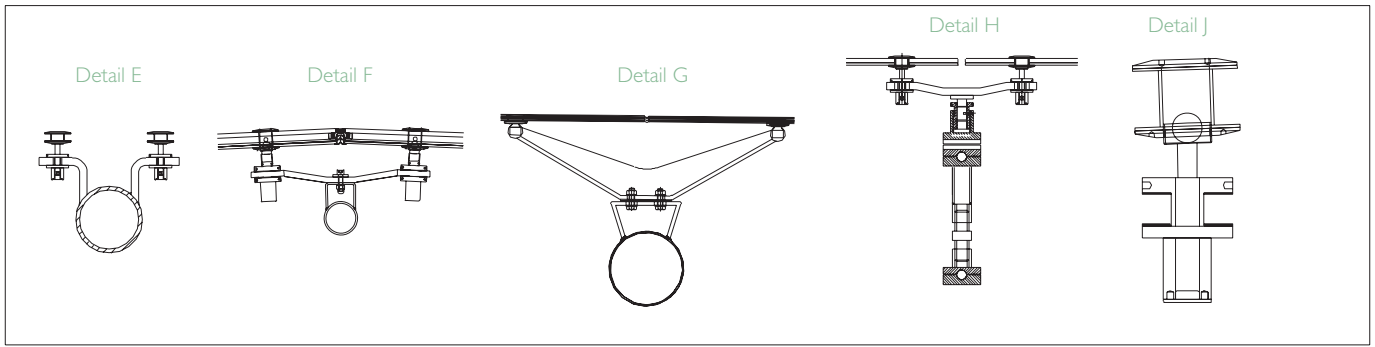
Glazed units

In common with other glass roof types, the inner glass of a double glazed unit is usually made from laminated glass. In the event of a double glazed unit being broken, the inner laminated sheet remains intact, while the broken pieces of the heat strengthened or fully toughened outer sheet come to rest on top of the damaged, but intact, inner sheet. The double glazed units are first fixed

and adjusted to form even joint widths between all the units. Joints of 20-28mm are used, though around 20mm is the most common joint width (in elevation) that allows for both structural movement and the slight variations in the size of the glass panels. Unlike capped roof glazing systems, the entire double glazed unit is visible from both outside and inside, and the edges are not set behind pressure plates that conceal any variations in glass panel size. Joint widths up to around 28mm, which is deemed close to the maximum practical joint width for the adhesion of silicone sealant in a regular double glazed unit, is used where brackets penetrate the outer seal from inside the roof to outside. If required, these brackets are used to

support external sun shading and maintenance equipment. These brackets are usually in the form of flat plates that are welded to the internal supporting structure, and project through the joint, as (M). Although an additional lip around the projecting plate may provide additional protection to water penetration between the silicone and the bracket, in practice it has been found that this detail as shown in (M) performs well if the seal is applied to a good level of workmanship.

Seals between double glazed units are made as an outer silicone seal with an inner backing rod of extruded EPDM. The gasket has projecting flaps on each side to form a 'fir tree' section which prevents any water



that penetrates the external seal from reaching the inner face of the seal. This EPDM gasket also serves as an inner air seal, and provides a crisp appearance of sharp lines in the interior face of the glazed roof.

In the manufacturing of double glazed units, the butyl seal between the spacer and the glass creates a slightly wavy line, visible to the eye when it spreads beyond the face of the spacer. This slightly uneven appearance of the edge of the glazed unit can be concealed by the use of edge 'fritting', or a baked-on screen printed edge in black, which ensures that the edge of the unit, as shown in (N), has a crisp black edge. This is mainly where the rooflight glass can be seen at close proximity.

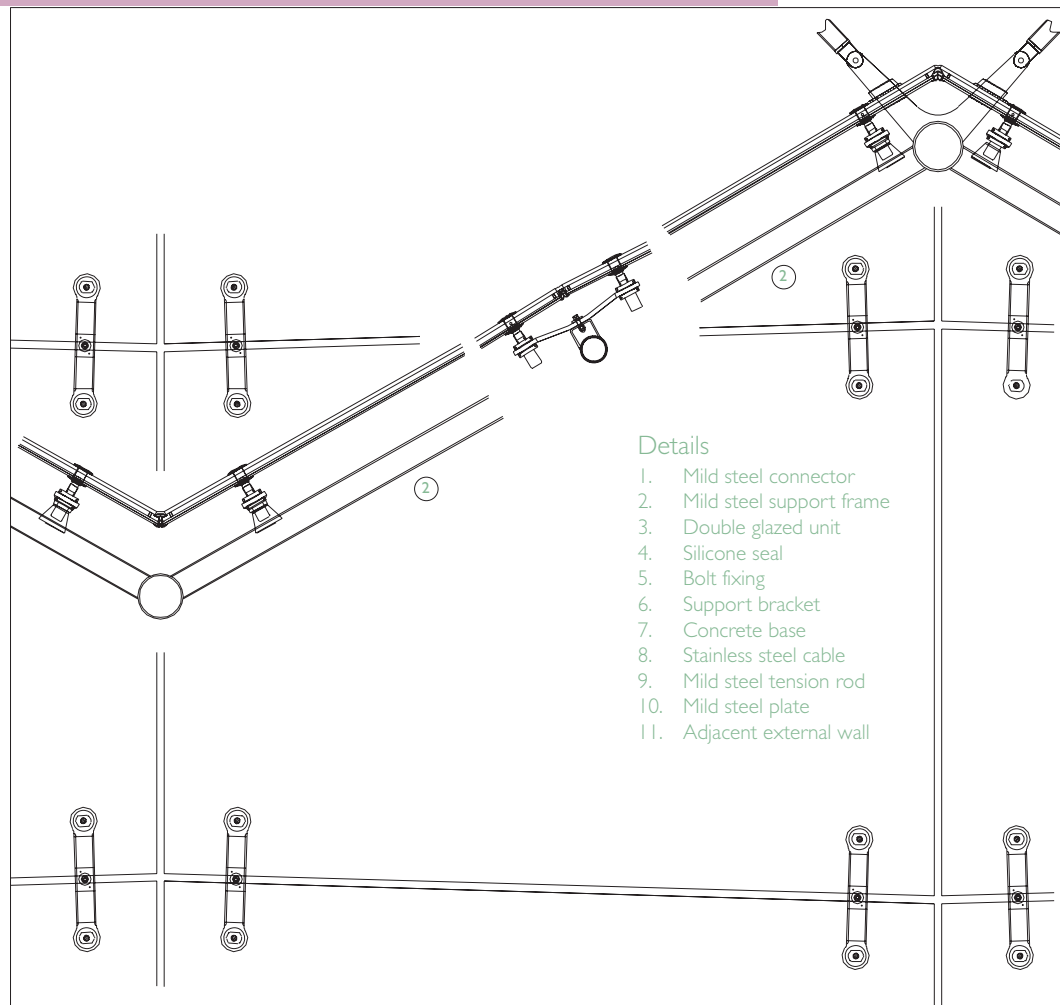
The holes in double glazed units, to which the bolt fixings are attached, are made by cutting holes in the glass around 10mm larger than the metal circular sleeve that fits between it. The circular sleeve bonded to the glass is sealed around it to maintain the sealed cavity of the double glazed unit. This is particularly important in the case of argon filled cavities, where the gas improves thermal insulation.

The drilling of the glass itself is now well established in glass manufacturing, with both float glass and laminated glass being drilled before any heat treatment to make them either heat strengthened or fully toughened. Where coated glasses are used, such as solar control coatings or low emissivity (low e)

coatings, this is done after heat treatment.

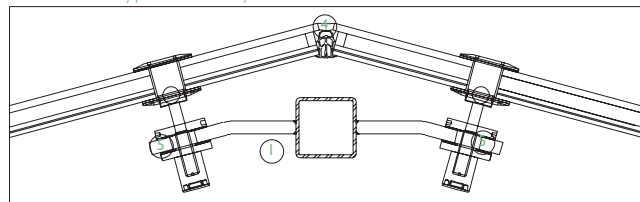
Details

1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall

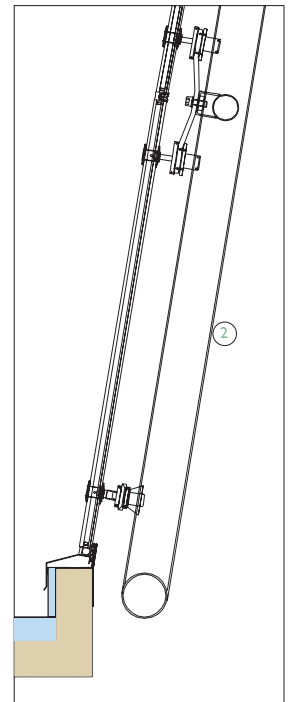


Section 1:25. Typical assembly

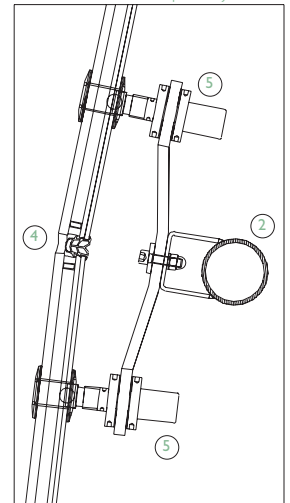
Section 1:10. Typical assembly



Section 1:25. Panel to panel junction



Plan 1:10. Panel to panel junction



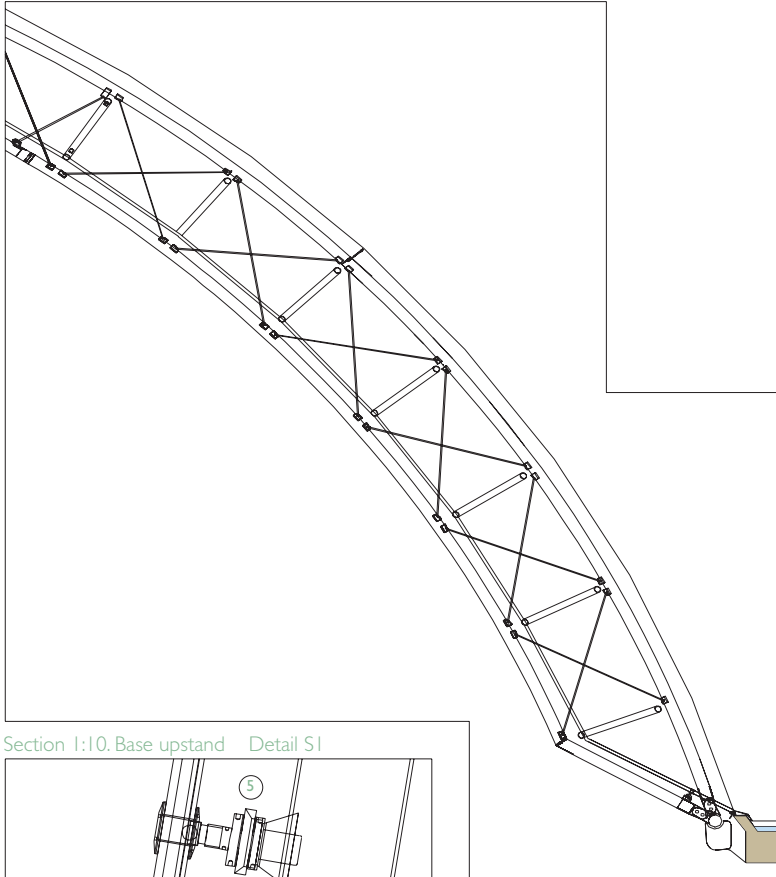
The generic support structures described in the previous section suit a range of roofs in a single plane, whether pitched or (nominally) flat. Supporting structures which are faceted or curved to form complex geometries require a slightly different approach. These supporting structures are dictated more by the demands of the form that is being created rather than by optimising the position of supporting members to maximise visual transparency through the structure. Structures for arches or curved surfaces are usually made with as little structural depth as possible, with the visually successful types using a single 'plane' of structure formed in 'ladder' forms as shown in (P). Circular hollow sections and box sections are preferred for their

visual consistency regardless of where the glazed roof is viewed below the roof. The ladder principle as shown in (P) is actually two vierendeel trusses linked together, with the short cross members welded to the long members. If additional stiffness is required in part or all of the structure, then cross bracing is typically added. Additional structural stability is provided by folding, curving or ribbing the surface the surface of the structure, also as shown in (P). This avoids the need to deepen the structure with trusses that significantly reduce the visual transparency offered by bolt fixed roof glazing.

The 'ladders' are bolted or welded together to form the complete structure. If

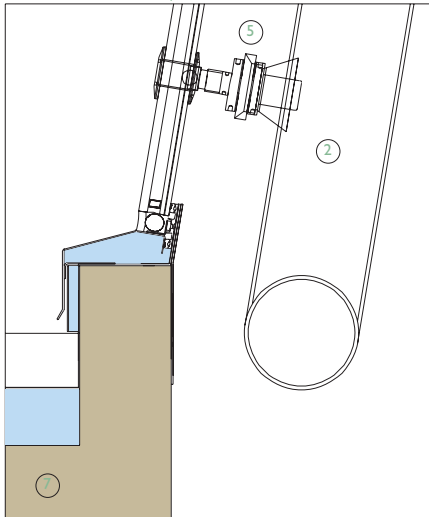
welded, then an inner sleeve is inserted between the sections being jointed and the edges of joints are welded together and painted. An alternative fixing method is to bolt the sections together. This method avoids the bolts being visible, leaving only a hairline joint visible at the junction, giving the joint a minimal appearance and avoiding welds which form a visible ring around the joint. This joint method also allows a faster installation than if welding were used, with the additional benefit that steelwork can be installed with a fully painted finish from the factory if required. In this method, a mild steel plate is welded to each end of the tube being jointed. A rectangular hole is cut into a wall of one of the hollow steel sections, big

Section I:75. Typical assembly

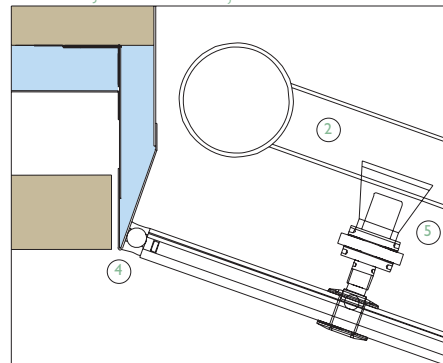


Conference Bubble, Lingotto Factory Conversion, Turin, Italy. Architect: Renzo Piano Building Workshop.

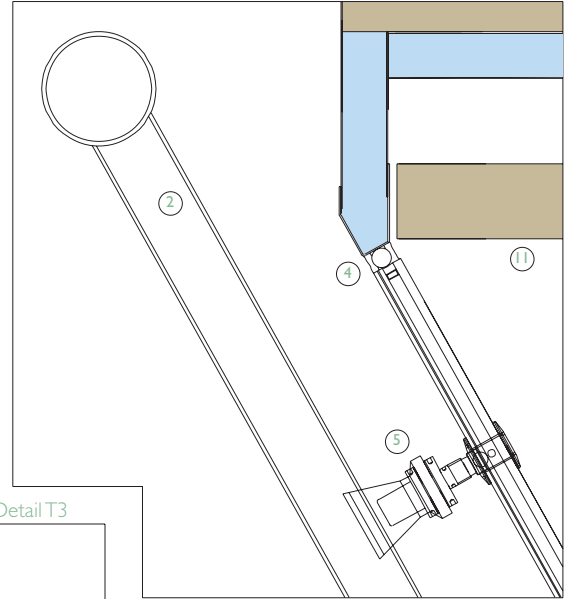
Section I:10. Base upstand Detail S1



Plan I:10. Junction with adjacent wall Detail T3



Plan I:10. Junction with adjacent wall Detail T4



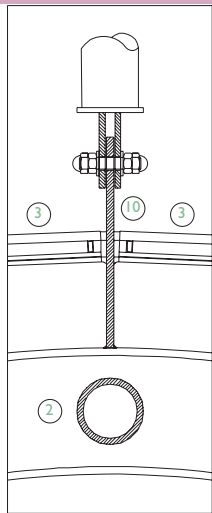
enough to pass a hand through. Accessing the inside of the hollow section from the rectangular hole, bolts are fixed through the end plates to fix the two steel sections together. The rectangular hole is then covered with a thin metal plate which is either bonded to the surrounding metal or is screwed into the surrounding wall of the hollow section.

The structural form of the 'ladder' usually corresponds to the layout of the glass panels, since the corners of panels are fixed back to the supporting structure, which is preferably as close to the glass joints (in elevation) as possible. In (Q) and (R) the structure is set in line with the joints in the glass. In (Q) the bolt fixings for the glass is fixed to

a tubular supporting structure with mild steel brackets fixed to the main tube (as described in the previous section). The positions of the bolt fixing in relation to the edge of the glass is optimised to reduce the glass to an economic thickness. In (R), bolt fixings are set mid distance between two horizontal ladders. This might correspond to a joint between two double glazed units or an additional bolt fixing to secure a large double glazed unit. A v-shaped mild steel bracket is set at 90° to the brackets in (Q). The stainless steel bolts are aligned in elevation with adjacent brackets in (Q).

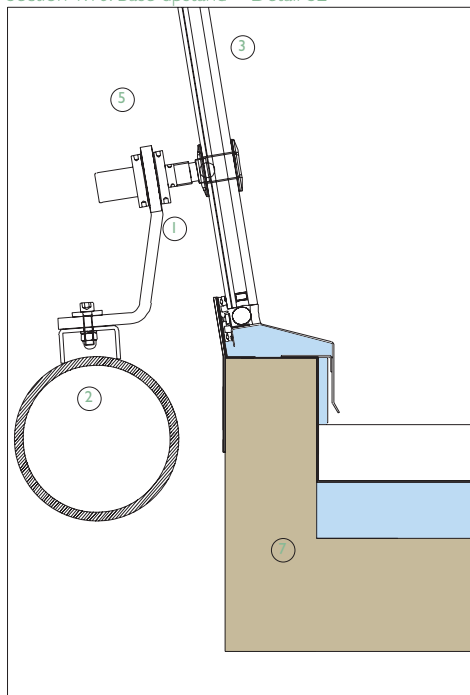
Base of glazed roof

Junctions of the bolt fixed glazed roof, or rooflight, and a surrounding reinforced concrete slab is shown in (S1), (S2) and (S3). An essential feature of junctions in bolt fixed glazed roofs at their perimeter is that there is no mechanical connection between the double glazed unit and the adjacent roof deck, or parapet, since the glass is bolted some distance away from the corner, and the edge of the glass is cantilevered from the bolt fixing. The adjacent roof or external wall (in a different material) meets it with two sets of silicone seals only, or alternatively with EPDM seals which are bonded to the edge of the glass unit. In (S3), a low pitched roof meets a reinforced concrete upstand



Plan 1:100. Penetration of plate through glass joint

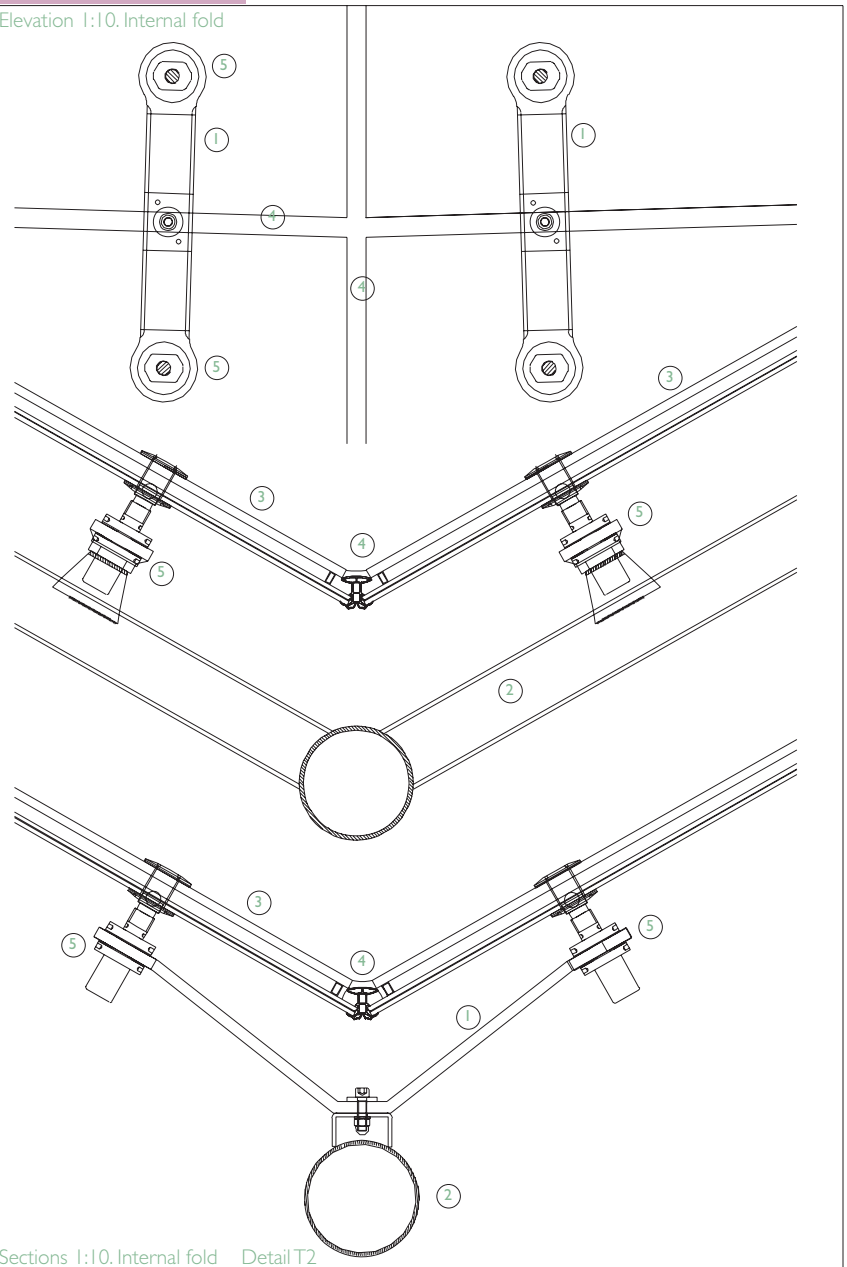
Section 1:10. Base upstand Detail S2



Details

1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall

Elevation 1:10. Internal fold



Sections 1:10. Internal fold Detail T2

forming part of a concrete roof deck. The supporting steel structure is fixed to the edge of the concrete slab, which typically forms a continuous ring beam around the opening to carry the load of the glazed roof. The base of the glazing has a cantilevered edge of the double glazed unit which is sealed to an aluminium flashing. An additional flashing, which is continuous with the waterproofing membrane, is set on the inside face of the glass. This folded aluminium strip is bonded with silicone to the bottom of the double glazed unit. It can be either concealed by the interior finishes or be coated, usually in a PVDF or polyester powder coated finish. This aluminium strip is bonded to the edge of the waterproofing membrane that extends

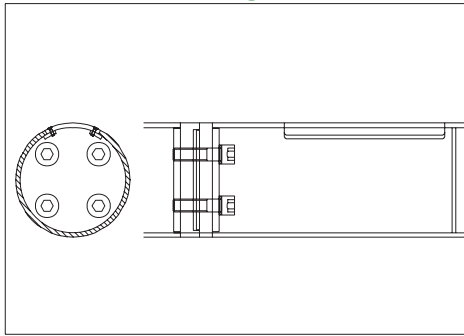
up the face of the upstand across the top. This combination provides an inner, second line of defence to the flashing above. The outer flashing is set on the outer face of the glass, and has a folded edge in order to bond it with a silicone seal, typically 20mm wide to match visually with the other seals between the glass units. Any rainwater which penetrates the outer seal is drained away on the inner metal flashing onto the waterproof membrane. The void between the two flashings is filled with closed cell thermal insulation, sometimes as injected foam to fill the cavity completely. Variations of this principle are shown in (S1) and (S2). In (S1) an all-metal upstand flashing is used, while in (S2) the upstand is concealed by an accessible

timber deck.

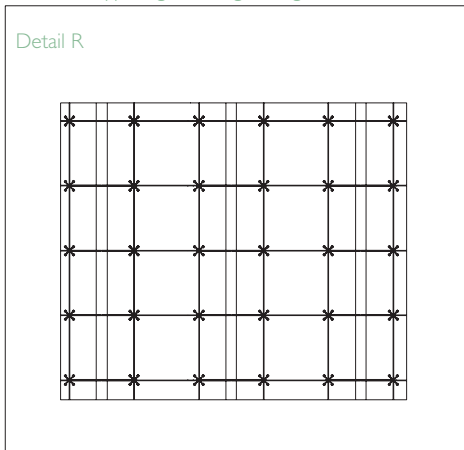
External and internal folds

Changes of direction in bolt fixed roofs that form ridges and valleys are formed as external folds and internal folds respectively. While the joint is formed in the same way as other joints, with an outer silicone seal and an inner extruded EPDM baffle, or air seal, the double glazed units are stepped on their edges to ensure that the joint is not wider than adjacent joints, as in (T1) and (T2). With an external fold the outer glass is stepped beyond the edge of the unit to maintain a constant width through the depth of the joint, as (T1), while in (T2) the internal fold has the inner laminated glass extending

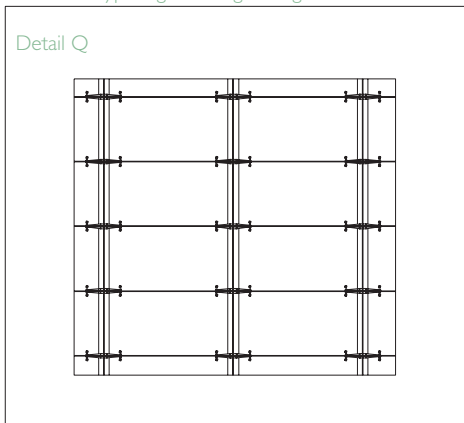
Plan I:100. Concealed framing connection



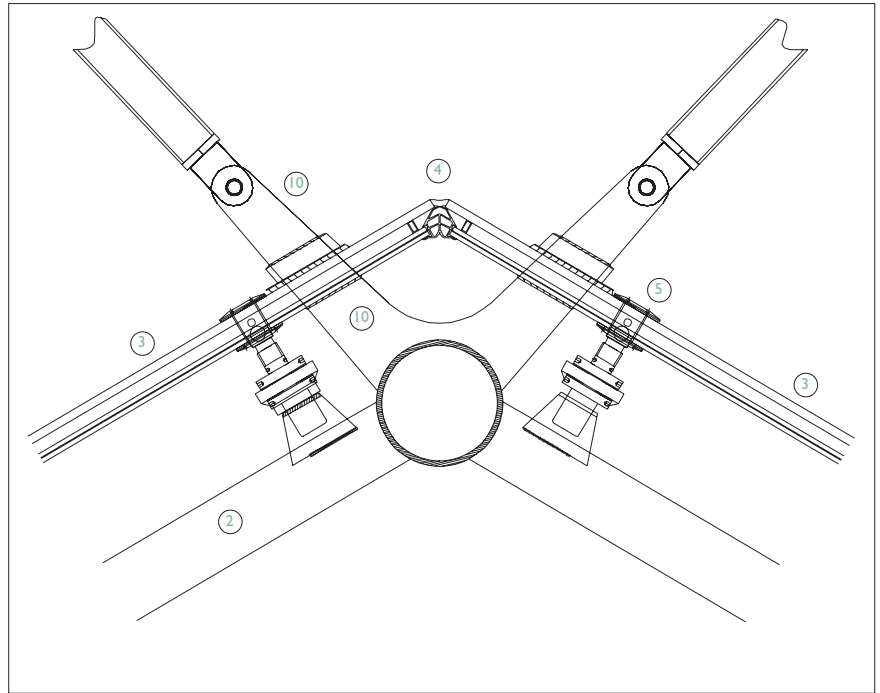
Plan I:100. Typical glass fixing arrangements



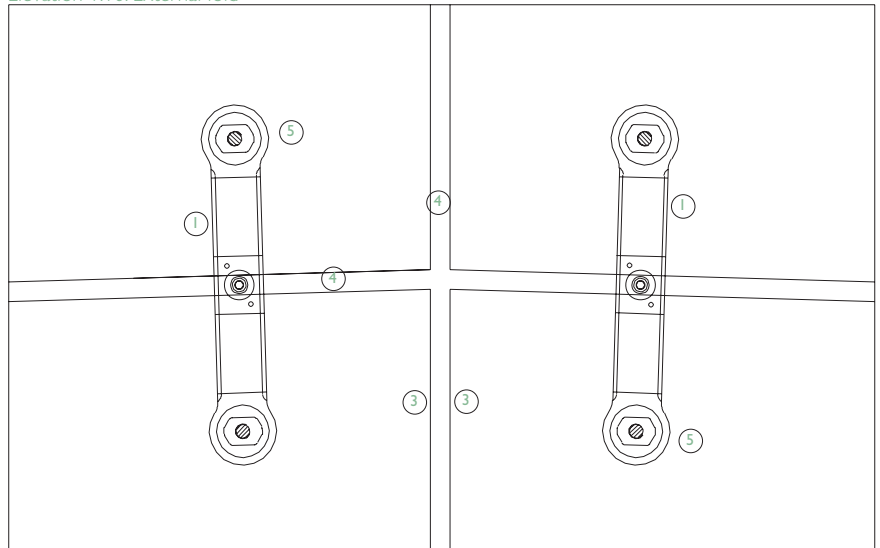
Plan I:100. Typical glass fixing arrangements



Section I:10. External fold Detail T1



Elevation I:10. External fold



beyond the outer glass to perform the same function. The joint width both externally and internally is made to match the width of adjacent joints in order to allow the same extruded EPDM gasket to be used as an inner seal.

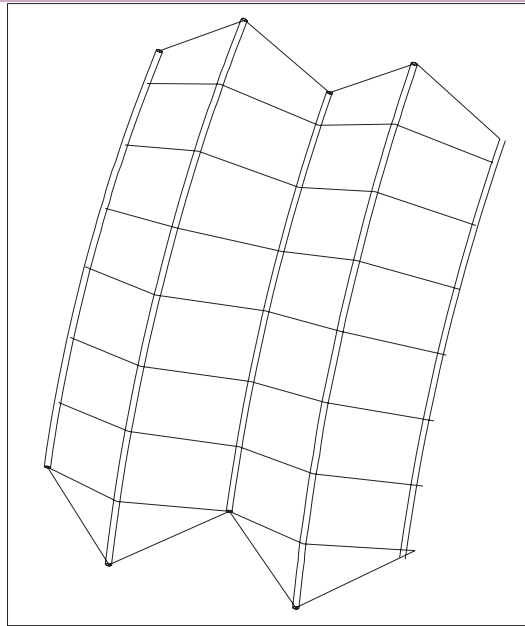
Junctions of the edge of the roof with external walls in other materials as (T3) and (T4) are similar to flashings at the base of the roofs, as (S3), with which these joints can be continuous as the roof perimeter turns from roof to external wall. In (T3), an insulated aluminium closer is bonded to the edge of the double glazed unit and is sealed against the adjacent wall construction. In (T3) the roof meets a metal rainscreen wall, while in (T4) a bolt fixed roof meets an

external wall clad in terracotta panels.

Support brackets for external shading and for rope fixing points for abseil-based cleaning are sometimes designed to penetrate through the joints between the glass joints. This method is described in the previous section. Where these brackets occur at external and internal folds, the brackets are usually designed so as to avoid penetrating the joint at the corner itself. This is done to avoid a complicated junction of the bracket together with the four corners of a joint meeting at the same place. This is both difficult to seal and difficult to give a smooth, continuous appearance as seen from inside the building.

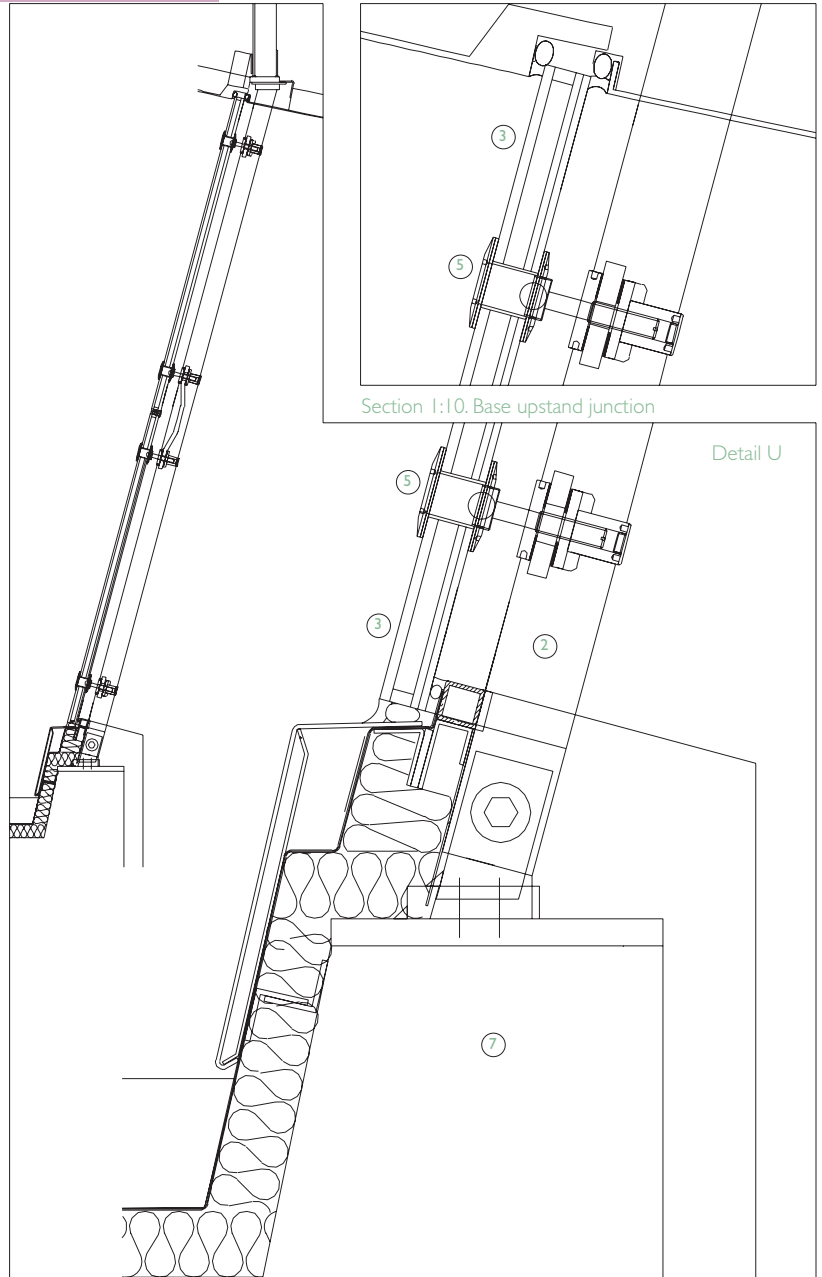
Small glazed rooflights

An essential aspect of small rooflights is the greater number of interfaces with surrounding construction and other materials than is usually the case with large glazed roofs. Where small rooflights have a bolt fixed glazing assembly mixed with gutter elements in a typical single rooflight, as (U), the glazing is sealed against the adjacent construction. In (U) an outer seal is formed against an external roof panel in a different panel. A second inner seal is made with an inner metal panel. Glazing channels can also be used (as described in the previous section) in order to seal the gap but the glazing channel must be connected to a flexible seal such as an EPDM strip to allow the bolt



Isometric view of roof assembly Detail P

Conference Bubble, Lingotto Factory Conversion, Turin, Italy.
Architect: Renzo Piano Building Workshop.



fixed glazing to move independently of the other materials making the junction. In (U) it is assumed that these structural movements are small.

In small rooflights the supporting structure is made visually lightweight in order to maximise the effect of the bolt fixed glazing. Stainless steel cables are often used to increase transparency. In (V1), a small rooflight of 3500mm x 3500mm in plan is made from a mild steel tube supporting structure. The top of the rooflight requires four glass panels in order to span from side to side. The bolt fixings in the centre of the top of the rooflight are supported by two cable trusses spanning diagonally from the corners, intersecting in the centre. The four

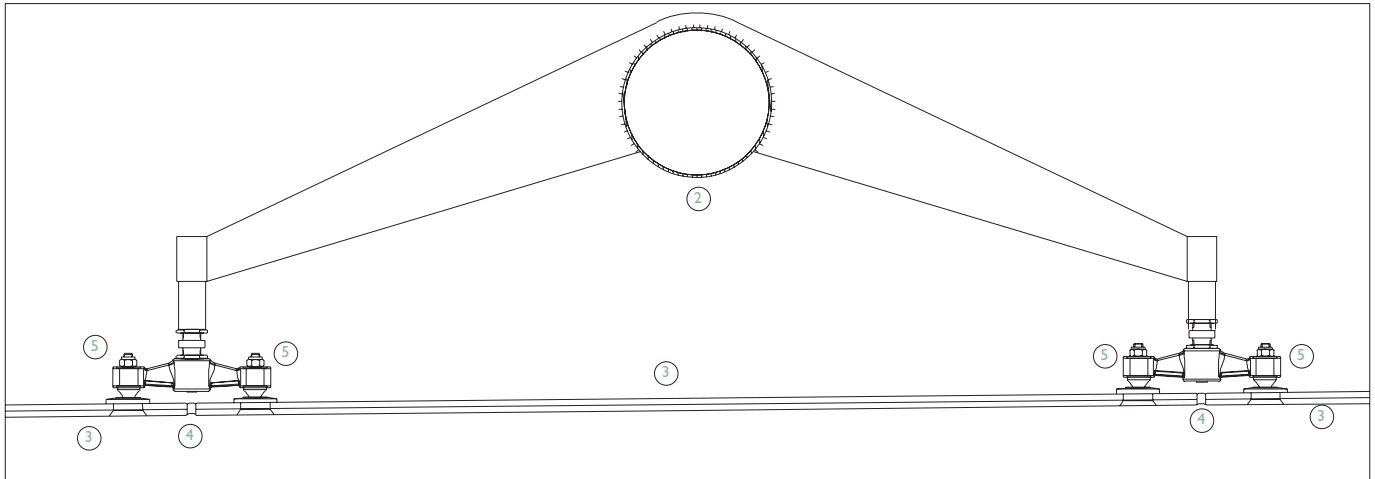
bolt fixings are secured to a cross-shaped bracket which is in turn bolted to two halves of a clamp bolted to the supporting cables. A vertical mild steel rod forms the central vertical element in the truss, as shown in (V2). The absence of steel tubes spanning across the centre of the top of the rooflight increases its visual transparency. Junctions at the corner and at the base of this typical small rooflight as shown in (V3). In plan in (V4), external corners are formed by stepping the edges of the double glazed unit in order to maintain a constant joint width for all rooflight joints. The visible area of silicone behind the glass can be concealed with silk screen printing, or 'fritting', usually in a black colour. Although external and internal cor-

ners of meeting double glazed units in bolt fixed roofs have a wide sight line, the continuity of the glass and its reflections obscure the effect of the fritting and silicone seals behind.

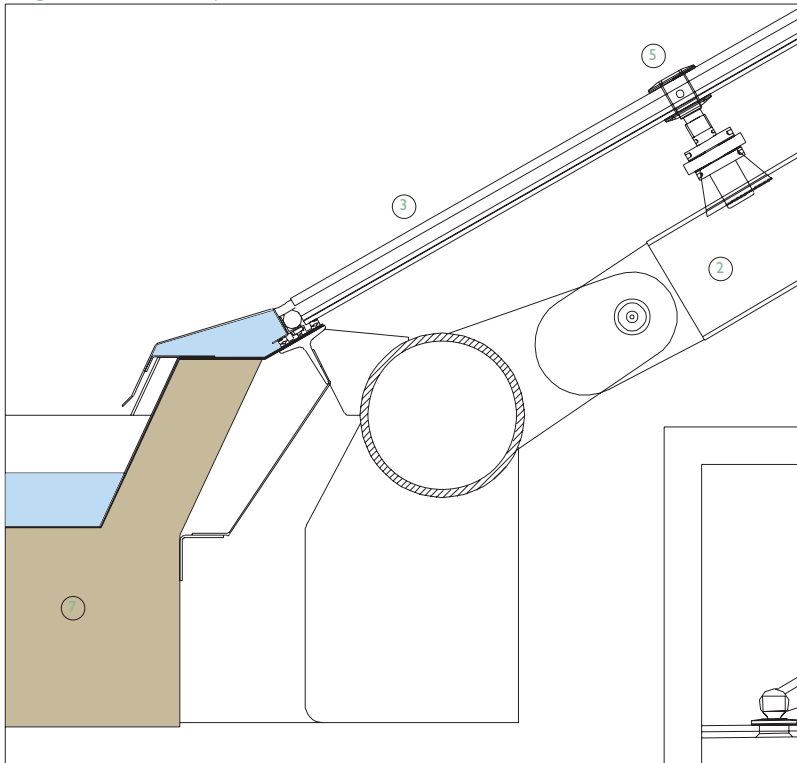
Larger rooflights

For bigger rooflights up to around 5.0 metres high and 8.0 metres wide, lightweight hollow mild steel sections, together with stainless steel cables are commonly used. This rooflight size suits glass sizes which are around 2000mm x 2000mm for horizontally-set units and around 2000mm x 2500mm high for vertically-set units. A modest rectangular steel frame forming the edges of the generic rooflight shown in (W1) and (W2)

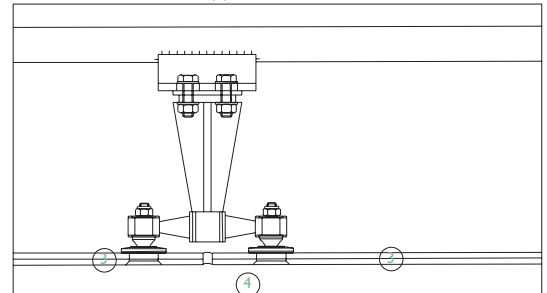
Section 1:10. Bracket support



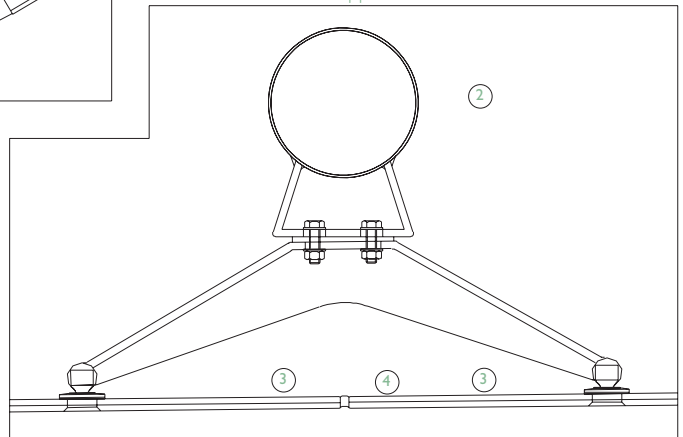
Long section 1:10. Base upstand Detail S3



Section 1:10. Bracket support



Section 1:10. Bracket support

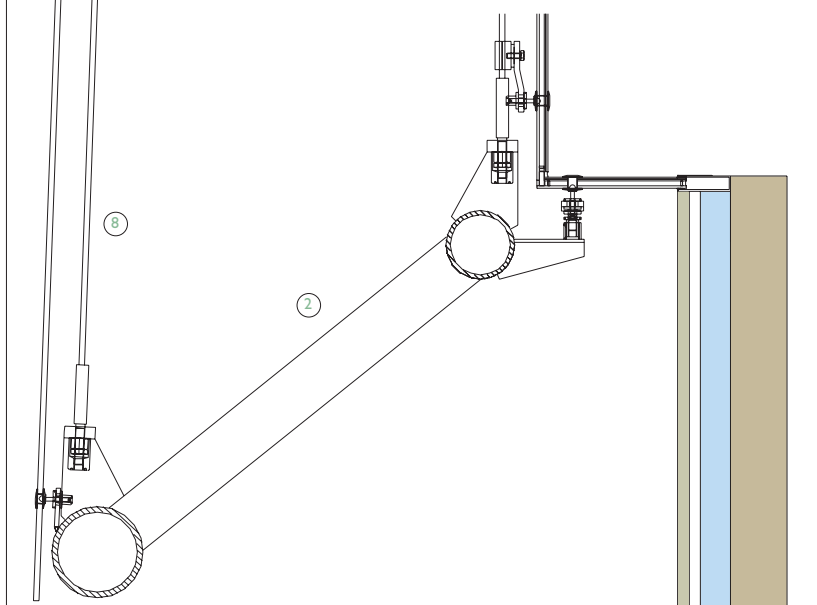
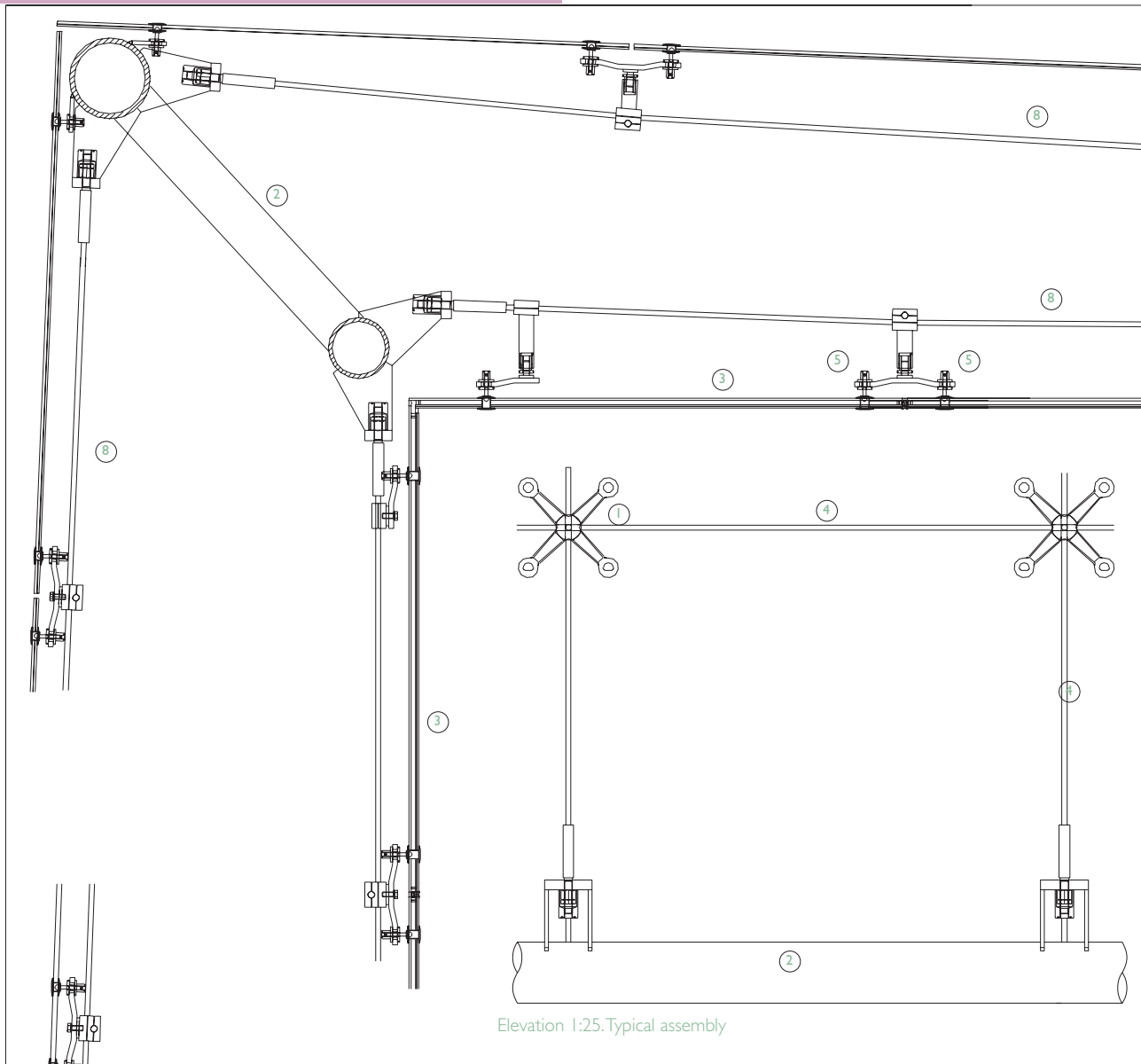


can support stainless steel cables spanning both vertically and horizontally to which bolt fixings and cross-shaped brackets can be fixed. The cross-shaped bracket is fixed to a clamp which is bolted to the cable, as in (W3). For glass joints set directly in front of the tubular steel structure, the bolt fixings are secured directly to a channel-shaped bracket welded to the main supporting steel tube, as in (W4). All bolt fixings in these modest sized rooflights have their adjustment for fixing tolerance made at the junction of the bolt fixing and the support bracket. The glass units set horizontally can be supported at their corner fixings by either a grid of steel tubes immediately below the joint, or with a cable truss, which provides

greater visual transparency than the all-tube solution. The main stainless steel cables of the truss span across the diagonal corners, meeting at a central vertical tubular post, as described in the previous paragraph for small rooflights. The increased span is assisted by a set of secondary steel cable trusses set at 45° to the diagonal geometry (orthogonal with the glass), as shown in (W2). The secondary trusses both stiffen the main trusses and provide a fixing point for all bolt fixings. The principle of this medium size generic rooflight can be adapted to suit a range of individual designs of similar overall dimensions.

Details

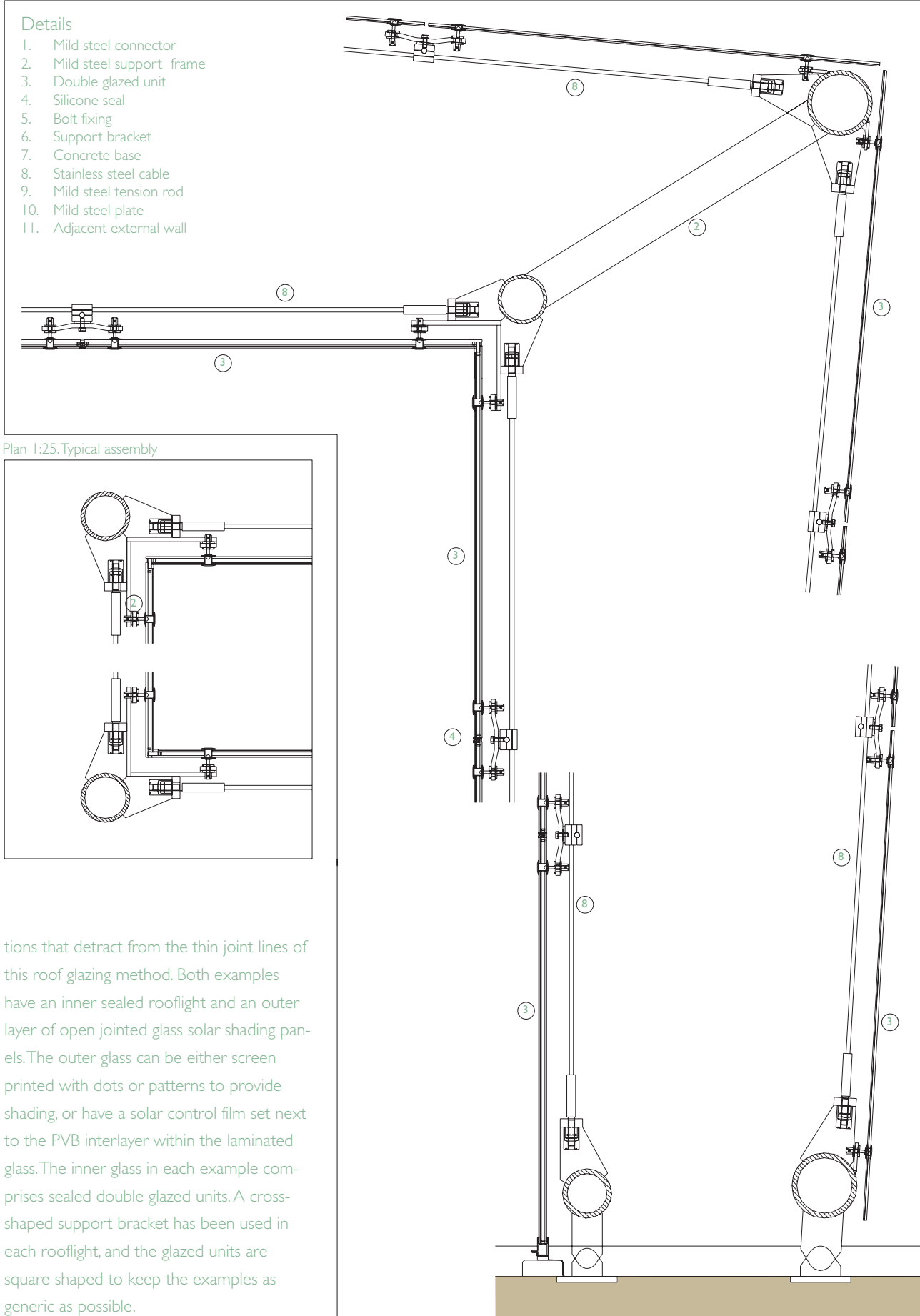
- | | |
|-----------------------------|----------------------------|
| 1. Mild steel connector | 8. Stainless steel cable |
| 2. Mild steel support frame | 9. Mild steel tension rod |
| 3. Double glazed unit | 10. Mild steel plate |
| 4. Silicone seal | 11. Adjacent external wall |
| 5. Bolt fixing | |
| 6. Support bracket | |
| 7. Concrete base | |



Bolt fixed glazing can be used as solar shading in twin wall rooflights. Two generic examples are shown here for a square-shaped rooflight and a circular-shaped rooflight, both of a medium size. The square example is 8.0 metres x 8.0 metres for the inner glass roof, and the circular rooflight has a radius of 9.0 metres across its inner glazing. Both use the same structural principle of a tubular steel frame with stainless steel cables stretched between them, but the position of the structure in relation to the bolt fixed glazing is different for each rooflight. These examples aim to show a visually lightweight solution that suits the quality of visual transparency that can be achieved with bolt fixed glazed roofs rather than more conventional framed solu-

Details

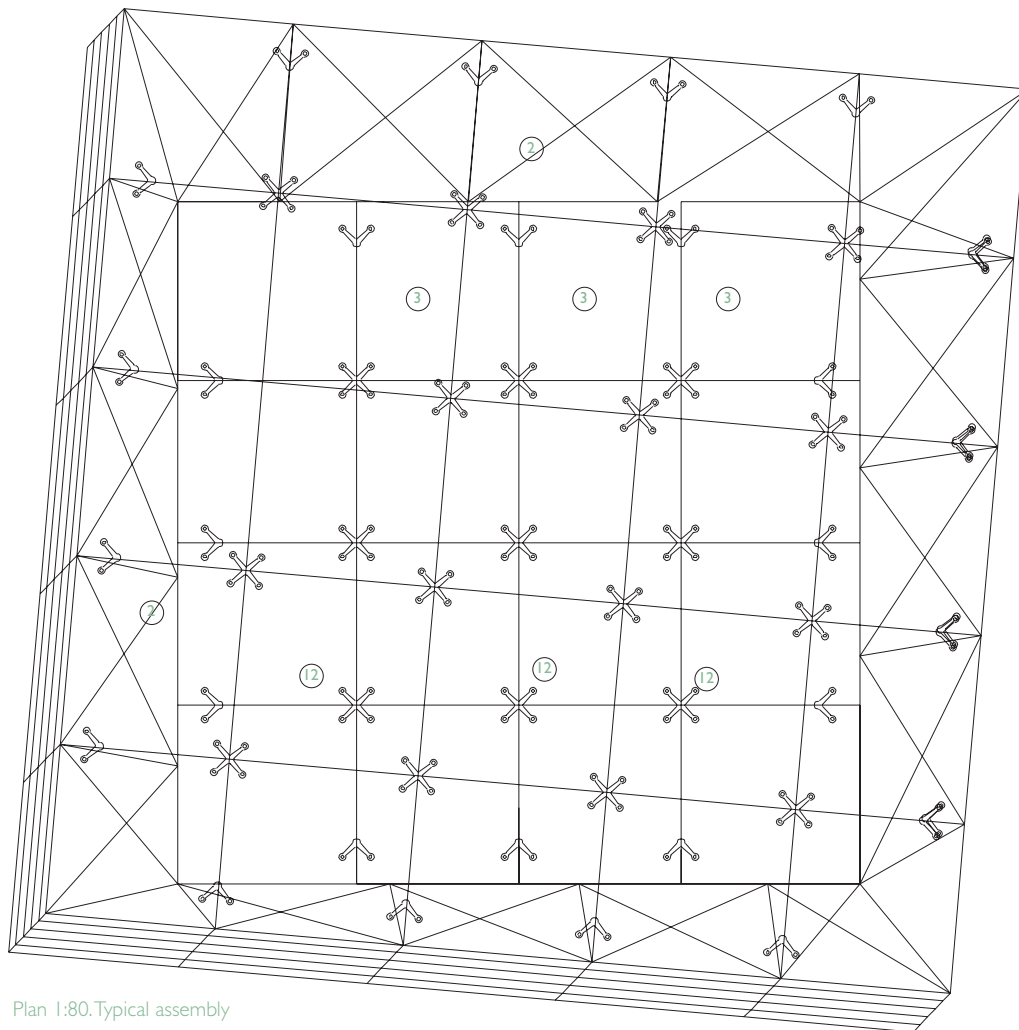
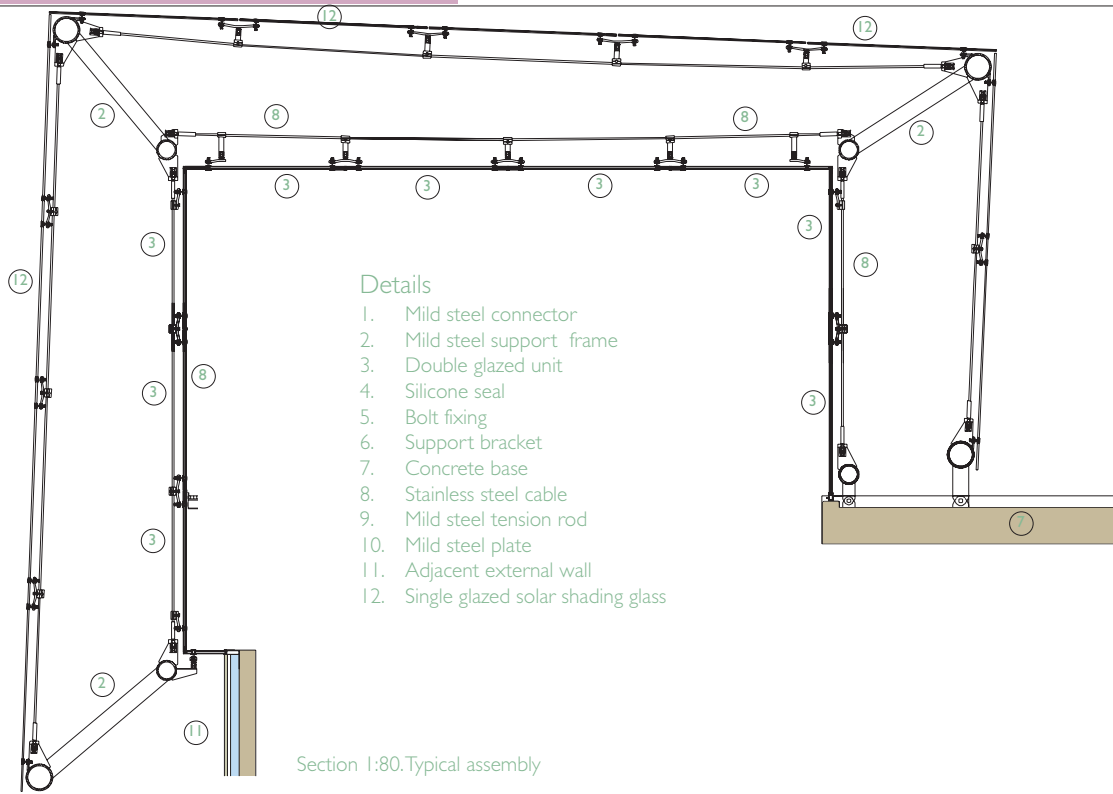
1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall

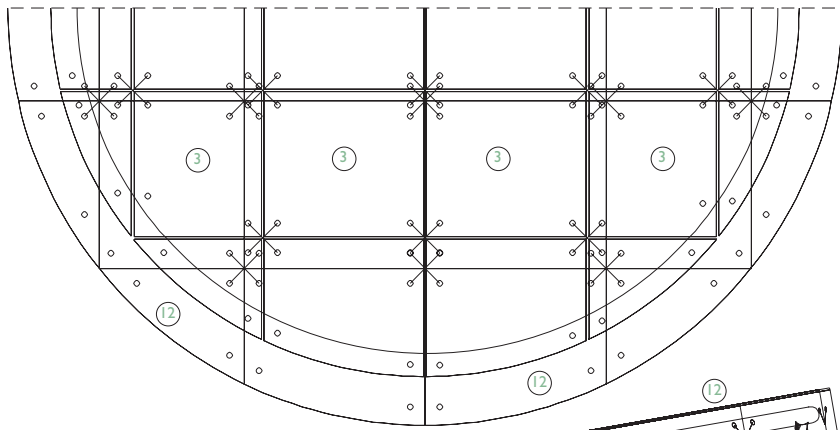


Plan 1:25. Typical assembly

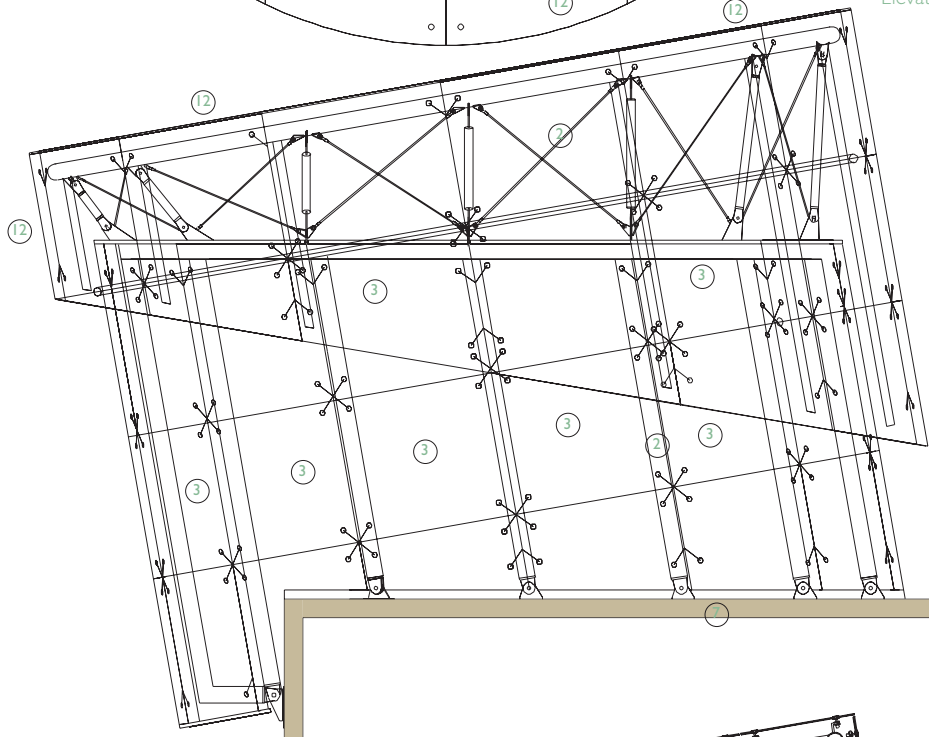
tions that detract from the thin joint lines of this roof glazing method. Both examples have an inner sealed rooflight and an outer layer of open jointed glass solar shading panels. The outer glass can be either screen printed with dots or patterns to provide shading, or have a solar control film set next to the PVB interlayer within the laminated glass. The inner glass in each example comprises sealed double glazed units. A cross-shaped support bracket has been used in each rooflight, and the glazed units are square shaped to keep the examples as generic as possible.

The square rooflight has two rectangular frames, one set inside the other, linked by diagonal members. The inner roof is hung

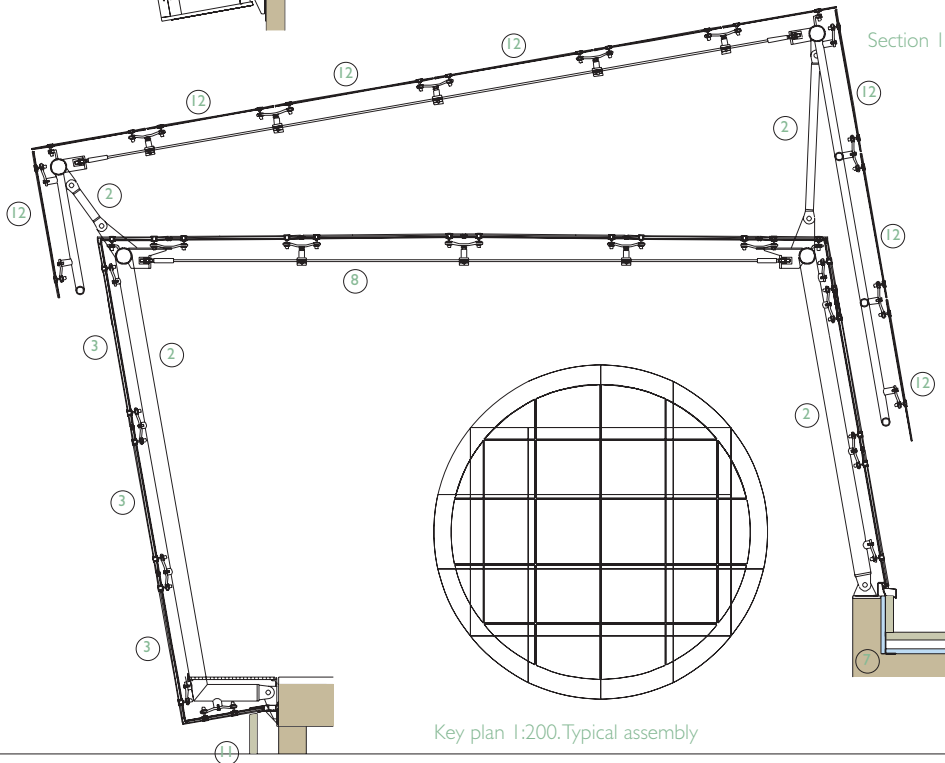




Part plan 1:80. Typical assembly

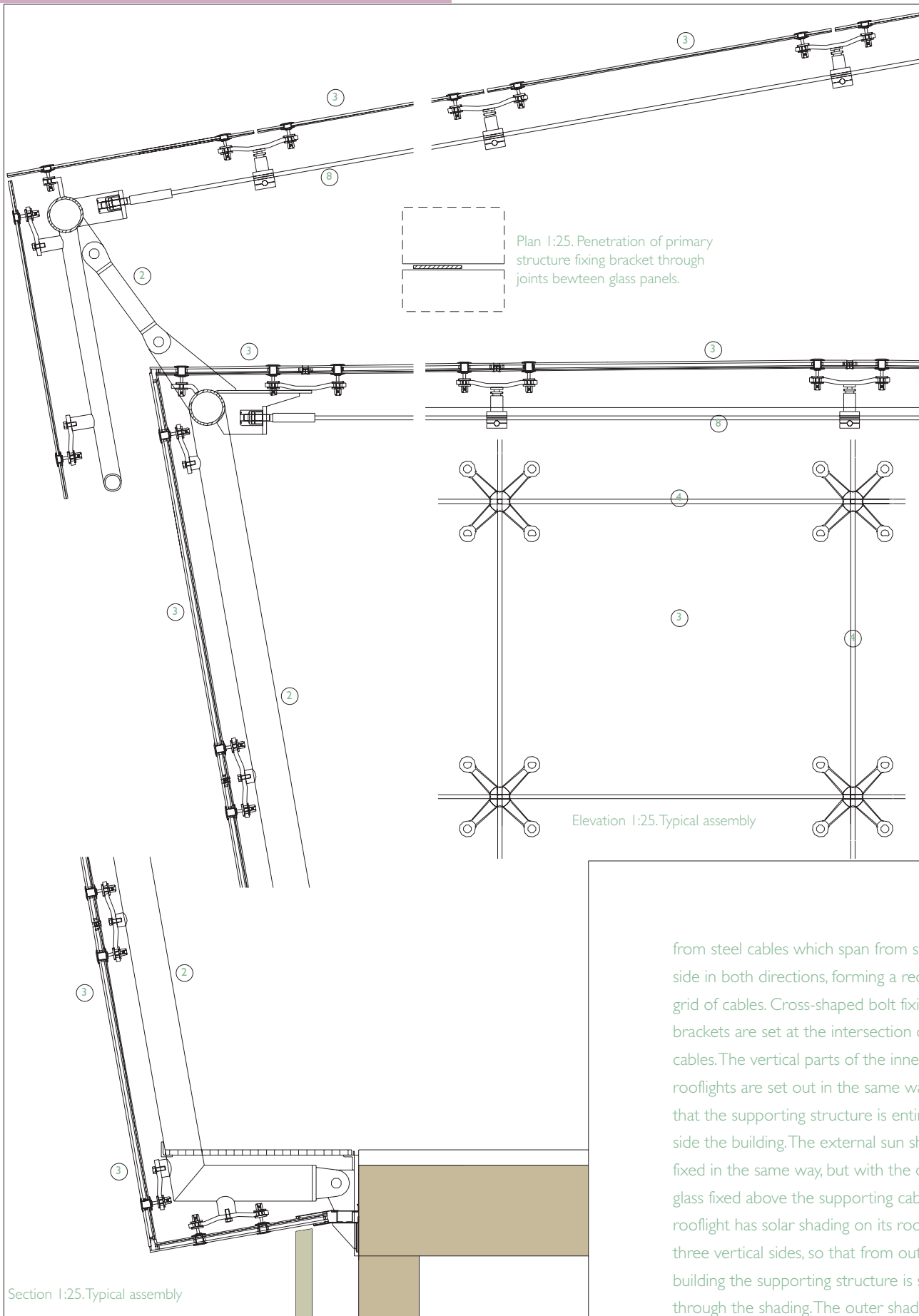


Elevation 1:80. Typical assembly



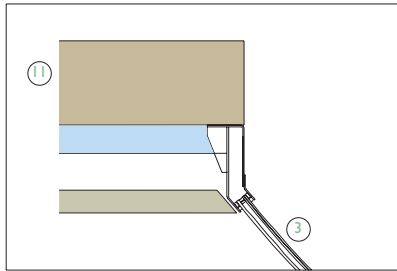
Section 1:80. Typical assembly

Key plan 1:200. Typical assembly

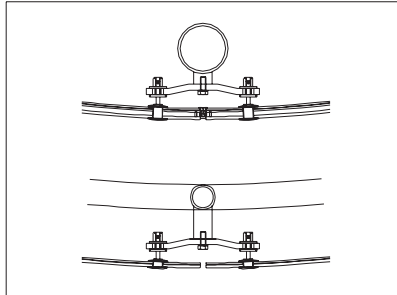


from steel cables which span from side to side in both directions, forming a rectilinear grid of cables. Cross-shaped bolt fixing brackets are set at the intersection of these cables. The vertical parts of the inner sealed rooflights are set out in the same way, so that the supporting structure is entirely outside the building. The external sun shading is fixed in the same way, but with the outer glass fixed above the supporting cables. The rooflight has solar shading on its roof and on three vertical sides, so that from outside the building the supporting structure is seen only through the shading. The outer shading is tilted out of plane in relation to the inner cube. With this construction method the inner and outer cable structures do not need to

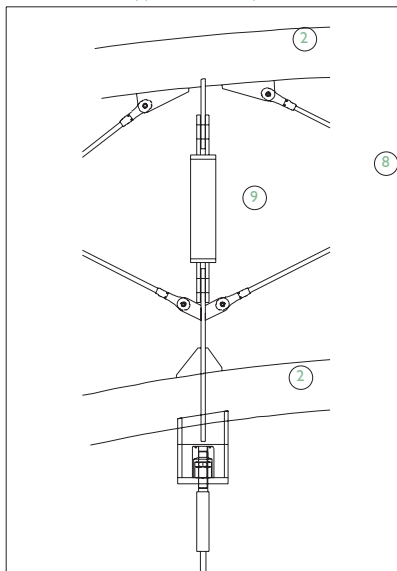
Plan 1:25. Typical assembly



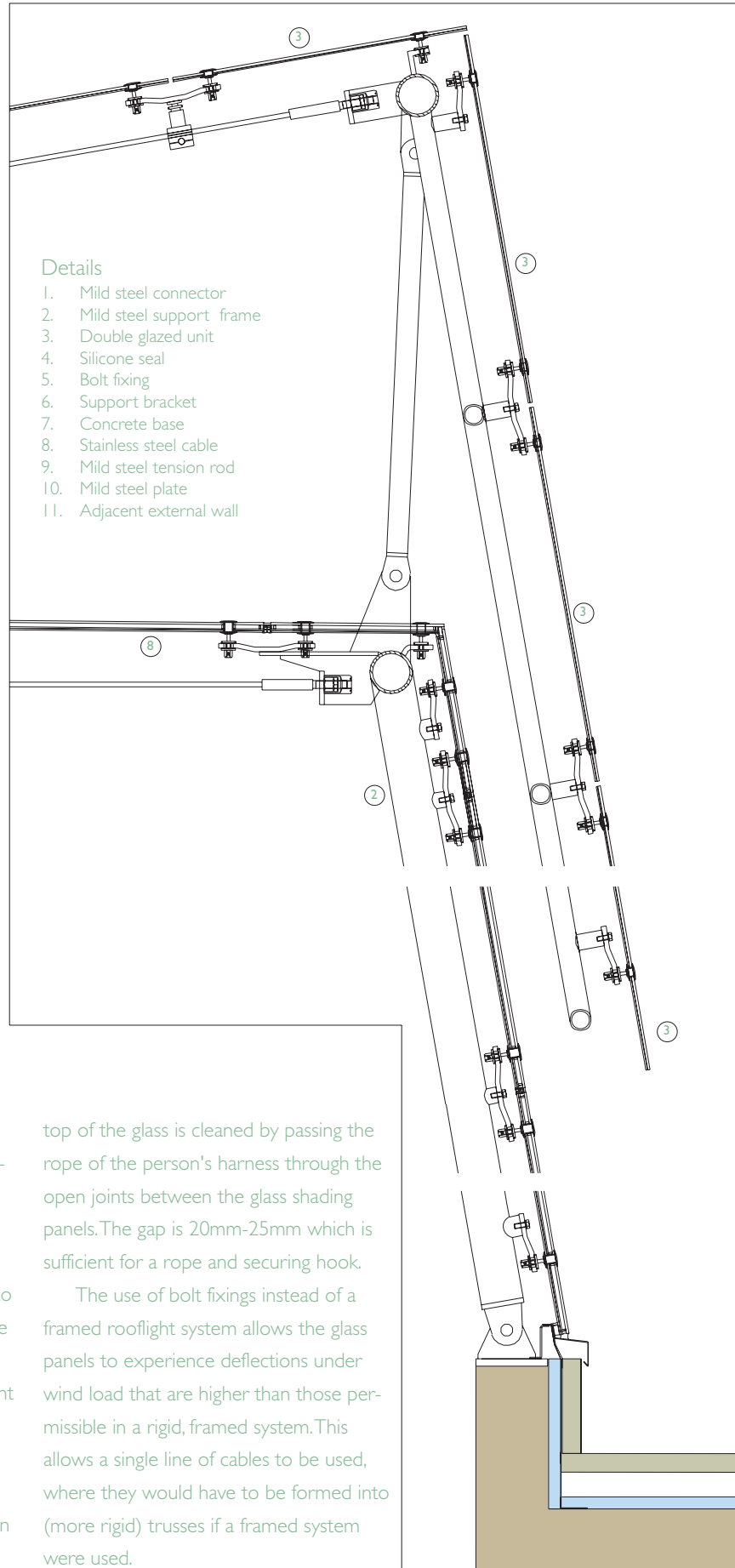
Section 1:25. Typical assembly



Elevation 1:25. Typical assembly



Section 1:25. Typical assembly



Details

1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall

follow the same geometry.

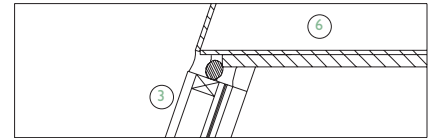
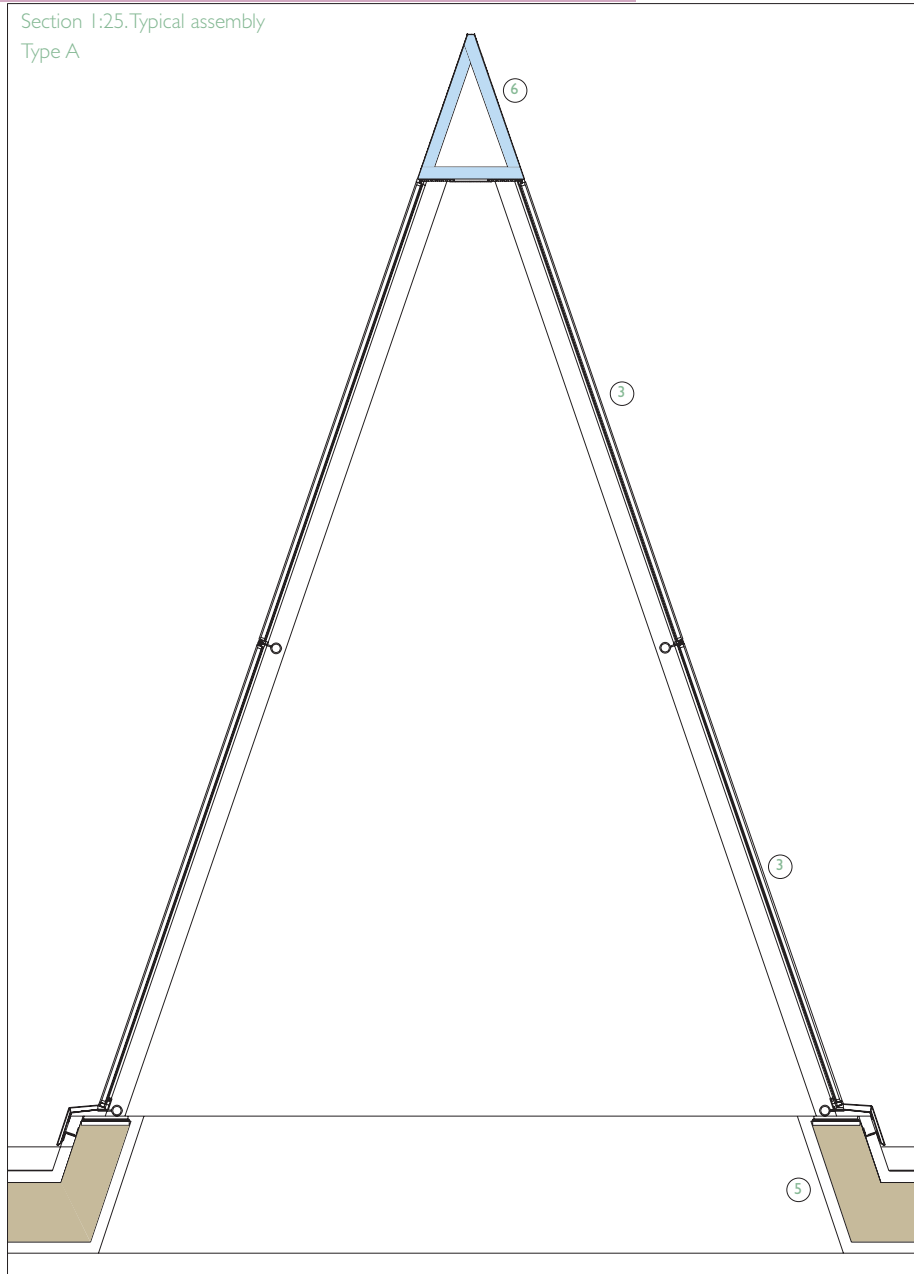
The circular rooflight has an outer shading set on top of the inner sealed rooflight to provide partial solar shading. Where the square rooflight has a gap of approximately 1.0 metres between the two skins of glass to provide maintenance access for cleaning, the circular rooflight has a gap of only 600mm around its edge. Where there is not sufficient space for a 600mm to 1000mm gap for maintenance access, a structural tube is removed when access is required.

Cleaning and maintenance is undertaken on both rooflights by walking on the glass itself, with individuals wearing harnesses which are secured to the upper cables, which also serve as a fall arrest cable. The

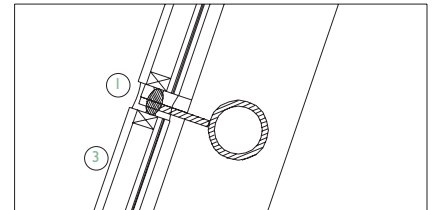
top of the glass is cleaned by passing the rope of the person's harness through the open joints between the glass shading panels. The gap is 20mm-25mm which is sufficient for a rope and securing hook.

The use of bolt fixings instead of a framed rooflight system allows the glass panels to experience deflections under wind load that are higher than those permissible in a rigid, framed system. This allows a single line of cables to be used, where they would have to be formed into (more rigid) trusses if a framed system were used.

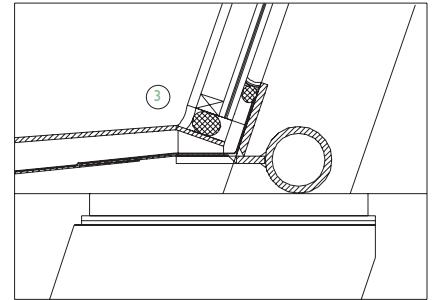
Section 1:25. Typical assembly
Type A



Section 1:5. Junction with adjacent material

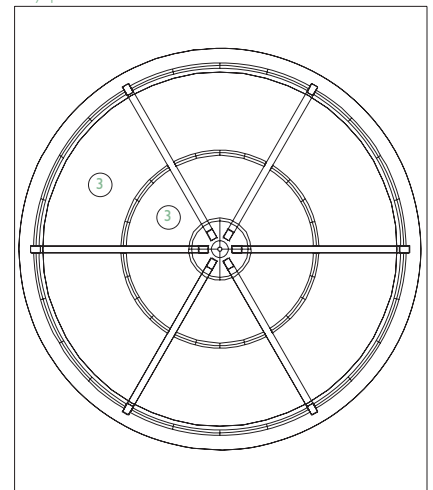


Section 1:5. Glass to glass junction



Section 1:5. Junction with upstand

Key plan



The method of silicone bonding glass to aluminium framing is well developed for use in glazed curtain walling to provide visually smooth glass facades with no visible cappings. The use of silicone sealed rooflights, discussed in an earlier section, can be taken a step further to become a full bond without the need for the mechanical restraint of pressure plates. In silicone bonded rooflights, the glass is glued to a supporting frame. The glue is also the external seal. This technique is useful for small rooflights, where cappings would be very difficult to fabricate, and in rooflights which are walked upon, where the rooflight is an external glass floor.

In (A) a generic conical rooflight has curved double glazed units bonded to an alu-

minium frame. Silicone bonding avoids cover caps which would have to be curved both vertically and horizontally, which would be extremely difficult to fabricate. In (B) a rooflight is bonded together without a supporting structure; the glass provides its own support. In (C) a flat monopitch rooflight is bonded to a frame to provide a small rooflight from one double glazed rooflight. In (D) laminated glass sheets are used to form a glass roof which can be walked upon. Similar to a glass floor used inside a building, it must also take heavier traffic loadings and be weathertight.

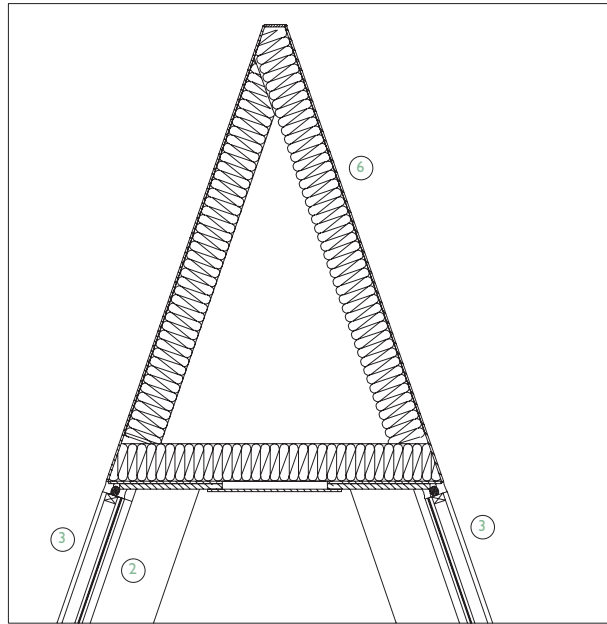
Generic conical rooflight

In (A) a lightweight steel frame is used to support double glazed units that form a rooflight. The structural frame comprises box sections set vertically, held in place by thin tube sections running horizontally to form a circle. The glass panels are supported on steel flat sections which are welded to the horizontally set tube section, as (E). The glass is levelled on blocks set onto the horizontal flat section, and the silicone is applied to the joint. At the base, the horizontal metal section projects out to form a flashing over the upstand in which the rooflight is set. An additional inner metal upstand can be provided with another silicone seal if there is risk of future flooding from blocked rainwater out-

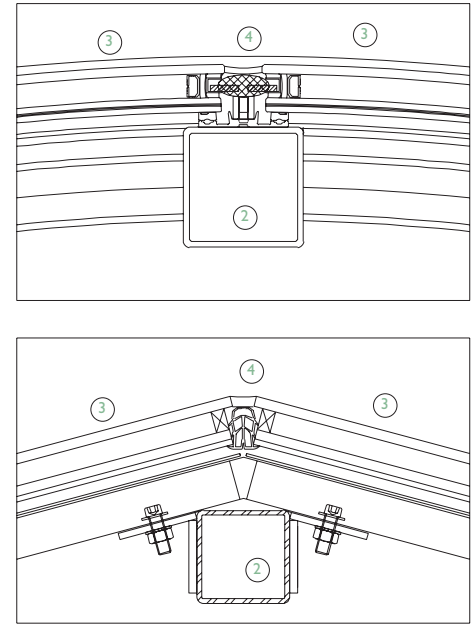
Details

1. Silicone bond
2. Mild steel support frame
3. Single glazed laminated glass panel
4. Silicone seal
5. Concrete base
6. Insulated metal panel
7. Folded metal flashing
8. Reinforced concrete support frame

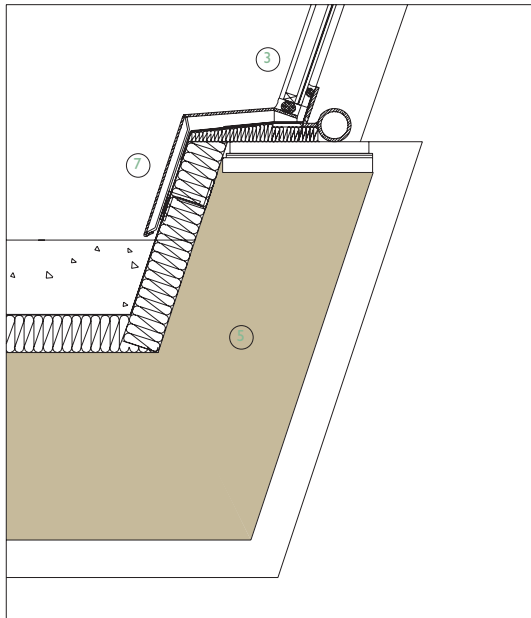
Section 1:10.Base upstand.Junction with adjacent material. Detail F



Plans 1:5. Glass to glass junction



Detail E



Pavilion, London. Architect:Toyo Ito & Associates



lets, for example. In (E) the waterproof membrane for the roof slab is continued up the upstand and is bonded to the base of the horizontal section that supports the glass. This provides a complete seal from the glass to the roof membrane, with the metal flashing providing both a protection to this seal and a means of concealing the closed cell thermal insulation set on top of the waterproof membrane.

At the top of the rooflight, a metal panel is used to seal the pointed form. The glass can be continued almost to the top, with only a small pointed metal cover; but this example aims to show how the glass is sealed to another material set above it. The metal cover is folded inwards at its junction

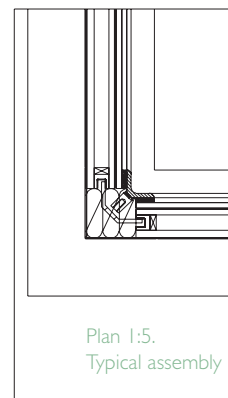
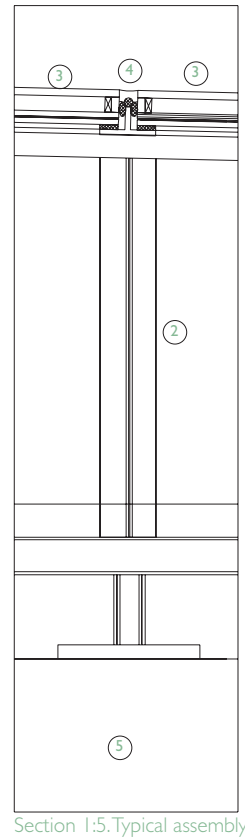
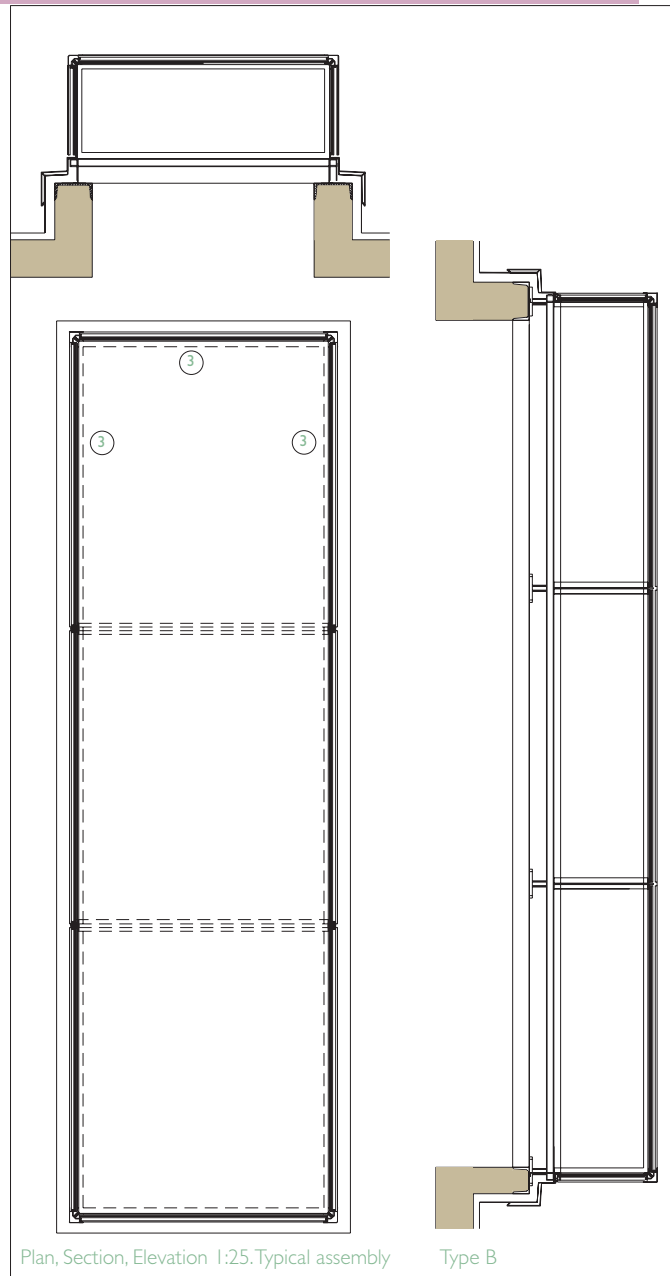
with the double glazed unit, as shown in (F). The fold forms an edge to make a silicone seal. The glass is bonded to another steel flat set below the metal cover. This provides lateral support to the glass unit as well as making an additional inner seal. The metal cover is typically formed from a single piece of aluminium or stainless steel that is welded and ground smooth, and is insulated with injected foam or mineral fibre quilt to provide a continuity of thermal insulation.

The use of silicone bonding in this rooflight avoids the need to use visually obtrusive bolt fixings, allowing the form of the rooflight to be seen more clearly. In some countries, additional restraining clips are required on the outside of the glass, at

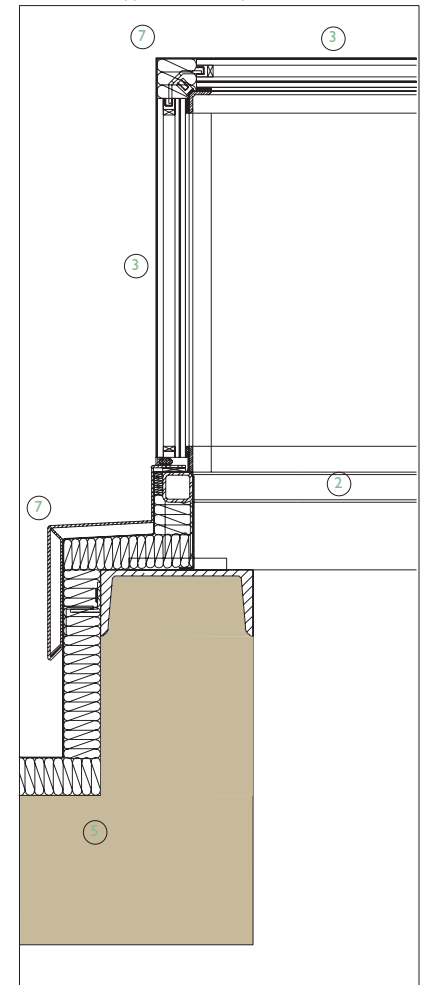
the corners, but this additional safety feature is dependent upon the individual rooflight design and the local building codes.

Generic rectangular rooflight

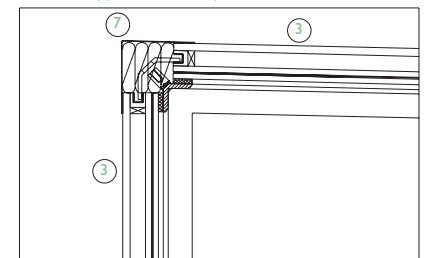
In (B) a rooflight is constructed without a supporting frame. Mechanical restraint is provided at the corners in the form of pressure plate clips. The double glazed units at the corners are fabricated with a recessed groove on the two sides of the panel forming the corner in order to receive the clip. An alternative method is to fix the metal clip to the outside of the glass at the corner. This avoids the need for specially made corner pieces but it does form a visible fixing. The modest size of this rooflight allows the hori-



Section 1:5. Typical assembly Detail G



Plan 1:5. Typical assembly



horizontally-set glass to span from side to side with no additional support. The corners of the rooflight are stiffened by short lengths of pressure plate which hold the glass in place. The glass has a specially shaped groove in the depth of the double glazed unit, to which the pressure plates are fixed. Corner joints have an outer corner piece of folded aluminium which is silicone bonded either to the face of the adjacent glass units, or is folded at 90° to bond it to the side of the unit. Glass-to-glass joints between horizontally-set units have a silicone seal with an aluminium angle set on the inside face to provide a second seal.

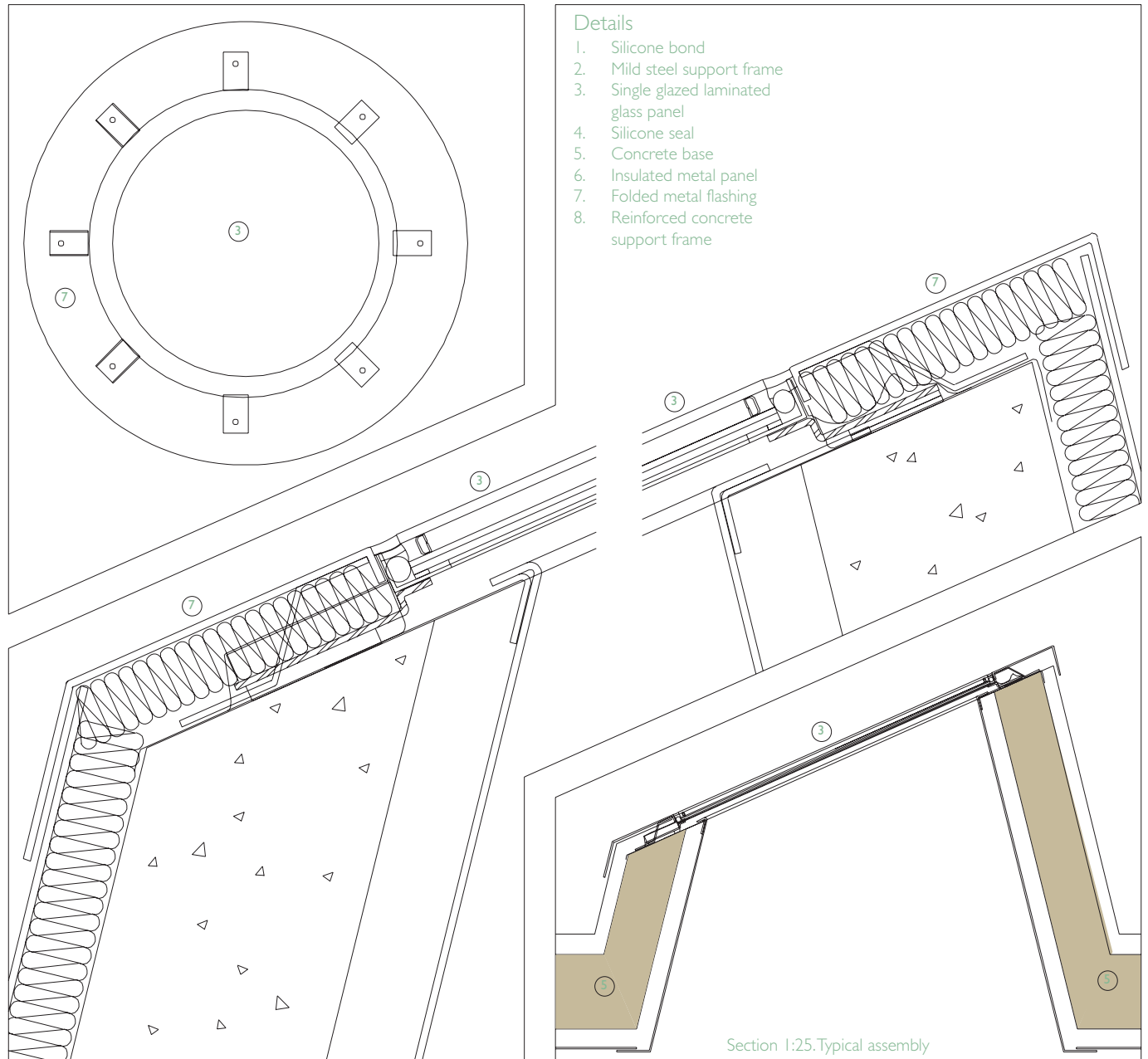
At the base of the rooflight the glass units are seated on aluminium or mild steel sections which are in turn supported on

brackets to the required height of the flashing. These metal brackets are fixed to the adjacent roof deck. A concrete upstand is shown in (G). The waterproof membrane for the adjacent roof extends up the upstand and up the face of a folded aluminium sheet that forms a complete weathertight seal. Closed cell thermal insulation is applied to the outside of this membrane, and an outer pressed aluminium flashing is fixed to protect both the membrane and the thermal insulation. The insulation forms a continuous layer from the junction with the roof insulation up to the silicone seal in order to avoid any thermal bridges that would cause condensation to form on the inside face of the framing in temperate climates. Although thermal

insulation can be difficult to install in such situations, the continuity of insulation is essential to avoid the effects of thermal bridging.

The inside face of the double glazed unit at its base is bonded to an inner metal angle. The outside face of the glass is sealed to the metal flashing below with silicone. Any water that passes through the outer seal is drained to the external face of the roof membrane beneath.

Small rooflights can have upstands as flashings which can appear to be large in relation to the area of glass. In highly visible or accessible roofs this can be avoided either by setting the rooflight on the outer edge of the upstand to create a flat appearance to the flashing, or by adding a layer of decking



to conceal the upstand. Decking is usually in the form of open jointed concrete slabs or timber boards.

Generic monopitch rooflight

The monopitch rooflight (C) provides a visually simple method of closing a roof opening formed in a different material. The circular rooflight is formed by a circular ring of aluminium fixed on Z-shaped brackets which are fixed to the concrete upstand beneath. A vertical metal flat section is screwed to the Z-sections and the junction with the flat ring is sealed with silicone. The circular double glazed unit is set into this ring frame in a bed of silicone with spacer blocks to locate it evenly on the ring. The joint

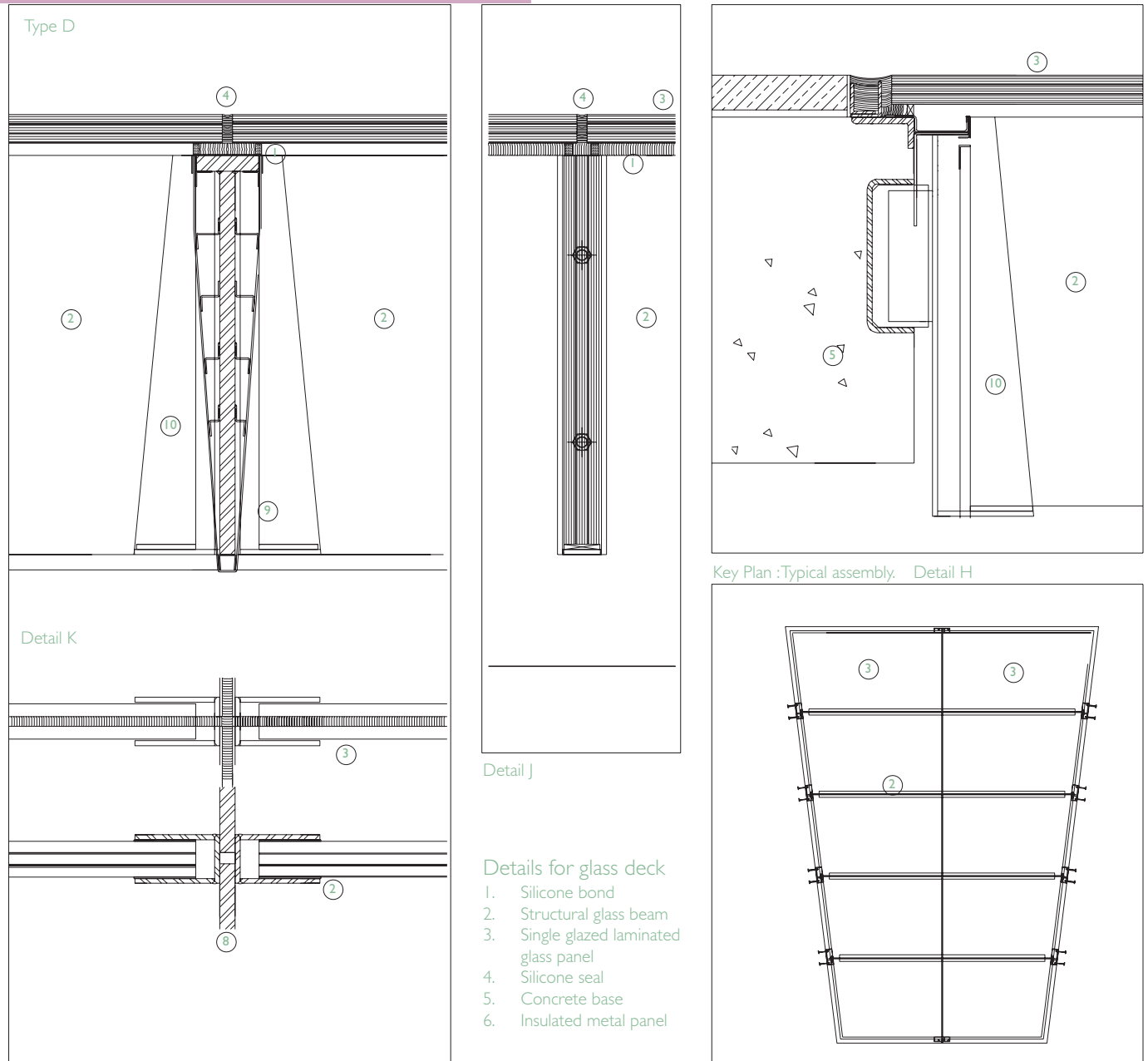
between glass and frame is then sealed with silicone using a polymer backing rod. The surrounding waterproof membrane is lapped up the edge of the vertical ring to provide a continuous seal around the rooflight. Detail (G) shows a metal panel forming the edge of the silicone seal around the glass. The continuity of thermal insulation is provided by closed cell insulation set onto the roof membrane that extends up to the silicone seal.

Glass roof decks

Rooflights formed as (nominally) flat, accessible roof decks have been in use over the past 10 years. Previously used only inside buildings for walkways and stairs, they are now being used as fully waterproofed exter-

nal decks, manufactured as proprietary systems. Single glazing is used, since double glazed units are difficult to use as a result of solar gain around the edge of the unit, where the glass is exposed to the outside, but is supported on its underside, allowing heat to enter but not to escape. Where black coloured edge 'fritting' is used, the situation is made difficult. However, double glazed roof decking is in development and will no doubt become much more common over the next 10 years.

The glass used is laminated, in common with other rooflights, both to avoid the possibility of any falling objects from penetrating the glass on impact, as well as preventing damaged glass from falling immediately into



the space below. The glass is set into a series of extruded aluminium angles to which it is bonded on its underside. A gap between the frame and the top of the glass is sealed with silicone of a different type. An additional condensation channel is set below the glass to catch any water that penetrates the silicone seal, or any water that passes through a damaged joint.

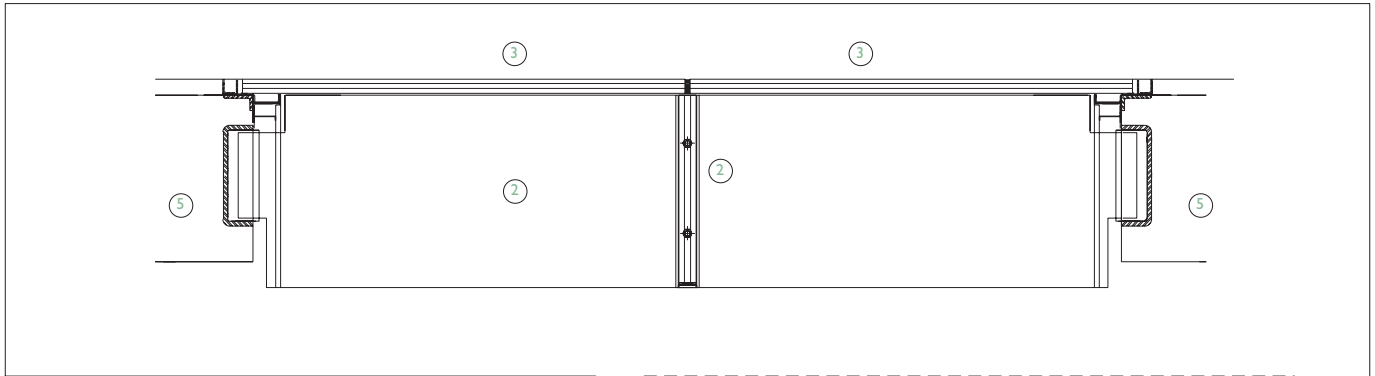
The details here show alternatives for both steel beam and glass beam supports to the glass panels. Detail H shows a typical rooflight with glass panels 2400mm x 1200mm in size. The supporting structure has a glass beam set in the centre, spanning the full length of 6000mm. Its depth is approximately 600mm, but the beam depth will vary

depending upon the individual design. The glass beams here comprise three layers of glass, each 19mm thick, which are laminated together. In the event of one glass being broken, the remaining two glasses will take the full load, avoiding collapse of the beam. The overall thickness of the beam, of approximately 60mm, also provides sufficient bearing for the two glass sheets that meet on top, as shown in (J). Each glass has 20-25mm bearing, with a 15-20mm joint width between the glass decking sheets, to suit the individual design. Where steel plate is used to provide a beam instead of laminated glass, as (K), a steel flat is welded to the top of the beam to form a T-section that gives enough bearing for the glass deck. The ends of the

glass beams are supported by a metal shoe support, made from either mild steel or aluminium as (L). Stainless steel is used where corrosion is an essential consideration of the design. The metal shoe is bolted back to the supporting structure or reinforced concrete floor slab. The gap between the edge of the glass deck and the adjacent roof finish material is made with a silicone seal as shown in (L).

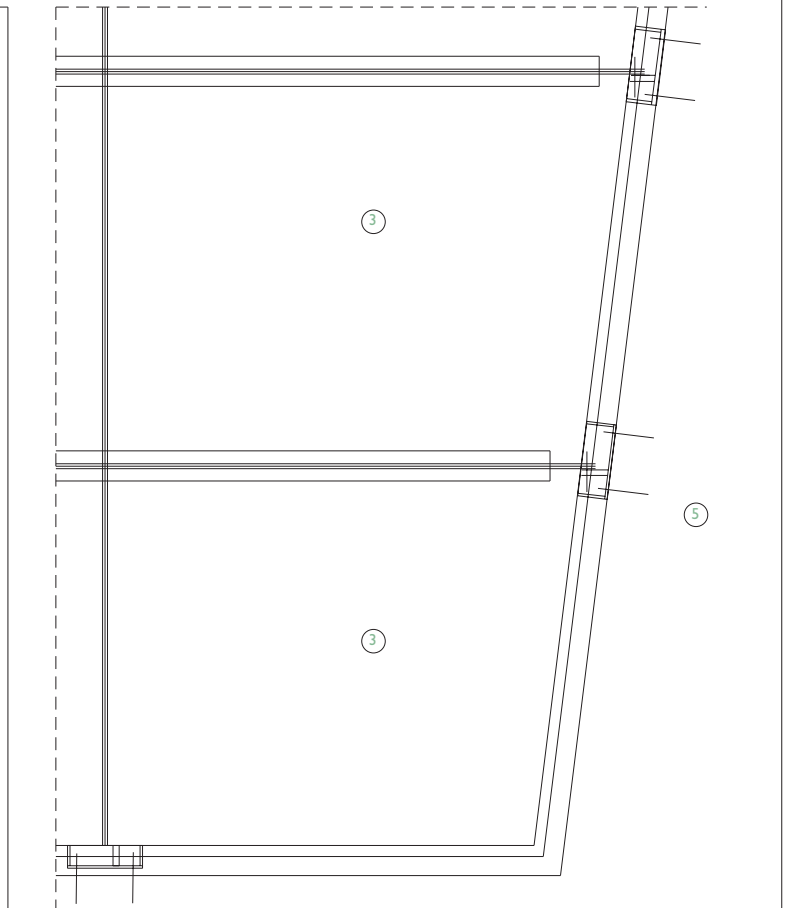
Typical glass deck panel sizes range from 1000mm x 1000mm to 1500mm x 1500mm. Both panel size and overall glass thickness are determinants in the overall rigidity of the glass deck and its associations vertical deflections. Typical vertical deflections for the glass build-ups, given below,

Section, plan 1:25. Typical assembly



- 7. Folded metal flashing
- 8. Mild steel plate beam as alternative support
- 9. Folded aluminium decorative cover
- 10. Steel aluminium support 'shoe'

Pavilion, London. Architect: Toyo Ito & Associates



range from 0.2mm to 2.0mm, though the acceptable amount of vertical deflection under full design load is dependent upon the specific design application. Typical laminated glass build-ups for the range of panel sizes just mentioned are as follows. The thicknesses of interlayers have been ignored for clarity:

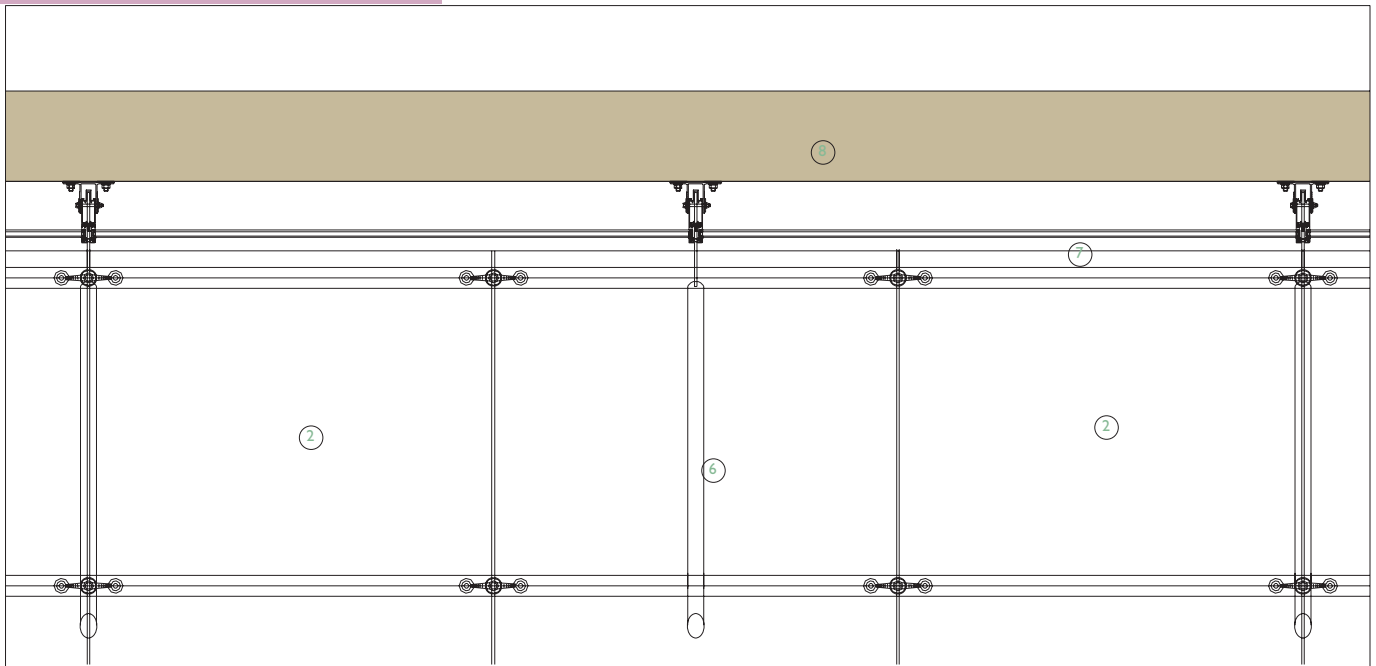
- 15mm+12mm+12mm = 39mm thick
- 15mm+15mm+12mm = 42mm thick
- 15mm+15mm+15mm = 45mm thick

At the junction of glass beams, the secondary glass beam is fixed to the primary beam by either a mild steel shoe, in the manner of timber floor construction, or mild

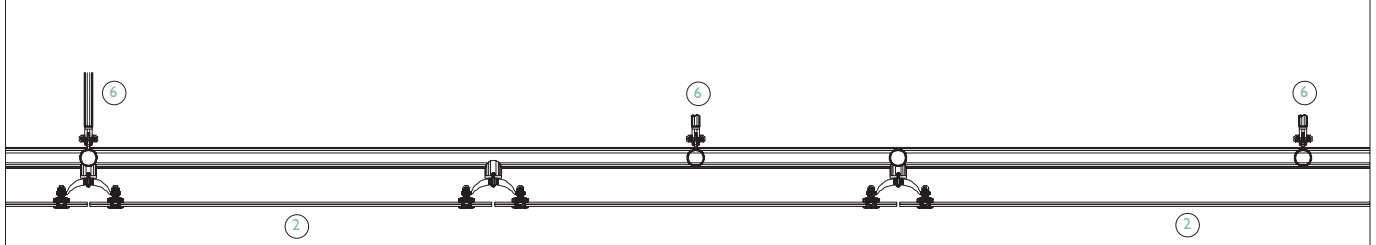
steel cleats in the manner of steel framed floor construction. Both methods require at least one of the glass beams to be drilled in order to bolt the metal component to the beam. When bolting a glass beam to a steel beam, as in (K), the same principles apply of using a metal shoe. The drilling of glass is a well established technique developed mainly for bolt fixed glazing.

Glass decks usually have an additional layer applied to the top surface of the glass to increase its friction which reduces the possibility of a building user from slipping while walking on the glass. Carborundum is sometimes added to the top surface of the glass for this reason. An alternative method is to 'frit' or screen print the top surface of the

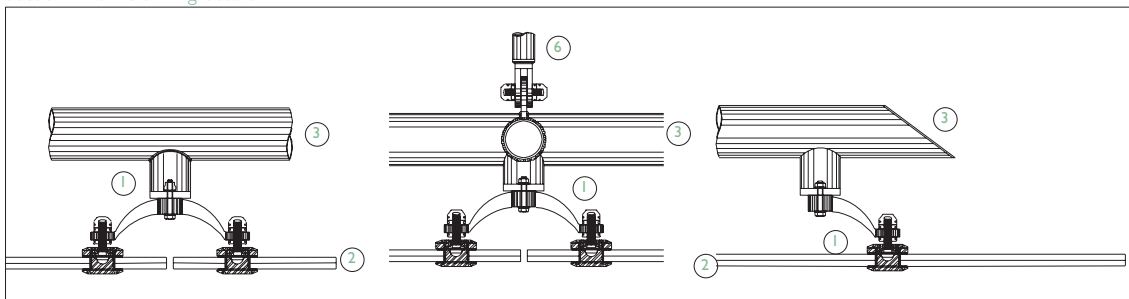
glass, which has the added benefit of reducing visibility through the glass from below.



Plan, section 1:25. Typical assembly Example A



Section 1:10. Bolt fixing details



Details

1. Cast mild steel or stainless steel angle bracket
2. Single glazed panel
3. Mild steel or aluminium tube
4. Support bracket
5. Bolt fixing
6. Steel strut secured to primary structure
7. External wall
8. Building structure

An essential development in glazed canopies has been in the use of frameless glazing techniques to create an effect of increased transparency, where the glass surface and its reflective qualities are visually stronger than the supporting structure and the visual rhythm of the glazing bars. In framed glazing canopies, particularly those of traditional design, the framing is more visually dominant. Both bolt fixed glazing and clamped glazing techniques are used, with bolt fixed glazing using in frameless glazing, typically, a supporting steel frame, and clamped glazing using laminated glass beams as a supporting structure fixed with stainless steel clamps.

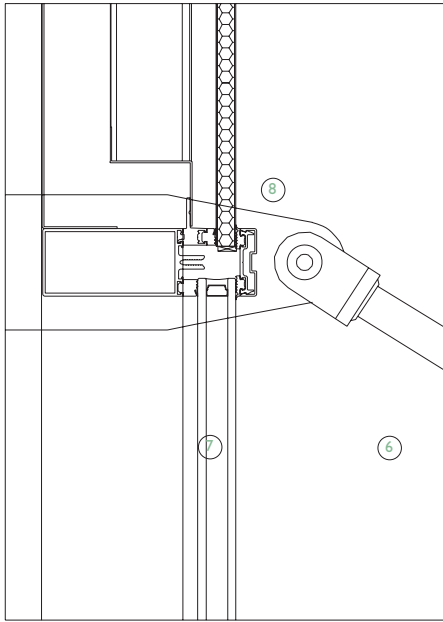
The bolt fixed example shown in generic example (A) shows a glazed canopy fixed to

the side of a flat roofed building, that might be one or two storeys high. The tubular metal structure shown can be fabricated in both steel and aluminium. Because of the relative small scale of the construction, the canopy frame can be built to very close fixing tolerances in relation to the glass, allowing the bolt fixings to be secured without the usual slotted connections used in bolt fixed glazed wall or glazed roof construction. This gives a visually refined appearance, with the curved support arm for the bolt fixing being fixed directly to the supporting structure with a precisely positioned threaded hole. This use of high levels of fixing precision, which is much more difficult in large assemblies due to the difference in position

between glass and supporting structure, can be controlled much more carefully in smaller-scale canopy construction.

In generic example (A) the metal frame comprises horizontally-set tubes fixed at one end to the building structure. The other end is supported by a diagonally-set rod hung at an angle of 30°, the rod being fixed at its upper end back to the building structure. The horizontally-set tube is fixed to the diagonally-set rod with a pin connection, typically a 12mm diameter bolt, for this scale of construction. A rod is used rather than a cable, since the glass canopy is required to withstand wind loads which are both positive and negative, that is, for both downdrafts and updrafts of wind. The visible bolt con-

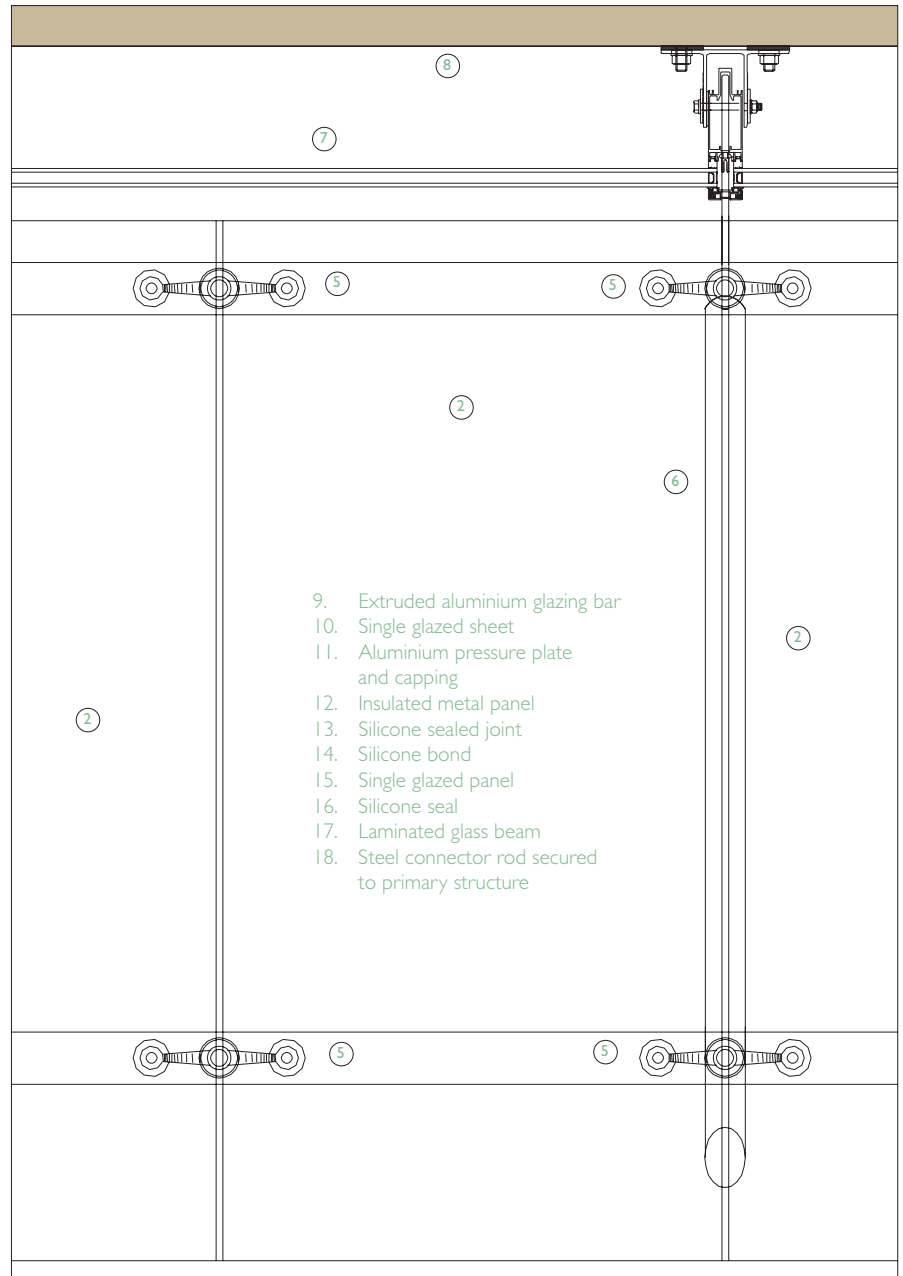
Plans 1:5. Connection at top of strut



Train Station, Heilbronn, Germany.
Architect: Auer und Weber / Schlaich Bergemann und Partner



Plan 1:10. Typical glass panel



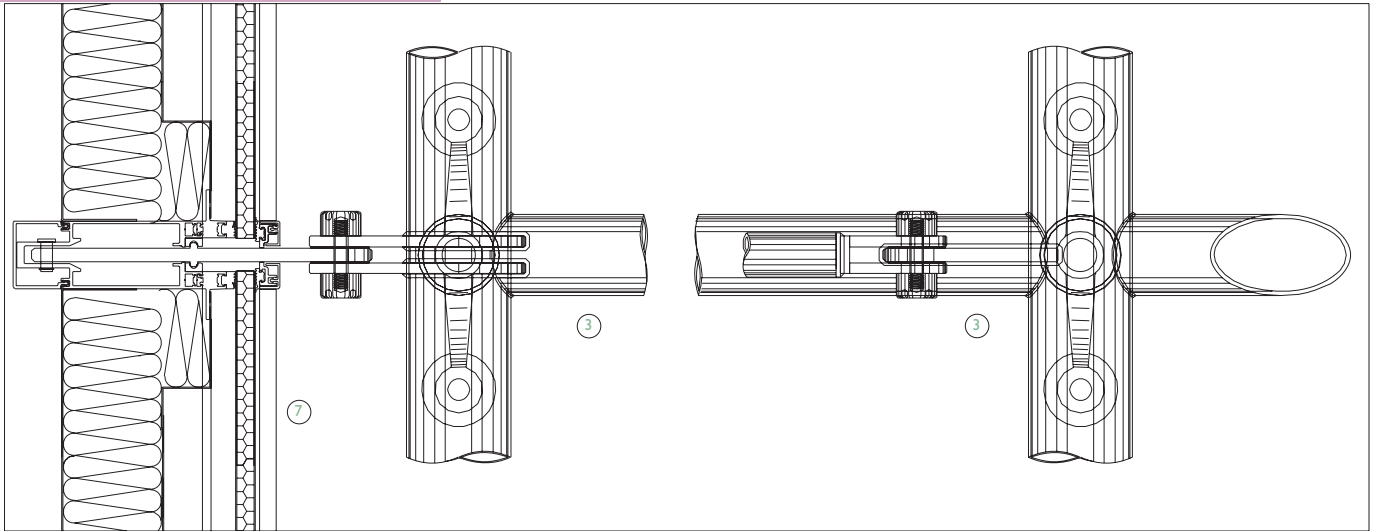
connections for the supporting structure to the glass are typically dome head, flat head, or of specially machined shape, as shown in the drawn example. These types are visually more refined than the traditional hex head type, which leaves the thread of the bolt exposed on one side. The small dimensional tolerances needed both during construction as well as to accommodate structural movement are provided by oversize holes in the glass. The slight difference in alignment between hole and bolt fixing is concealed by the disc-type fixing in the drawing. Counter-sunk fixings are also used but this results in the fixing tolerance being moved back to the junction between the bolt fixing and the support bracket to which it is fixed, resulting in

the slotted hole junction.

In common with the inner glass of overhead glazed rooflights, laminated glass is used in order that the glass will hold together as a single piece if broken, typically as a result of an object falling onto the canopy from above. The glass is made sufficiently thick to avoid any visual deflection along the front edge of the glass, which could otherwise result in a very 'wavy' appearance from glass sheet to glass sheet along the length of the canopy. Even if the safety criteria is met, the deflection of the glass under its own weight usually becomes the deciding factor in determining glass thickness, which may be greater than that required for safety in order to achieve a crisp, straight edge. The glass may

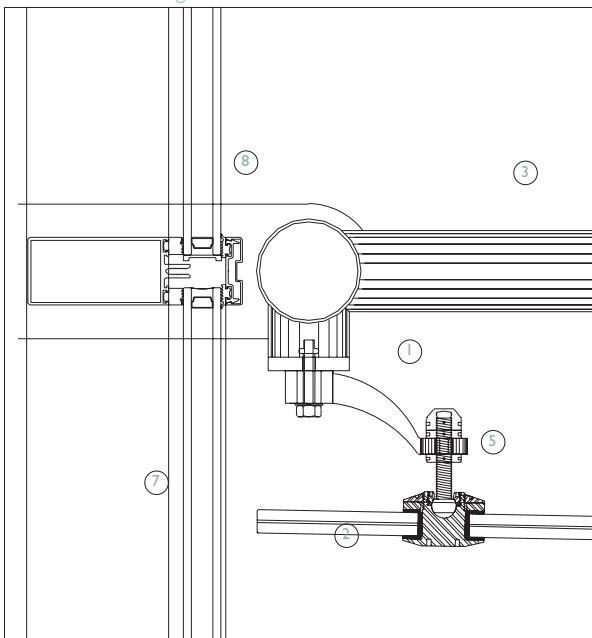
also be coloured or patterned by a screen printed process in order to provide solar shading, or simply a degree of opacity in order to conceal dust that would accumulate on top of the glass. The canopy as shown in (A) drains forward and discharges water over its front edge. A more typical canopy design would slope back to the building and drain into a gutter that is either visible or is concealed within the facade.

In the generic example, each bolt fixing is first attached to the glass using the method described in the first section on bolt fixed glazing in this chapter. The bolt fixing has a ball bearing joint inside the assembly which allows it to swivel up to around 12° in order to accommodate structural movement in

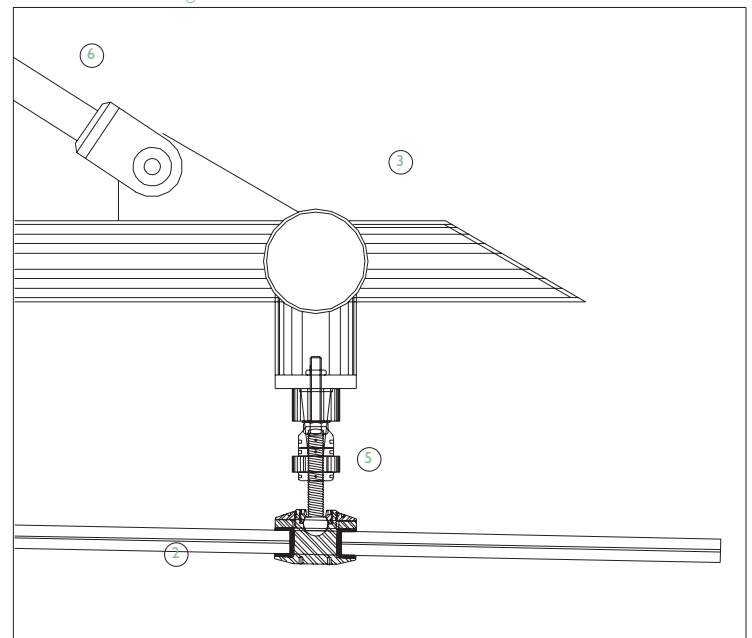


Plan 1:5. Bolt fixing details

Section 1:5. Bolt fixing details



Section 1:5. Bolt fixing details

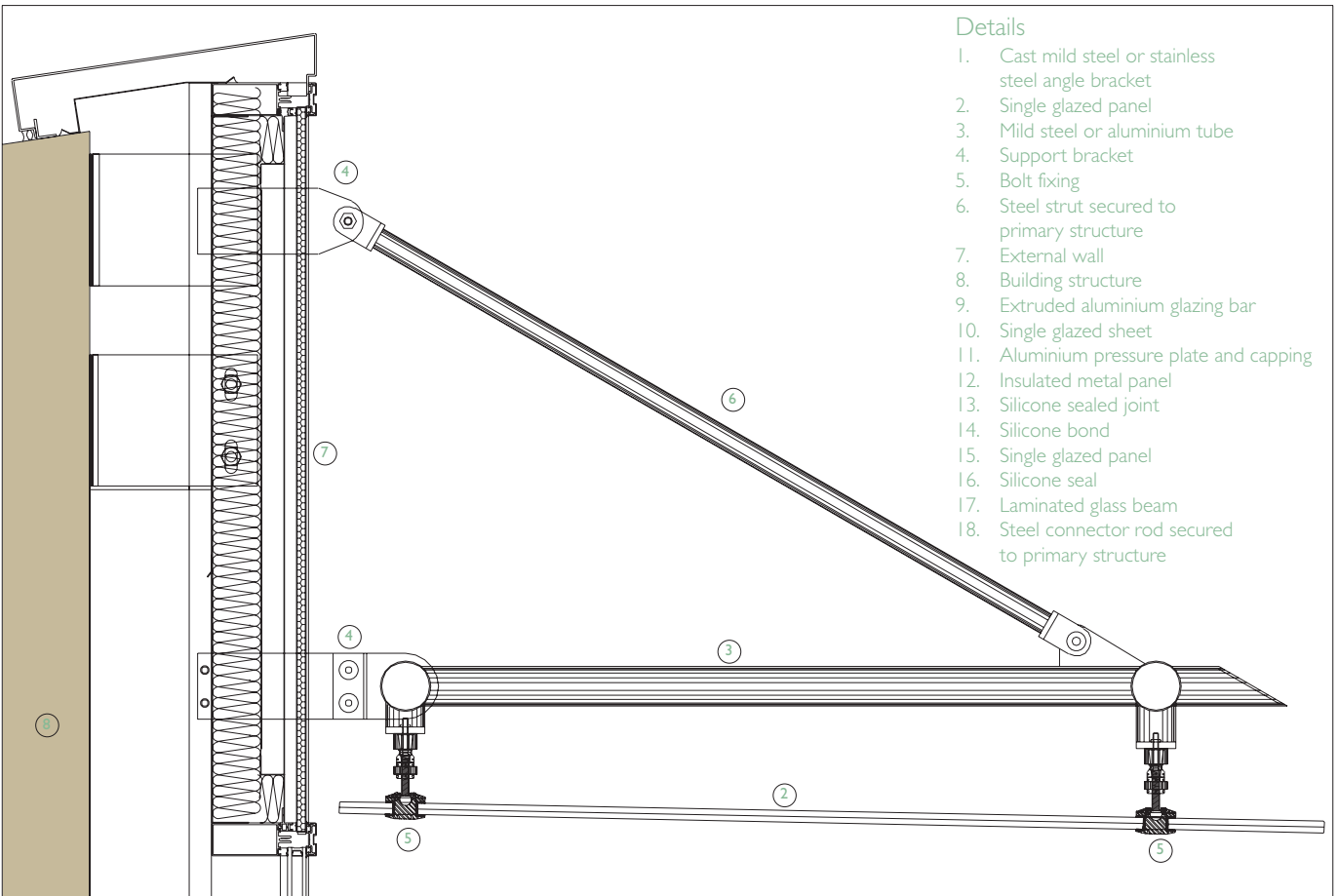


the supporting frame. The threaded shank of the bolt fixing is then fixed to the connector, which is shown as a cast steel bracket. Castings usually require some buffing after manufacture to remove the rough edges and uneven pitting as a result of the sand casting method normally used. When a semi-smooth finish is attempted, the results usually look very uneven. As a result, bolt fixing castings are either lightly buffed, or fully polished. If mild steel is used, the casting is usually buffed smooth, then painted. If stainless steel is used, the casting either has a light buff or is polished to either a brushed finish, which is not very reflective, or a fully polished finish, which is highly reflective. In the generic example, it is assumed that the supporting frame of

welded tubes is in painted mild steel and that the curved support arm is of polished stainless steel. The bolt fixing is made from polished stainless steel as is usually the case for all glazed roofs and glazed walls that use this technique. A separating pad, such as a nylon washer, is set between the stainless steel bracket and the mild steel frame to avoid corrosion between the two metals. The bolt securing the arm to the supporting frame is also made from stainless steel. This combination of materials gives a visual contrast between the two types of metal, but the choice of materials, other than for the bolt fixing itself, is a matter of individual design. The glass size here is 1500mm x 1500mm, with approximately 12mm thick

laminated glass used, but the glass thickness is determined for each application.

An alternative to drilling the glass sheets is to clamp the glass sheets together as shown in the photographs of a canopy at Heilbronn Train Station in Germany by Auer und Weber / Schlaich Bergermann. The glazed is clamped using a technique similar that used for glazed walls (as described in *Modern Construction Facades*). The glass sheets are bolted together with disc-shaped clamps set in the joints between the glass. In this example the discs are set at the intersection of four panels, but this reduces the size of each glass panel that can be used when compared to placing the fixing away from the corners. By fixing the clamps on all

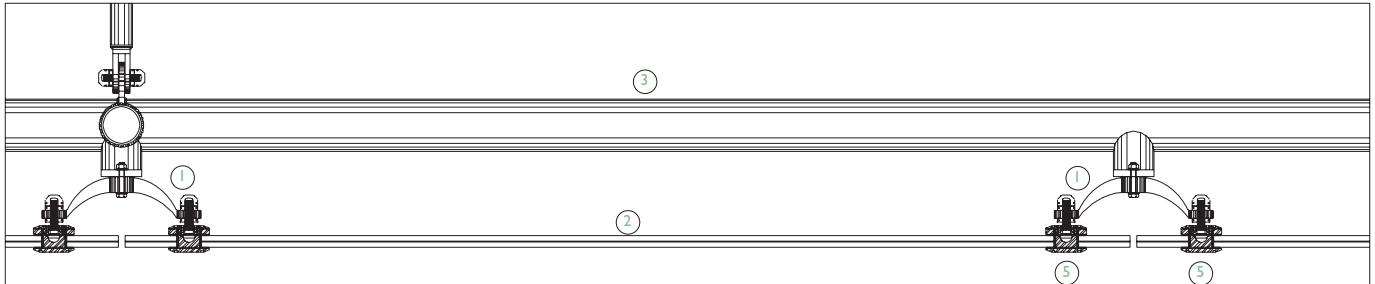


Details

- 1. Cast mild steel or stainless steel angle bracket
- 2. Single glazed panel
- 3. Mild steel or aluminium tube
- 4. Support bracket
- 5. Bolt fixing
- 6. Steel strut secured to primary structure
- 7. External wall
- 8. Building structure
- 9. Extruded aluminium glazing bar
- 10. Single glazed sheet
- 11. Aluminium pressure plate and capping
- 12. Insulated metal panel
- 13. Silicone sealed joint
- 14. Silicone bond
- 15. Single glazed panel
- 16. Silicone seal
- 17. Laminated glass beam
- 18. Steel connector rod secured to primary structure

Cross section 1:10. Typical assembly

Long section 1:10. Typical assembly



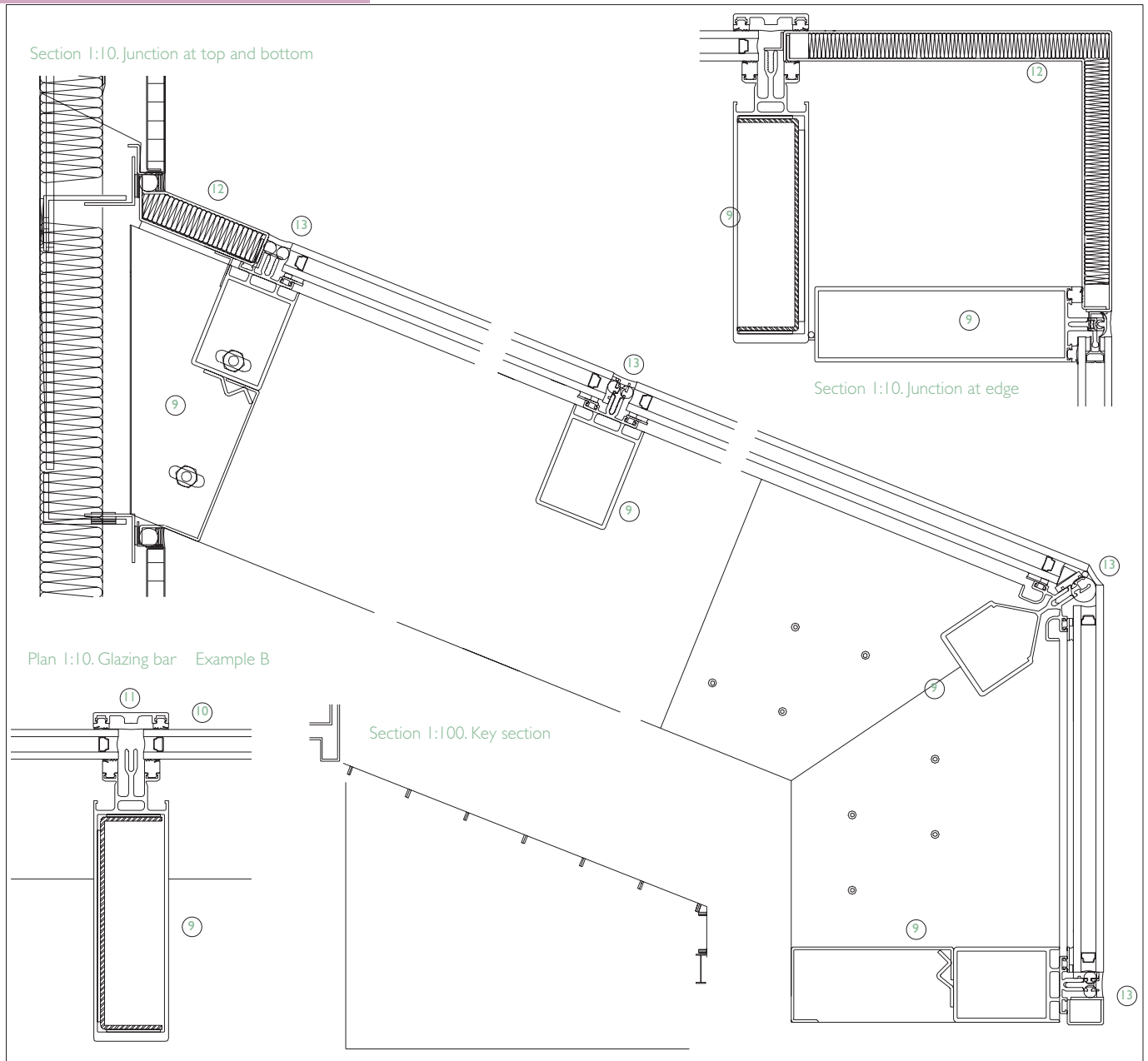
four sides, away from the corners, the distance between clamps is the same, but this allows larger panels to be used. In this example, the glass clamps are hung from a cable structure which is secured to a tubular mild steel supporting frame. Because the glass is fixed at the corners rather than away from the edges, as used in the bolted fixed canopy example, the distance between fixings increases, which usually makes the glass thickness greater for the clamped solution than that which would be required for the bolt fixed solution. But this increase in material cost is compensated by the saving made in not having to drill the glass to receive the bolt fixings.

Four edge restrained canopy

An alternative to the bolt fixed method is to use the more established method of glazing bars which capture the glass with pressure plates using the technique described in the second section of this chapter: Glazing bars with pressure plates and cover caps are set in the direction down the slope of the roof, while joints running across the slope of the roof have silicone seals which are flush with the top surface of the glass in order to allow rainwater to run down the roof. The rainwater is allowed to discharge freely from the roof and is terminated without a gutter at its lowest point depending on the size of the glass. Sometimes a gutter is provided along the bottom

edge of the canopy to avoid a sheet of rainwater falling onto building users passing underneath, but the ends of the gutter are open, serving as water spouts that freely discharge the rainwater to the ground below. This avoids the need for rainwater pipes that often do not suit the visual qualities of glazed canopies.

The glass size shown for the drawn generic example (B) is 1700mm wide x 1000mm long in 12mm thick glass. As with all these examples of glazed canopy, the glass sizes are for indicative purposes only, and are calculated for each application. In (B) the top of the glazing is terminated in an insulated metal panel which is sealed by a flashing to the external wall above. It is assumed that



the sloping rafters are supported at their base on a beam, and that the top end is fixed with metal brackets back to the building structure or to the external wall above. The rafters forming the sloping beams are shown fixed rigidly at the bottom of the steel beam, and have a sliding connection at the top in order to allow for structural movement in the rooflight frame. Generally, canopies using this captured glazing technique use the technique developed for rooflights of similar construction.

Bonded glass canopies

The most recent development in glazed canopies has been the use of all-laminated glass structures where glass beams are bond-

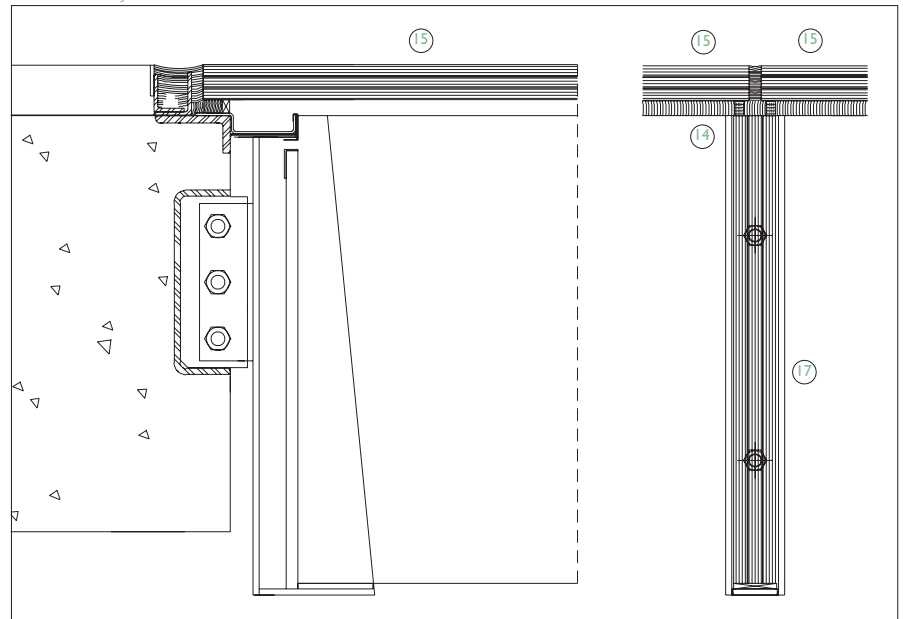
ed to glass sheets to give a canopy structure with no visible metal fixings. In generic example (C) a series of laminated glass beams are cantilevered from a supporting floor slab or reinforced concrete wall. The beams are cantilevered from mild steel brackets which are bolted to the building structure. An L-shaped bracket is set either side of each glass beam and the beam is clamped in place by bolts that pass through holes in the glass. This technique is now well established, and fixing tolerances achieved are very close, allowing the bracket to be exposed visually as an elegant connection within the assembly. The canopy here is shown projecting 1500mm from the edge of the adjacent glass roof, though much longer spans have been

achieved in bonded or 'structural' glass canopies already constructed. The laminated glass sheets forming the top of the canopy are bonded to the top of the glass beam, the beams being made wide enough to provide sufficient bearing for the two abutting sheets of glass. Since three thicknesses of glass are usually required for structural safety, the bearing of the glass is a minimum of 10mm. The joint between the glass sheets is sealed with a sealing silicone rather than the bonding silicone used between beams and flat sheet. The use of silicone as a bonding material allows the canopy structure of glass beams and sheets to form a rigid structure that requires no additional support.

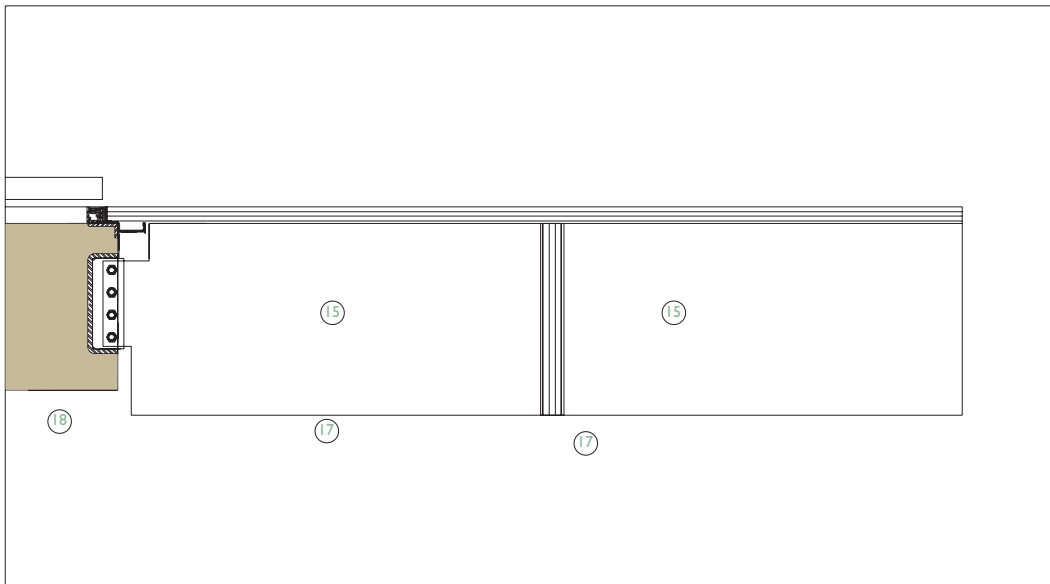
In the generic example (C), the canopy



Section I:10. Junction with structure



Section I:25. Typical assembly Example C



Details

1. Cast mild steel or stainless steel angle bracket
2. Single glazed panel
3. Mild steel or aluminium tube
4. Support bracket
5. Bolt fixing
6. Steel strut secured to primary structure
7. External wall
8. Building structure
9. Extruded aluminium glazing bar
10. Single glazed sheet
11. Aluminium pressure plate and capping
12. Insulated metal panel
13. Silicone sealed joint
14. Silicone bond
15. Single glazed panel
16. Silicone seal
17. Laminated glass beam
18. Steel connector rod secured to primary structure

is sealed against a metal flashing forming the vertical face of a parapet upstand. The glass is shown continuing over the upstand to form a glass coping. The vertical edge of the adjacent gutter, formed either in sheet metal or in a single layer membrane, is sealed to the glass with a compatible silicone. An additional second silicone seal is provided behind this outer seal to form a second line of defence against rainwater penetration. The top of the glass, where it passes over the coping, is fritted with an opaque screen print to conceal the silicone seal below. The void immediately below the glass is ventilated to avoid a heat build-up between the glass and the top of the coping below, which would otherwise cause breakage of the glass as a

result of thermal stress imposed by heat from the sun.

The use of coloured interlayers in laminated glass has led to the increased use of bonded glass canopies as translucent structures rather than fully transparent ones. The visual benefit of having no visible metal fixings allows the translucent structural members to take full visual priority over the bolt fixings or glazing bars used in other glazing techniques. The range of interlayer colours available has increased dramatically over the past two or three years, allowing gradual changes in tone and colour from beam to beam and from sheet to sheet, where required. The number of interlayers used in laminated beams can also be varied from

beam to beam. By increasing the number from one interlayer to four interlayers in successive beams, the same colour can be used to change the tone within the same colour to give a range of graded visual effects. The maximum number of interlayers recommended by glass manufacturers is usually four in a single lamination, but five interlayers have been used successfully in some applications. The use of coloured interlayers in laminated glass is set to develop over the next five years as interlayer manufacturers fabricate this material with specific shading coefficients, or g-values, in order to promote their use as a method of solar control shading.

3

CONCRETE

(1) **Concealed membrane**

System assembly

Framing profiles

Opening lights

Parapets, cills, penetrations

Corners

(2) **Exposed membrane**

System assembly

Framing profiles

Opening lights

Parapets, cills, penetrations

Corners

(3) **Planted**

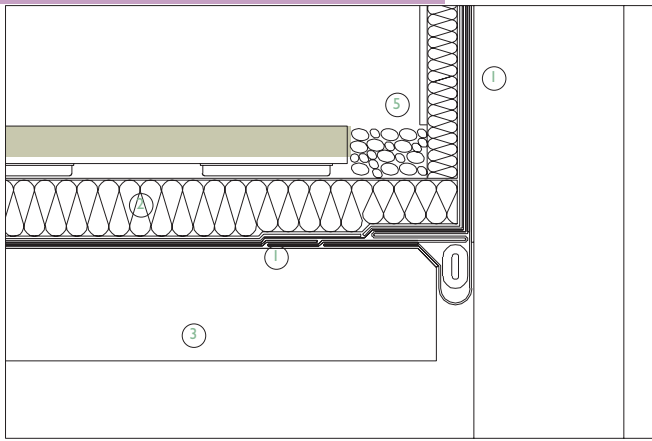
System assembly

Framing profiles

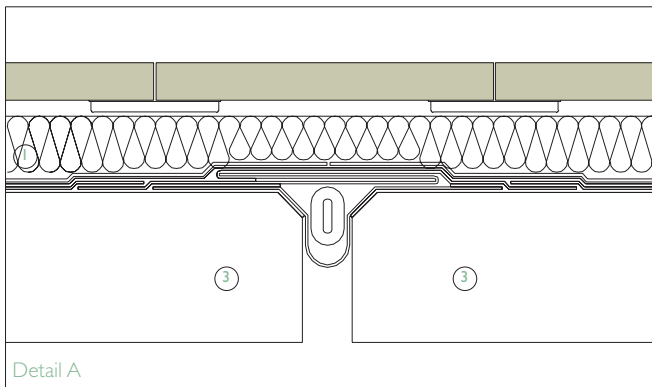
Opening lights

Parapets, cills, penetrations

Corners

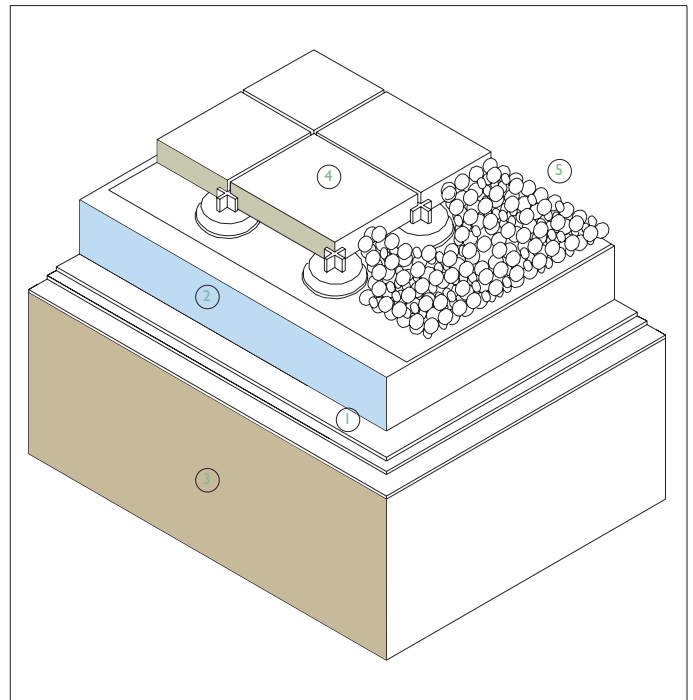
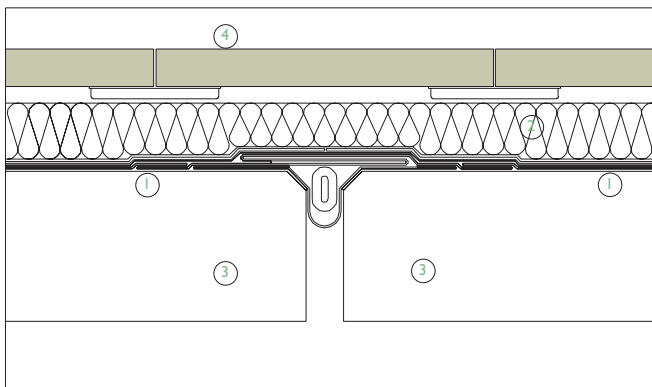


Section 1:10. Junction of external wall and roof slab



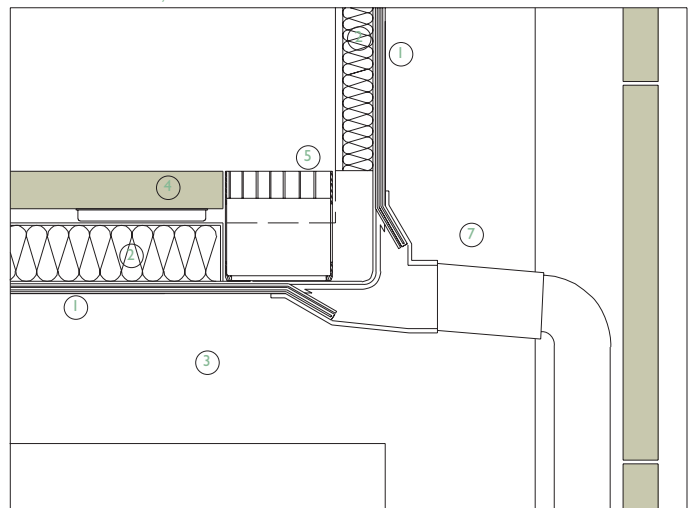
Detail A

Sections 1:10. Expansion joint in concrete slab



Isometric view of assembly

Section 1:10. 2-way drain outlet Detail L



Materials

Bitumen has traditionally been used as a waterproof layer, applied while hot in liquid form onto a concrete roof slab. As it cools it hardens, forming an impervious membrane, but will soften again if heated by the effects of solar radiation. For this reason, in order to keep the material cool, bitumen membranes are concealed by smooth pebbles, paving slabs, usually with thermal insulation set between the bitumen and the pebbles/paving. Traditional bitumen roofs are usually laid in two layers, with an overall thickness of around 20mm. One of the limiting factors with bitumen is folding the material through a right angle. When the material turns through a right angle from the hori-

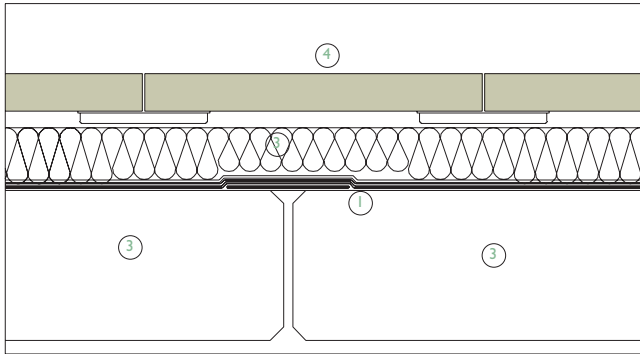
zontal roof to a vertical parapet wall, it can pass through a maximum of 45° in a single fold. For this reason 45° angle fillets are used to make a 90° turn from roof to wall.

Modern bitumen-based membranes that are concealed beneath roof finishes are typically a combination of bitumen-based sheet mixed with synthetic rubber to give flexibility combined with a reinforcement to give dimensional stability and tensile strength. This reinforcement often allows the material to be folded through 90°, making its use considerably easier, where angle fillets are not required.

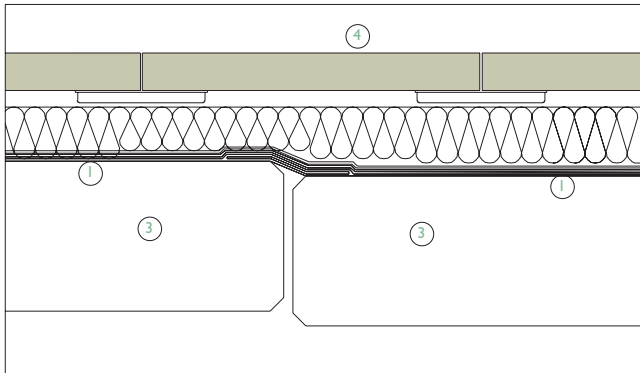
With the development of much thinner membranes in thermoplastics and elastomers, together with their competitive

costs, there have been considerable efforts made by manufacturers over the past 20 years to make the bitumen layers thinner, to reduce the material required while enhancing its properties of strength and flexibility. This has been achieved by replacing the thick 2-layer method with a mixture of thin layers, still applied in hot liquid form on site, but reinforced with an elastomeric sheet, usually bedded between the layers. This is typically two layers, each 3mm thick with reinforcing layers bedded into the material. This allows the bitumen to accommodate both small amounts of movement at these junctions, as well as the sharp fold in the material, which creates a weakness in the membrane which might otherwise be damaged during the life

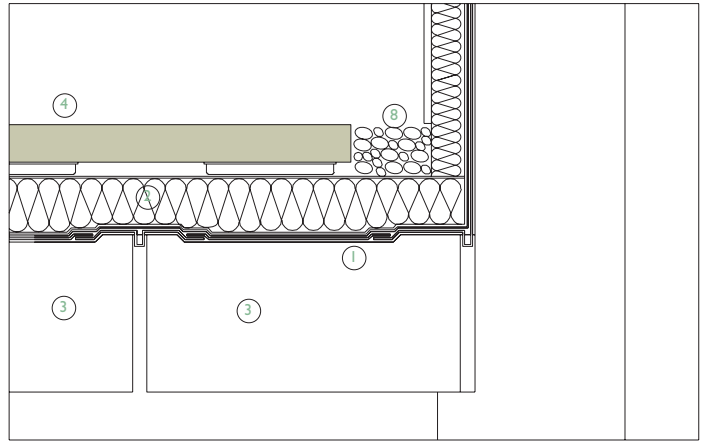
Section 1:10. Expansoin joint in concrete slab Detail B



Section 1:10. Expansoin joint in concrete slab Detail C



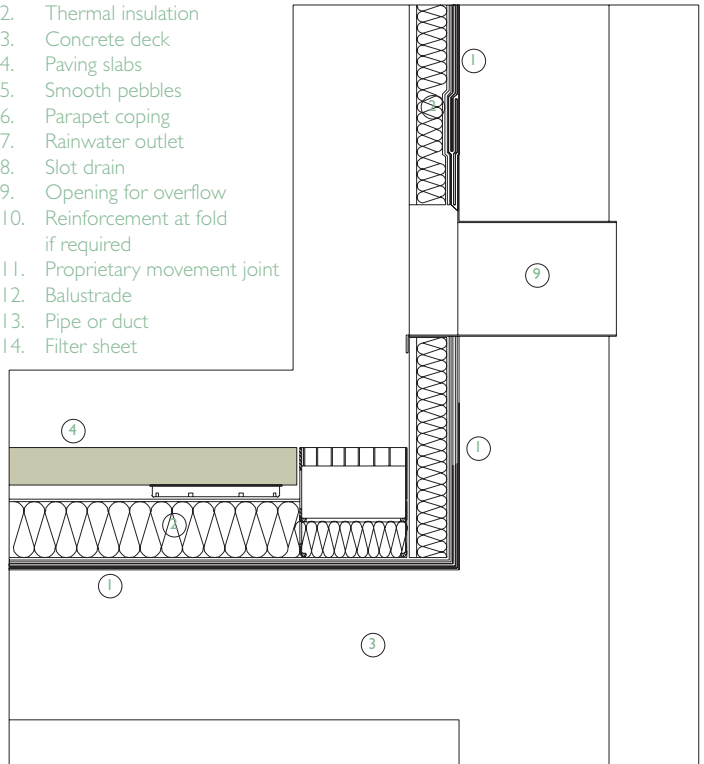
Section 1:10. Junction of external wall and roof with slot drain



Details

1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Slot drain
9. Opening for overflow
10. Reinforcement at fold if required
11. Proprietary movement joint
12. Balustrade
13. Pipe or duct
14. Filter sheet

Section 1:10. Junction of external wall and roof with overflow



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of the building. An outer protective layer is added for vulnerable locations such as at gutters and at upstands.

Concealed membrane roofs are increasingly being laid flat with no fall, unlike exposed membranes, where a slight fall is always required. This is partly because bitumen bonds more reliably to a concrete slab than to a thin screed, and partly because the slopes required to create falls in large areas of flat roofs create difficulties in level changes across the roof which can be difficult to drain. The more traditional methods of screeds laid to falls and thick layers of bitumen is used where the roof finish is sealed, such as paving with sealed joints.

Typically upstands are formed before the

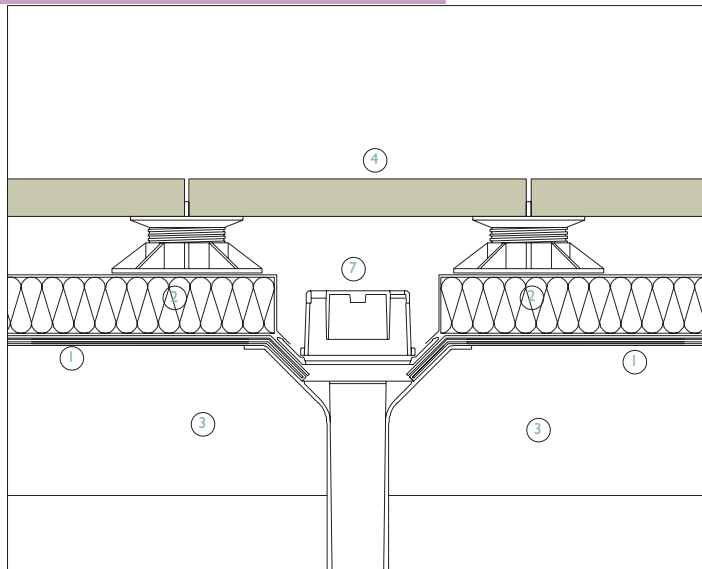
main areas of roof are waterproofed in order to allow external walls to be completed. When an area is completed, the roof deck is waterproofed and finished, with areas of flat roof being bonded continuously to the already completed upstands. This avoids the need to protect the membrane, which has attendant risks of being damaged before the building is finished.

Concealed membrane roofs are typically in 'inverted' roof configuration with either open joints or sealed joints in the top layer that covers the thermal insulation, usually paving. In the open joint version, the membrane, bonded to the concrete slab, is covered by a protection layer; with closed cell, rigid thermal insulation set on top. A poly-

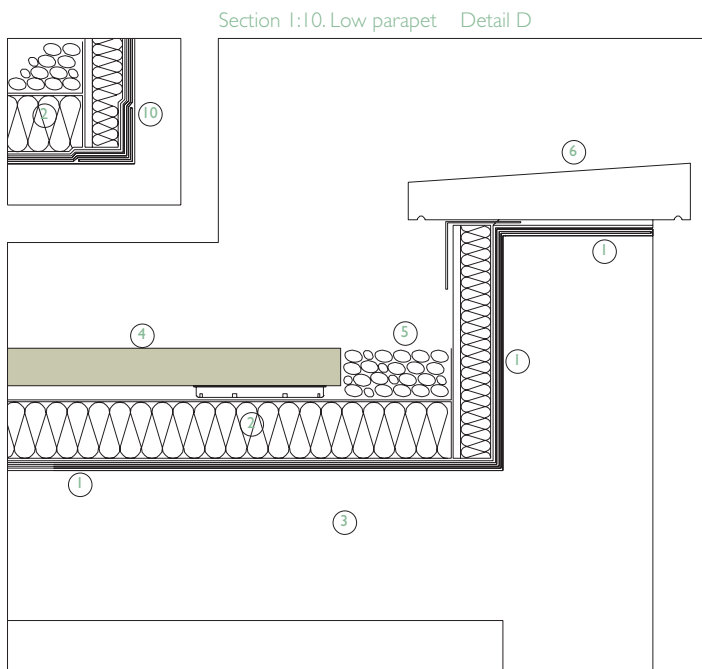
ester filter sheet is set on top, with paving or smooth pebble ballast on top to hold the insulation in place as well to walk on. Pebbles are 20mm - 40mm diameter; while paving slabs are around 600 x 600mm in size, 30mm - 40mm deep. In the sealed joint configuration, the bitumen membrane with its protection layer has a drainage layer on top, onto which is laid a minimum 65mm sand/cement screed, usually reinforced or made sufficiently thick to avoid cracking both in the screed and the sealed paving above. Paving slabs or blocks are bonded to the screed with mortar and grouted.

Structural joints

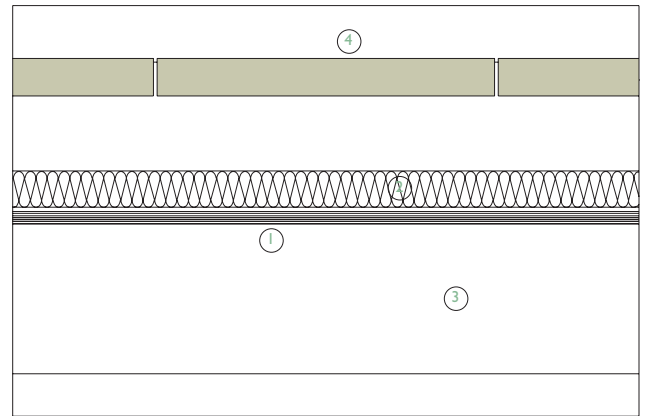
The main advantage of concealed mem-



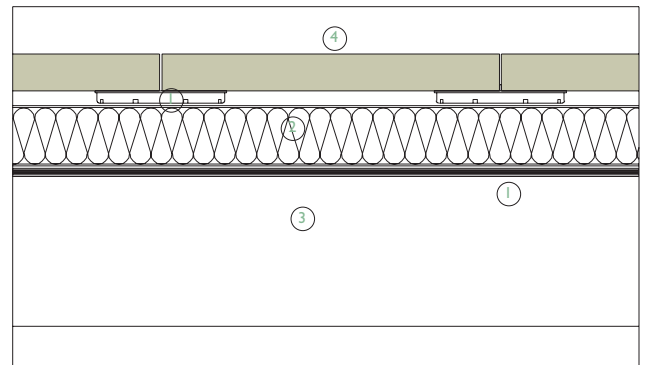
Section 1:10. Rainwater outlet Detail H



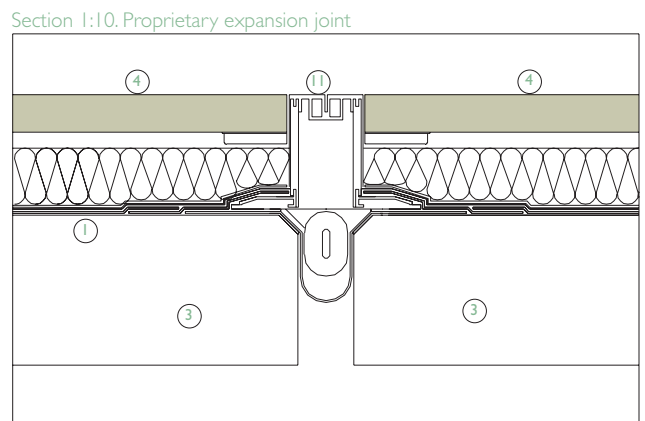
Section 1:10. Low parapet Detail D



Section 1:10. Open jointed paving



Section 1:10. Sealed paving



Section 1:10. Proprietary expansion joint

branes is their ability to span movement joints and expansion joints in reinforced concrete slabs with simple, reliable details that require no upstands to form the junction. Expansion joints between concrete slabs of widths between around 10mm to 50mm are formed by stopping the material each side of the joint and setting a rubber-based strip that dips into the gap between the slabs as (A), linking the membranes into a continuous seal. As the gap between the slabs varies with structural movements, the rubber-based strip is allowed to move without being stretched significantly. The joint is protected and reinforced with an additional layer, either flat and bonded on one side only, or formed as a folded, S-shaped cover that folds back over

itself, held in place by an additional protection sheet on top. The gap between the membrane, dipped into the joint, and the reinforcement cover is filled with a foam backing rod or tube, as used in the glass joints of bolt fixed glazing. The material used for the reinforcement is either the same bitumen based material, or increasingly, a rubber-based strip.

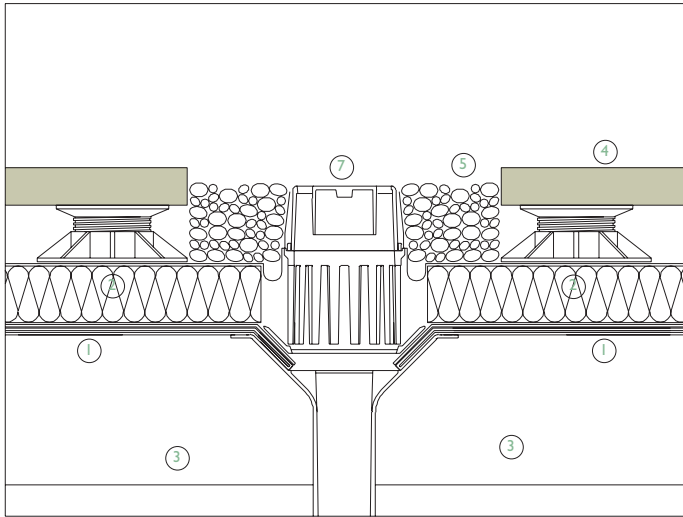
The top of the joint is finished as level as possible with the adjacent areas of roof to allow water to drain freely from the roof. The reinforcing membrane is sometimes folded down into the gap, separated from the membrane below with a foam backing rod. It can be difficult to drain water from this groove at the edge of the slab unless

water at this lower level can discharge into a rainwater outlet.

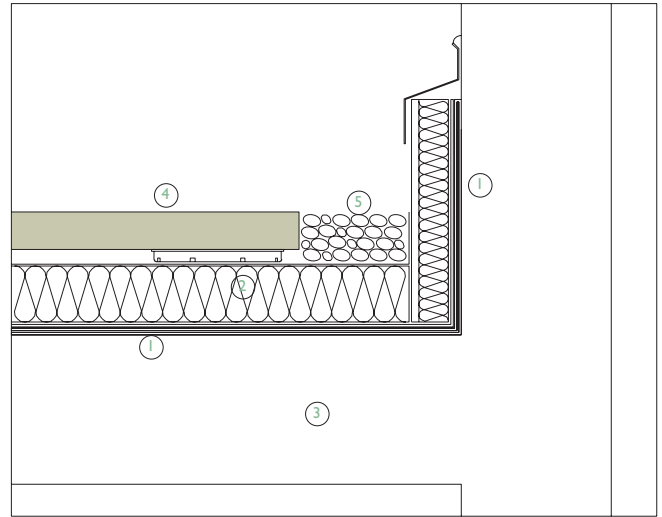
Junctions between concrete roof slabs and walls are treated in a similar way, with the membrane dipping down into the gap between wall and roof and the membrane continuing up the wall. Reinforcement is similarly applied, with a rubber-based strip folded through the 90° corner rather than the maximum 45° folds that are usually allowed in traditional bitumen-based membranes.

Proprietary metal-based expansion joints are used to form part of the visible finishes, typically with sealed roof finishes. In this case the seal is formed by bonding a strip of membrane to the metal assembly. The metal expansion joint assembly is fixed on top of

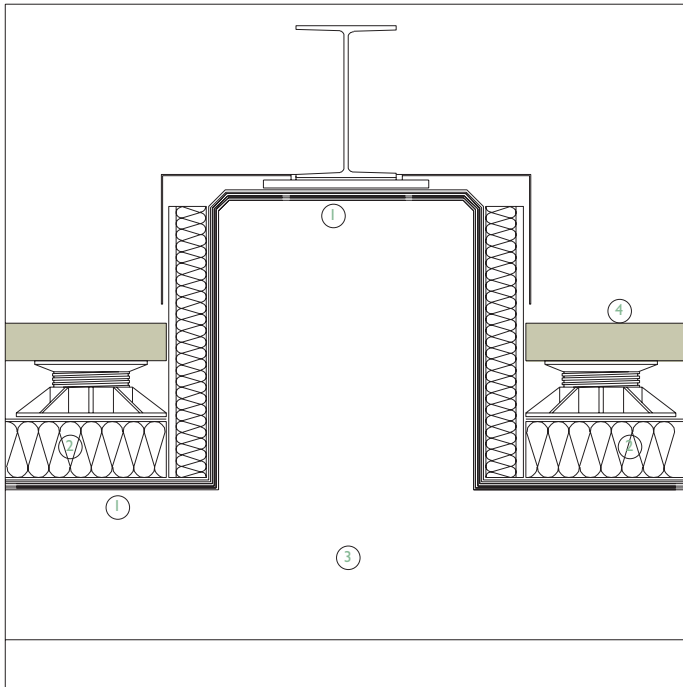
Section 1:10. Rainwater outlet Detail J



Section 1:10. Junction of external wall and roof slab



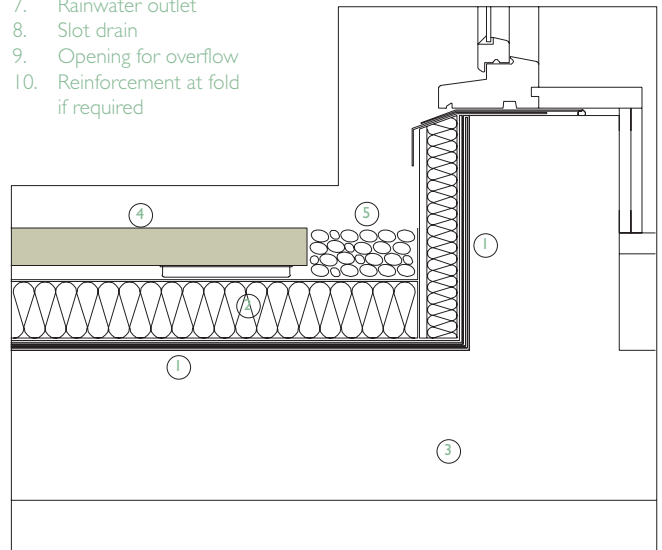
Section 1:10. Plinth



Details

- | | |
|---------------------------------------|--------------------------------|
| 1. Waterproof membrane | 11. Proprietary movement joint |
| 2. Thermal insulation | 12. Balustrade |
| 3. Concrete deck | 13. Pipe or duct |
| 4. Paving slabs | 14. Filter sheet |
| 5. Smooth pebbles | |
| 6. Parapet coping | |
| 7. Rainwater outlet | |
| 8. Slot drain | |
| 9. Opening for overflow | |
| 10. Reinforcement at fold if required | |

Section 1:10. Door sill Detail E



the membrane, which still dips down into the joint. A foam backing rod is set on top of the dipped membrane and is covered with a bed of compatible sealant to ensure that any water that penetrates the movement joint is drained to the sides of the movement joint. The waterproof membrane is then formed up out the base of the movement joint assembly to provide a complete seal across the joint.

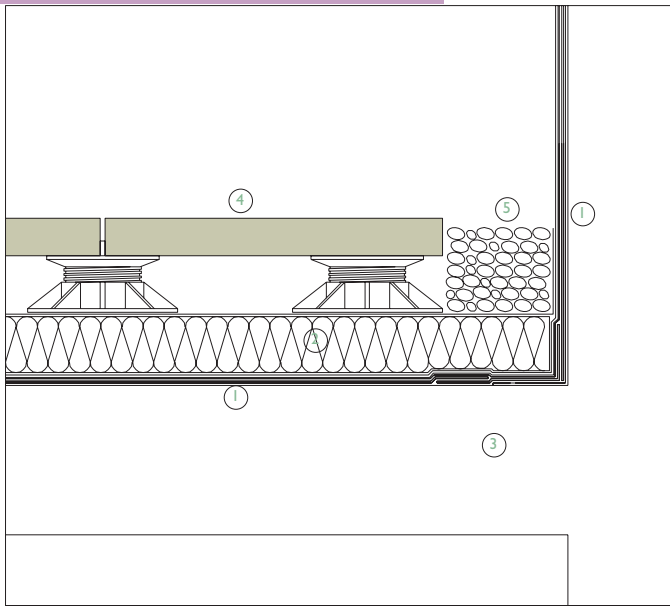
Joints between concrete panels, such as precast concrete slabs, where only negligible structural movement is expected, are also formed with rubber-based strips. The membrane forms a continuous lapped joint across the rubber-based strip, as (B) and (C), with a foam backing rod being provided

where there is a risk of damage during construction.

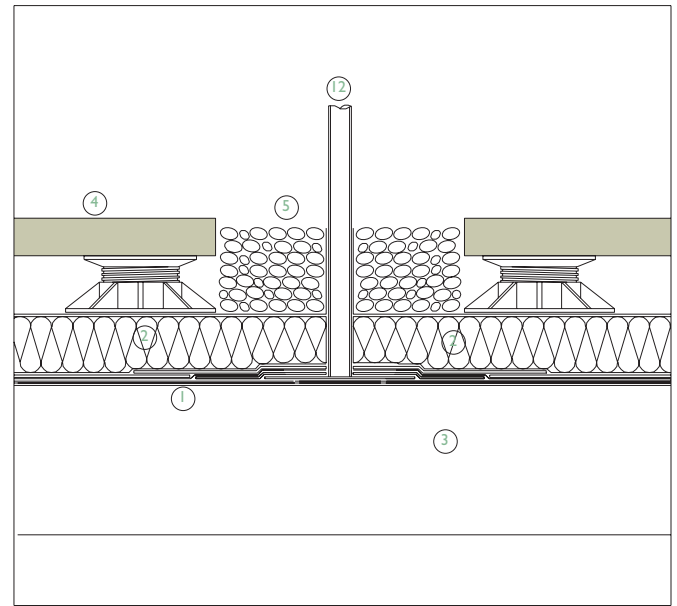
Parapet upstands

In forming parapet upstands, an essential requirement is to keep the waterproof membrane as well protected from the effects of the sun as elsewhere on the roof. For this reason, thermal insulation is applied to the inside face of the parapet even if this has no direct benefit to the passage of heat through the building. The membrane is turned through a full 90° as shown in the drawings, but an angle fillet is required by some manufacturers to limit the angle of any fold to 45°. A reinforcing strip is usually added where a 90° fold is made.

In (D) a low parapet wall is terminated by a concrete or stone coping. The waterproof membrane extends up the height of the upstand, which runs horizontally to form a full damp proof course underneath the coping. This ensures that the membrane provides a continuous waterproof layer at the junction with the external wall. An additional metal flashing to cover the top of the metal faced insulation to protect the junction between the top of the metal facing to the insulation, and the insulation itself. In (D) an open jointed arrangement of paving slabs is shown, with rainwater draining at the level of the membrane. To assist with the drainage of the rainwater from the parapet coping, a strip of pebbles is shown. This avoids staining

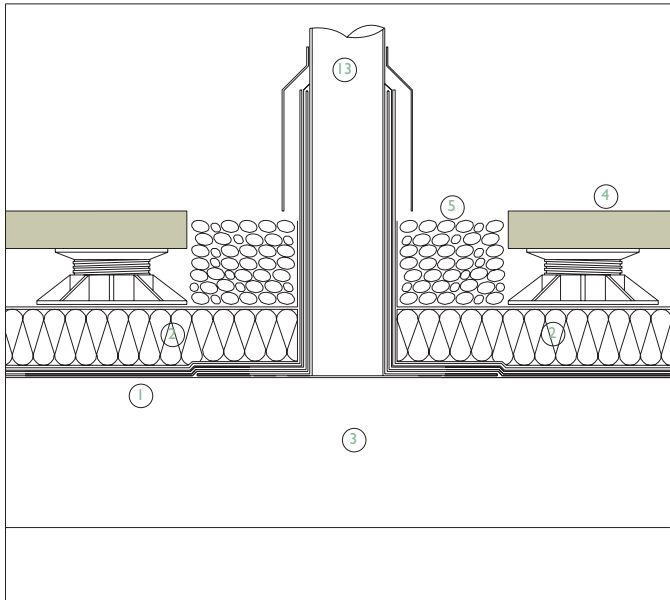


Section 1:10. Junction of external wall and roof slab

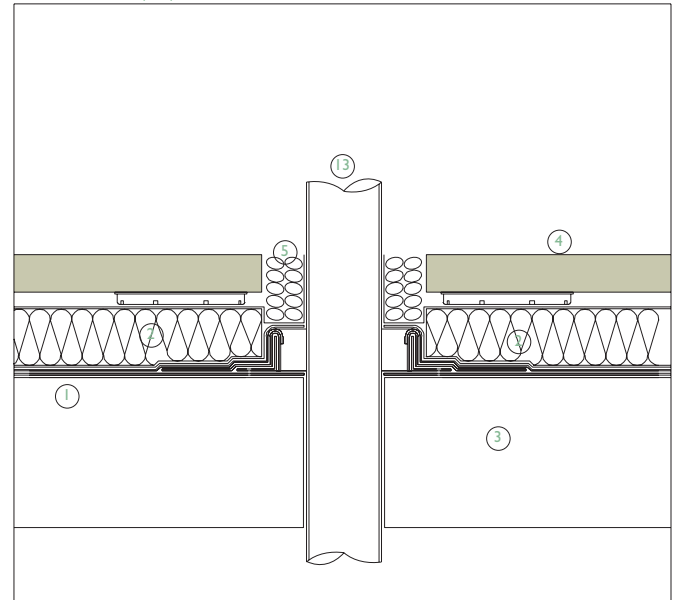


Section 1:10. Base of balustrade Detail F

Section 1:10. Base of balustrade



Section 1:10. Pipe penetrations



of the roof level paving where it meets the parapet upstand by allowing rainwater running off the inside face of the parapet coping to drain through the pebbles to the membrane beneath. In (E) the paving is shown continuing up the parapet upstand. Since the sill to the external door shown in the detail covers the opening, and is supported from the base of the opening, the waterproofing is shown stopping at the edge of the opening. As can be seen from these two details, the termination of the membrane varies with each situation.

Balustrades and plinths

The balustrade post shown in (F) is fixed to a base plate which is set onto the finished

waterproof membrane. The balustrade base plate is bolted through the membrane to the concrete slab below. If the membrane has an additional protection layer, then this is usually omitted around the base plate to give a more reliable seal. An additional membrane is then laid on top of the base plate with the protection layer. Alternatively, a rubber-based seal is bonded to the top of the base plate to provide a secondary seal to the penetrations in the membrane formed by the bolts securing the base plate. The polyester filter sheet, set loose laid on top of the insulation in the detail, is wrapped around the balustrade post below the level of the paving.

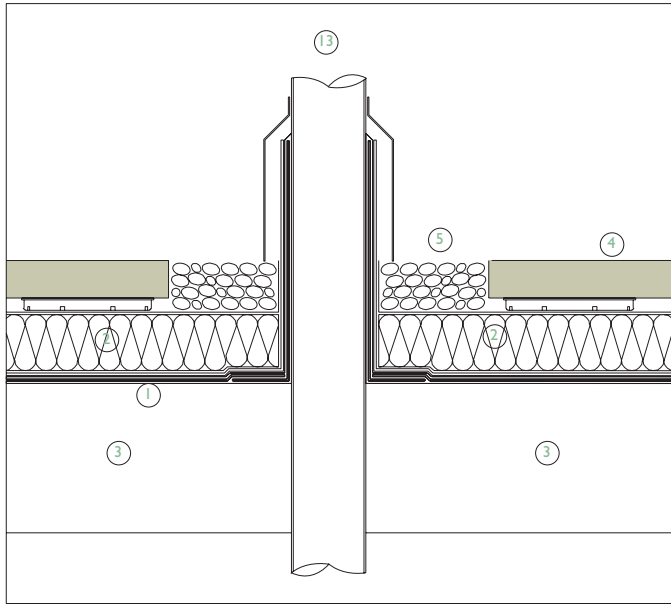
Plinths which are formed as short

columns for the support of roof-mounted mechanical equipment are waterproofed in a similar way to a parapet upstand. The membrane is folded up through 90° from the roof level and is formed to cover the complete plinth. Detail (G) shows a rail supporting an I-section that would support an air handling unit or a rail for a cleaning cradle trolley. The thermal insulation extends across the complete plinth to prevent a thermal bridge through the roof construction.

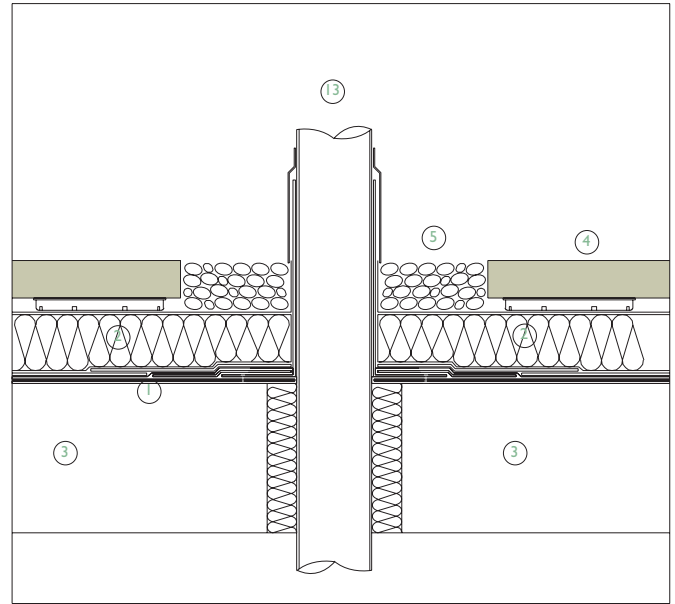
Rainwater outlets

The rainwater outlets shown in (H) and (J) are set at the level of the waterproof membrane, with that shown in (J) is shown drained at both the level of the sealed

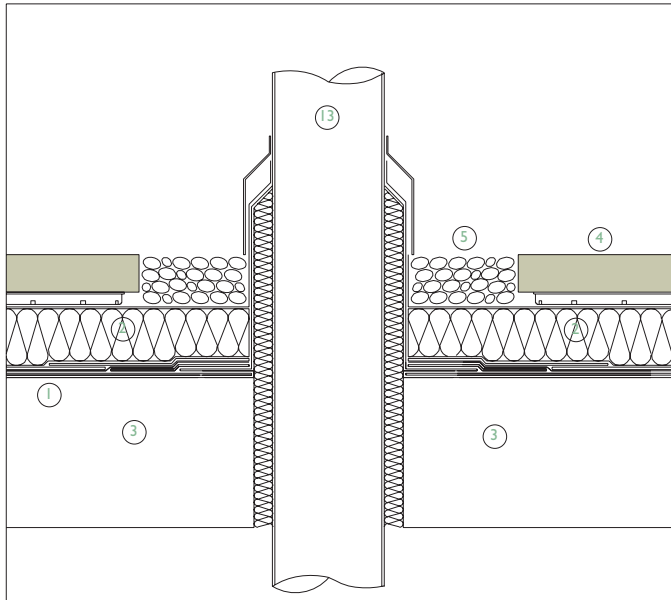
Section 1:10. Pipe penetrations



Section 1:10. Pipe penetrations Detail N



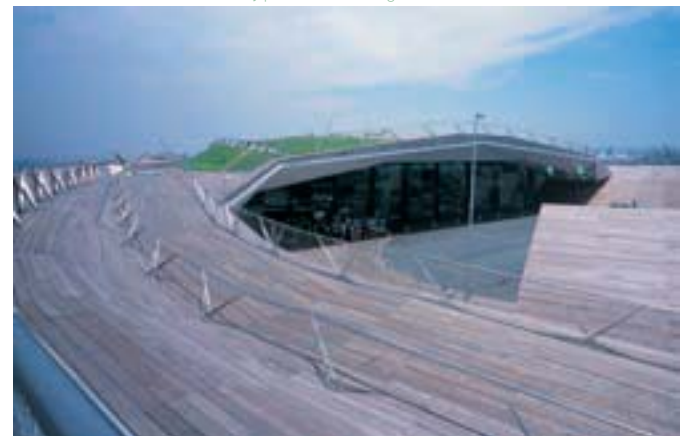
Section 1:10. Pipe penetrations Detail M



Details

- | | |
|------------------------|---------------------------------------|
| 1. Waterproof membrane | 8. Slot drain |
| 2. Thermal insulation | 9. Opening for overflow |
| 3. Concrete deck | 10. Reinforcement at fold if required |
| 4. Paving slabs | 11. Proprietary movement joint |
| 5. Smooth pebbles | 12. Balustrade |
| 6. Parapet coping | 13. Pipe or duct |
| 7. Rainwater outlet | 14. Filter sheet |

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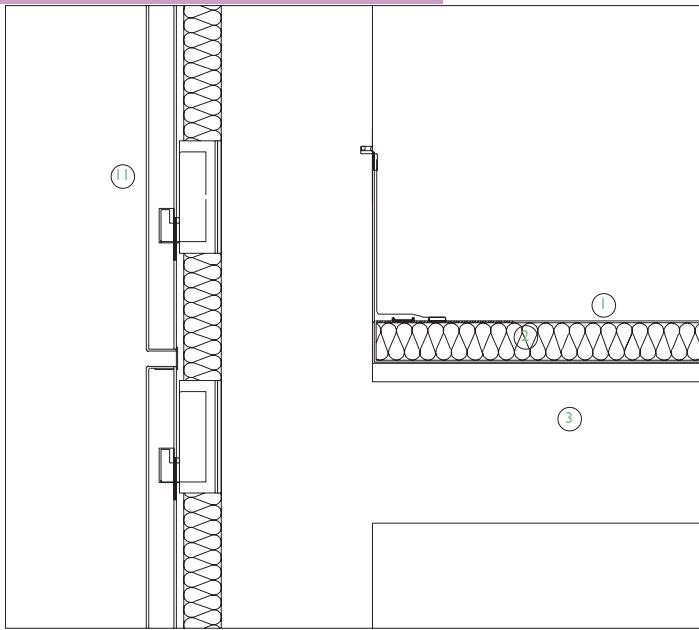
paving and the level of the waterproofing layer. In (H) the base of the rainwater outlet is fixed to the concrete slab. The waterproof membrane is dressed down into the top of the rainwater outlet and the upper part of the rainwater outlet is bolted down onto the part already fixed and sealed. The geotextile sheet is wrapped around the outlet to avoid dirt and debris being washed into the rainwater drainage system. In (J) the rainwater outlet is fixed in the same way, but the cover is much lower; since rainwater is drained only at the edges of the cover, and not through its full height as is the case in (H). In (J) the filter sheet is tucked down into the edges of the rainwater outlet. Because of its concealed position, the rainwater outlet

requires regular visual inspections by lifting up the paving slab immediately above to remove any debris that might collect in the gap between the rainwater outlet and the thermal insulation adjacent to it.

The rainwater outlet in (L) is used increasingly to drain roof terraces into external rainwater pipes fixed to the facade, or to a void immediately behind the facade, without the need for a visible opening in the parapet wall that is visually unappealing. The 2-way outlet is fixed in two parts in the same way as the outlets in (H) and (J). A 25mm gap is shown between the parapet wall and the edge of the paving slab to allow rainwater to drain into the outlet.

Penetrations for pipes and ducts

Penetrations are sealed by either forming an upstand around the opening, or by forming a metal collar around the pipe or duct, similar to the balustrade detail mentioned earlier. Where a concrete upstand is formed, a metal flashing is welded or mechanically fixed and sealed to the penetrating pipe or duct as shown in (M). In (N) a metal sleeve is bolted through the membrane and a reinforcing rubber-based disc is bonded to the top of the base plate. The pipe is set into this sleeve and is sealed with a tension clip at the top of the sleeve. In (M) the pipe flashing detail allows the pipe to be both thermally insulated and independent of the enclosing sealed sleeve.

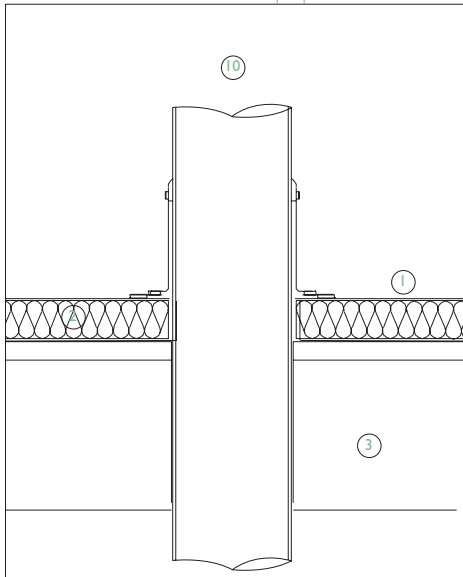


Section 1:10. Bonded method. Junction of external wall and roof slab

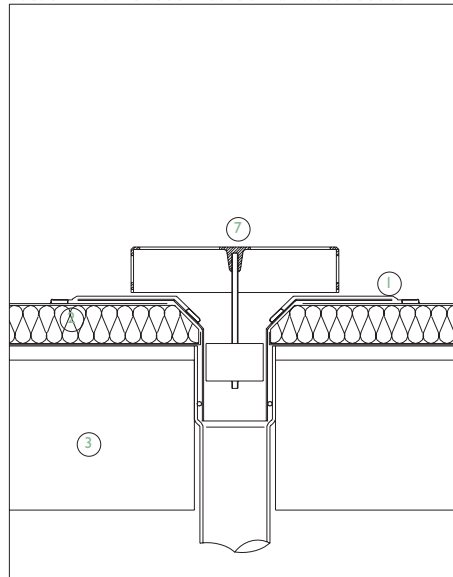


Natural Unit / Studio House. Architect: Masaki Endoh and Masahiro Ikeda.

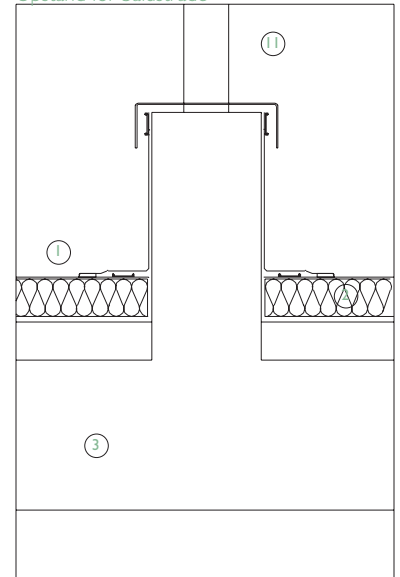
Section 1:10. Bonded method. Pipe penetration



Section 1:10. Bonded method. Rainwater outlet



Section 1:10. Bonded method. Upstand for balustrade



Exposed membranes have been used for flat roofs which are not visible from below, but this has changed in recent years as membranes are produced in increasingly smooth and regular finishes. Because of their lightweight nature, they are often used in conjunction with lightweight roofs such as profiled metal deck and timber. This section considers their use in concrete construction, though the same principles of waterproofing can be applied to these other materials.

It was still commonly the case 30 years ago for exposed membranes on concrete roofs to be made from bitumen or bitumen-based sheet materials. This material was expected to last around 10-15 years, after which time the roof covering should have

been replaced. In practice these roofs were patched up where leaks occurred since it was considered to be a major undertaking to install a completely new roof covering. Damage to the bitumen-based roof materials was typically a result of a lack of flexibility of the membrane that could not easily accommodate thermal and structural movements as well as deflections in the building structure. Although concrete roofs slabs are less susceptible to thermal movement than some other materials, interfaces between wall and roof, or roof and rooflights, for example, would often result in damage to the roof membrane where the roofing sheet continued across the joint at the junction of the two materials. The structural movement

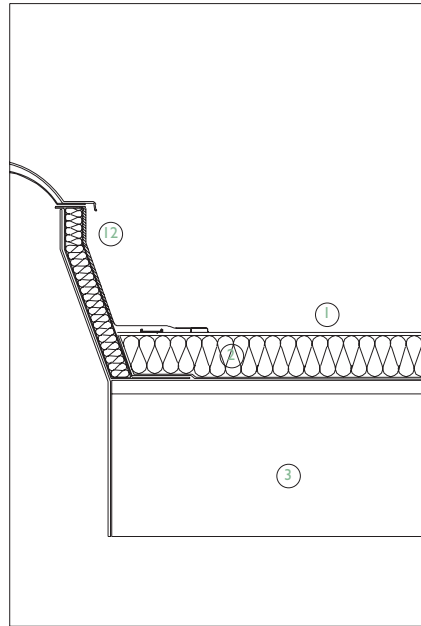
between the roof deck and the adjoining elements would sometimes result in the roofing sheet splitting or tearing, allowing rainwater to penetrate the roof construction. The weakness of these materials was partially overcome by introducing added sacrificial layers. Although this had the advantage of reducing risk of the membrane being punctured by foot traffic during maintenance, this method did not add any substantial strength to the membrane and damage would occur as before.

The introduction of polymer-based membranes provided economic waterproofing materials that were more flexible than their bitumen-based predecessors. First introduced in the 1960's and 1970's, they

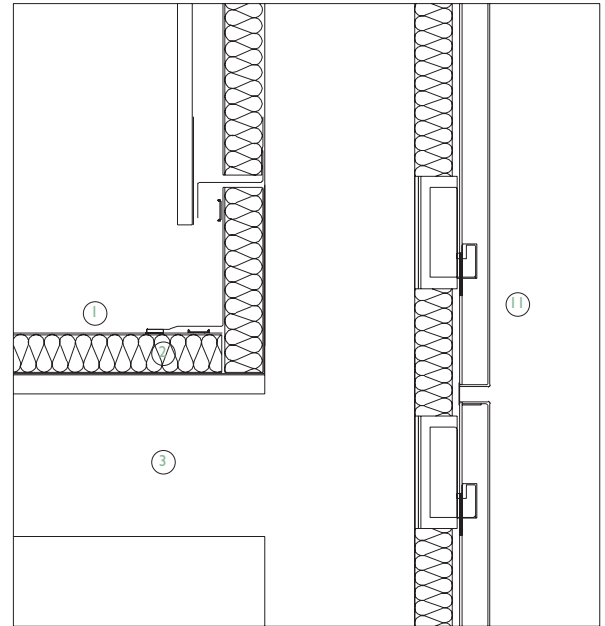
Details

1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Opening for overflow
9. Balustrade
10. Pipe or duct
11. External wall
12. Rooflight

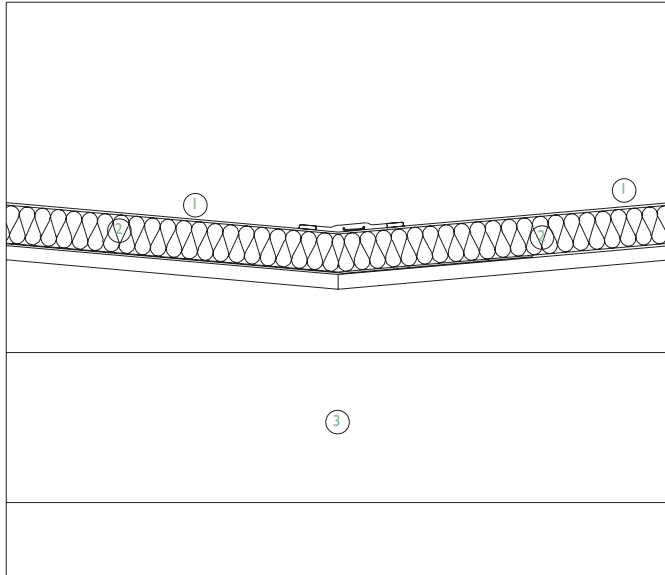
Section 1:10. Bonded method.
Junction with rooflight



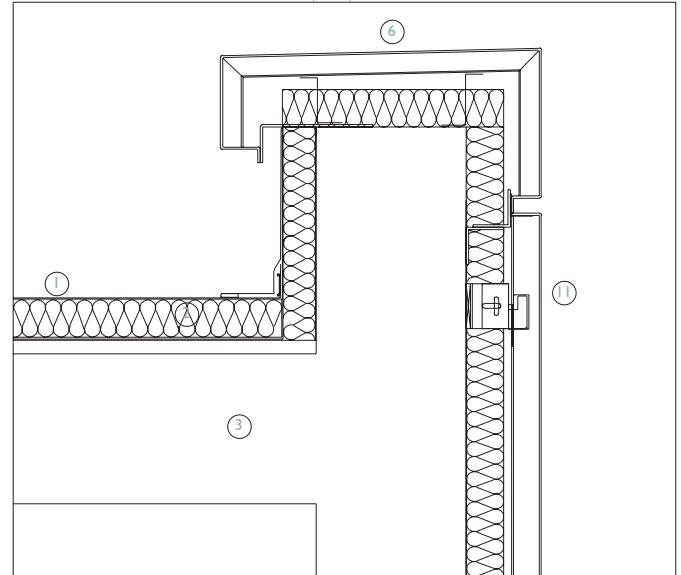
Section 1:10. Bonded method.
Junction of external wall and roof slab



Section 1:10. Bonded method. Roof fold



Section 1:10. Bonded method. Low parapet



became much more widely used in the 1980's and 1990's. The increased flexibility of the new sheet materials allowed for greater amounts of movement between adjoining components and assemblies, allowing the detailing of junctions to be relatively straightforward in forming reliable weathertight roof membrane. As a result of these developments, polymer modifications were also made in the older-generation bitumen-based materials to make them more flexible, in order to compete with the polymer-based sheet materials. As a result there is now a wide range of exposed membrane materials available to suit different budgets and individual roof designs.

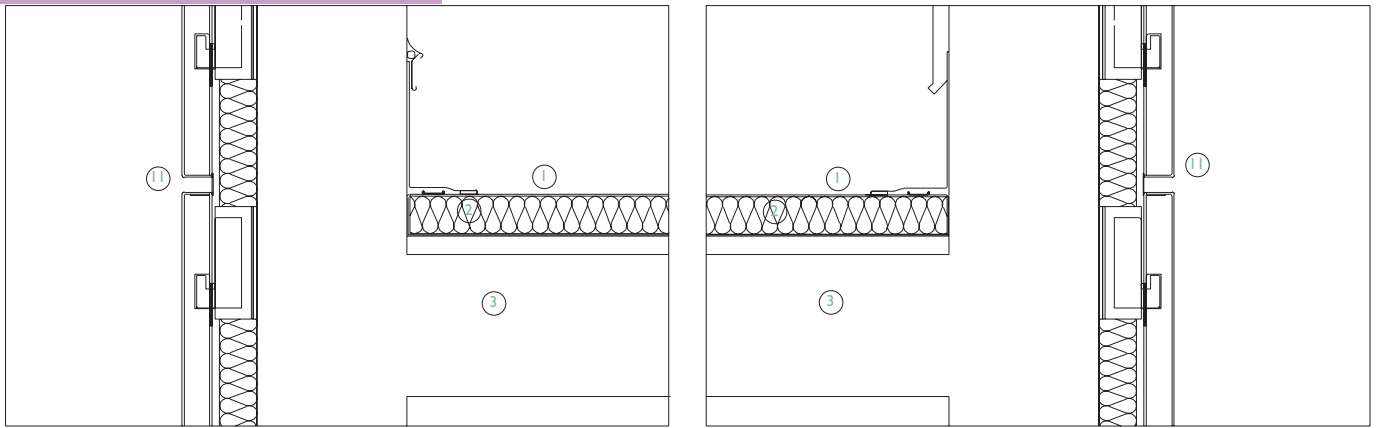
Polymer-based membranes

The main advantage of the polymer-based sheet materials is their ability to be cut and formed to complex shapes, allowing them to take up shapes precisely, sometimes pre-formed in the factory before being delivered to site. Single layer membranes are very practical on roofs with a large number of penetrations, typically in commercial buildings where mechanical ventilation equipment is regularly being modified or replaced during the lifetime of a building.

Single layer membranes are made from either elastomeric materials, typically EPDM, or from thermoplastic materials, typically plasticised PVC (PVC-P). Elastomeric materials are very popular in the US while thermo-

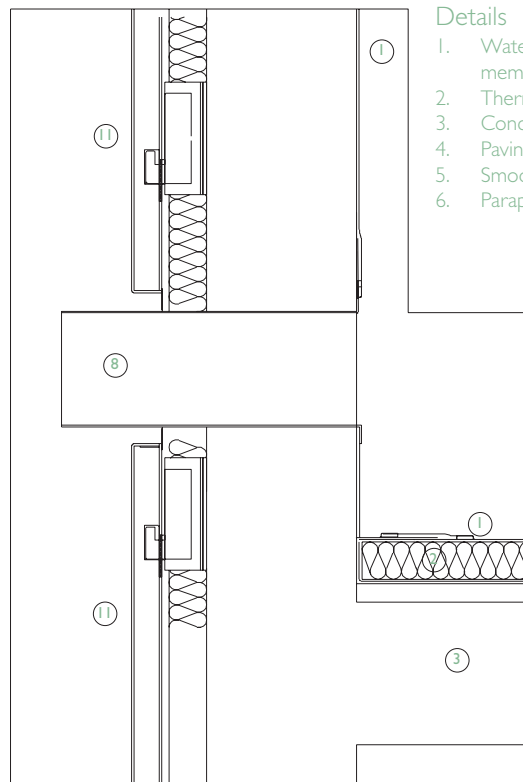
plastics are preferred in Europe. EPDM (ethylene propylene diene monomer) is a flexible and elastic material that has the appearance of a synthetic rubber. EPDM is manufactured in the limited colours of black, grey and white.

Both elastomers and thermoplastics can be mechanically fixed, bonded or secured with ballast to the concrete deck beneath. Developments in these materials has led to them being used on timber decks and profiled metal decks in addition to the concrete decks discussed here. Both thermoplastic and EPDM membranes can be welded together to form a continuous waterproof sheet. While both material types were glued, there is an increasing use of hot air welding



Sections 1:10. Bonded method. Junctions of external wall and roof slab

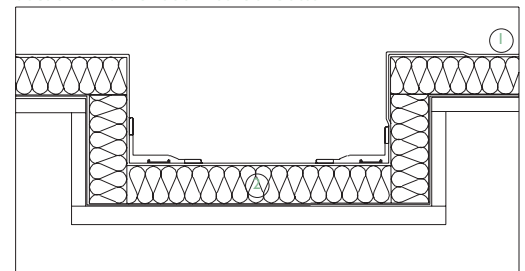
Section 1:10. Bonded method. Roof overflow



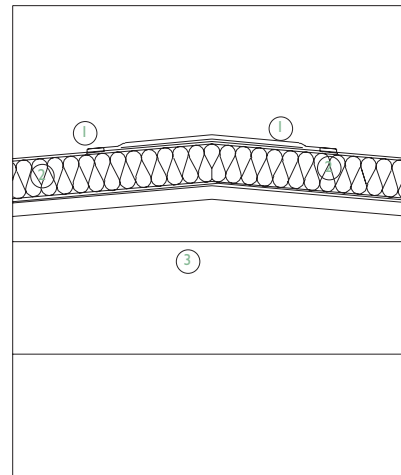
Details

- | | |
|------------------------|-------------------------|
| 1. Waterproof membrane | 7. Rainwater outlet |
| 2. Thermal insulation | 8. Opening for overflow |
| 3. Concrete deck | 9. Balustrade |
| 4. Paving slabs | 10. Pipe or duct |
| 5. Smooth pebbles | 11. External wall |
| 6. Parapet coping | 12. Rooflight |

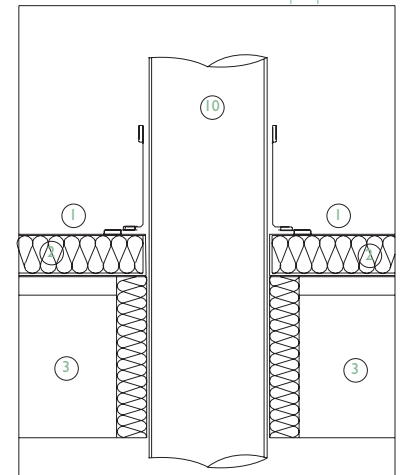
Section 1:10. Bonded method. Gutter



Section 1:10. Bonded method. Roof fold



Section 1:10. Bonded method. Pipe penetration



methods, which avoid the need for flame techniques or adhesive bonding methods that can be both slow and can damage adjacent work during their application. In hot air welding, a jet of heated air is used to soften the materials and weld together; applied from a range of tools that are either hand held or fully automated, depending on the application.

PVC membranes

PVC (polyvinyl chloride) roof membranes have been in use since the 1960's as a very lightweight and relatively economic roofing material, and has become widely used in recent years. Membranes in this material were first developed in Europe in the late

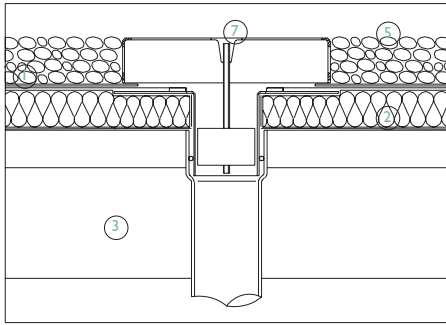
1960's and were used in the US from the 1970's onwards. PVC sheet material is usually reinforced with glass fibre to give it increased rigidity that is easier to bond to the substrate.

The PVC used in membranes is plasticised (PVC-P), unlike the unplasticised PVC (PVC-U, or uPVC) used to make window frames and rainwater drainage components. PVC-P is rigid at normal external temperatures, but softens when heated, making it flexible and allowing strips or sheets to be welded together to form a continuous membrane without the need for standing seams or visible joints. Plasticisers and filler material in PVC-P is added to give the material greater flexibility. The material has very

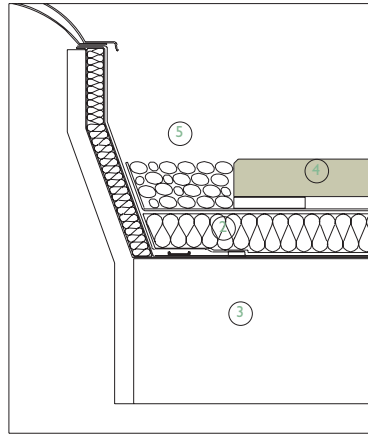
low levels of shrinkage, and is dimensionally stable and does not creep visibly with age. The material experiences only very small amounts of movement under full wind load.

Membranes are reinforced with glass fibre sheet or polyester fabric. These layers are bonded into the material. The glass fibre provides dimensional stability, making it more stable for bonding to the substrate. The woven polyester fabric, used in tent membrane structures, has high tensile strength to resist wind loads the mechanically fixed method is used. A typical build-up for a single layer membrane is a concrete deck with a vapour barrier set on top, with thermal insulation above that, sealed on top with a single layer membrane. PVC-P membranes

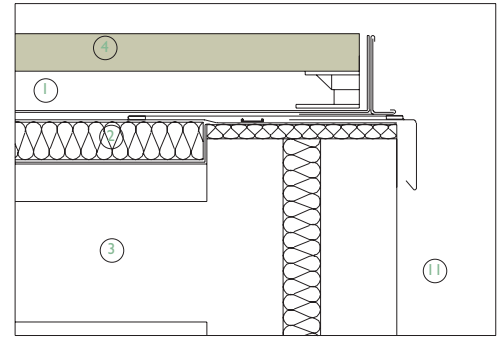
Section 1:10.
Ballusted method. Rainwater outlet



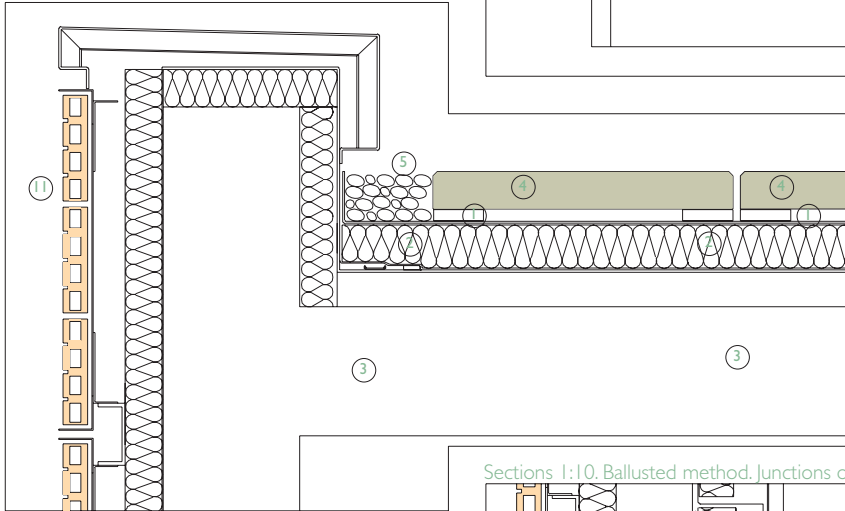
Section 1:10.
Ballusted method. Junction with rooflight



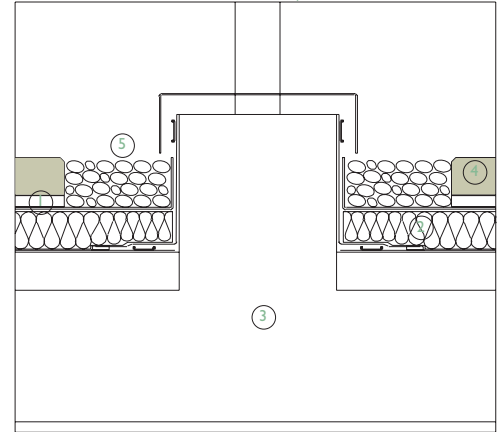
Section 1:10.
Ballusted method. Eaves



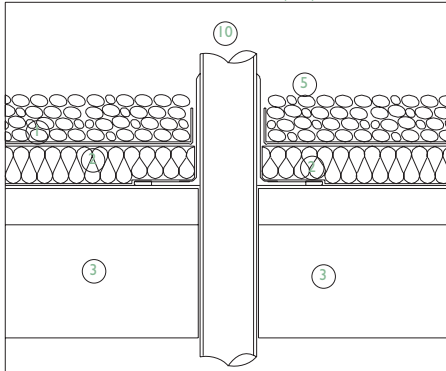
Section 1:10. Ballusted method. Low parapet



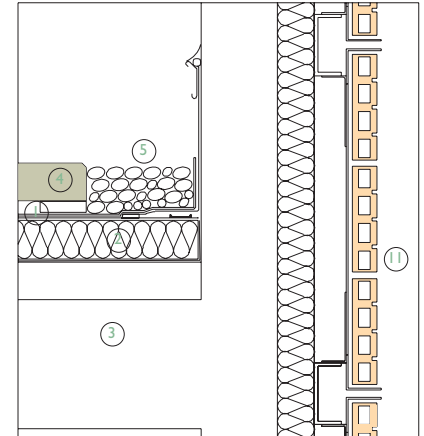
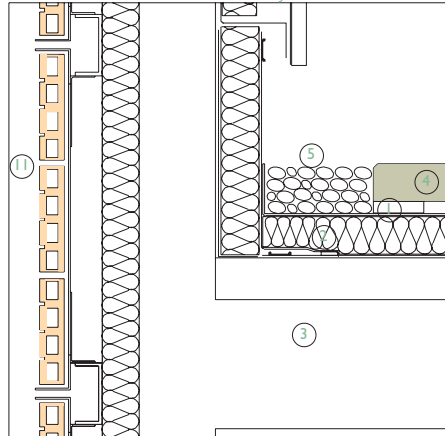
Section 1:10. Ballusted method. Upstand for balustrade



Section 1:10. Ballusted method. Pipe penetration



Sections 1:10. Ballusted method. Junctions of external wall and roof slab



are typically 1.5mm - 3.0mm thick, while EPDM membranes are typically 1.0mm - 1.5mm thick.

FPO (TPO) membranes

A recent development in thermoplastic membrane types are polypropylene- and polyethylene-based materials. They have greater flexibility than PVC-P membranes, but still require reinforcement in glass fibre sheet for increased dimensional stability and polyester fabric to give greater tensile strength. Fire retardant is added to provide fire resistance, unless PVC-P which is self-extinguishing when flame is applied.

Mechanically fixed method

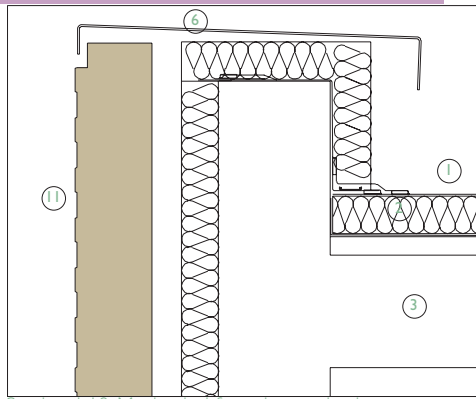
This fixing method is suited to applications with high wind uplift forces, as bonded systems tend to be limited by the bonding strength of the vapour barrier to which the membrane is itself bonded through the thermal insulation layer, which is typically made from expanded polystyrene board. The vapour barrier is loose laid on the concrete deck and thermal insulation is then mechanically fixed through this barrier to the deck beneath. The spacing of the fasteners varies with the design wind loads. A separating layer of glass fibre sheet is usually laid onto the insulation with an outer single layer membrane. The membrane is mechanically fixed with pressure plate bars, similar to

those used in glazed curtain walling systems to hold the glass in place. Bars form strips of pressure plate to hold the roof build-up in place. The pressure plates are fixed by bolts at centres along their length to the substrate below.

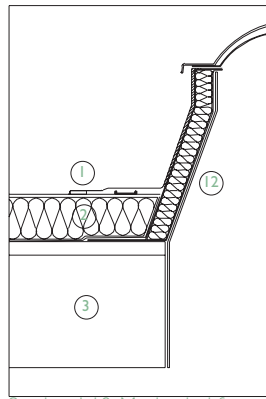
Membranes can also be secured by point fixings rather than by pressure plates. 50-75mm diameter rigid plastic discs are used to hold the build-up in place. These are set at centres to suit the design wind loads. The closed cell rigid insulation is typically made in panel sizes of 1200mm x 2400mm in thicknesses from 25mm to 100mm.

Bonded fixing method

The build-up of materials is the same as



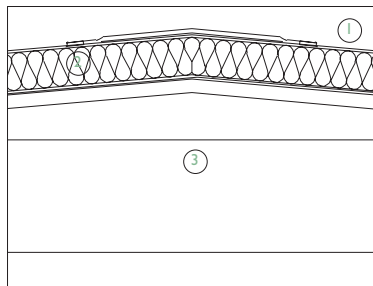
Section 1:10. Mechanical fastening method.
Low parapet



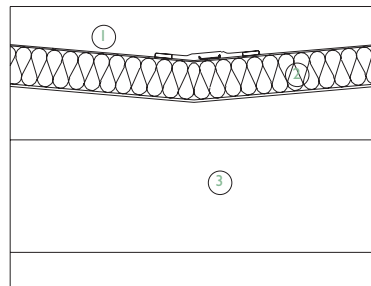
Section 1:10. Mechanical fastening method. Junction with rooflight



Natural Unit / Studio House. Architect: Masaki Endoh and Masahiro Ikeda.

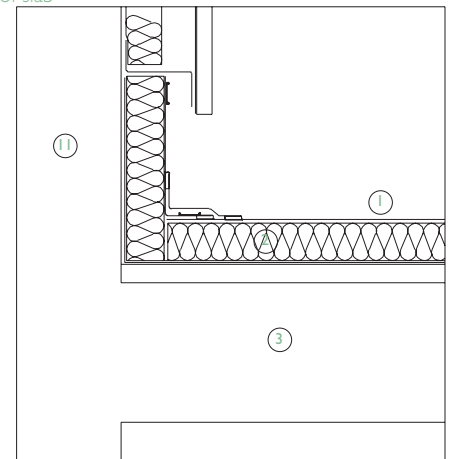
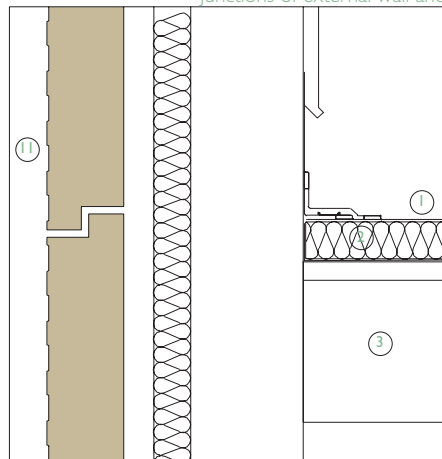
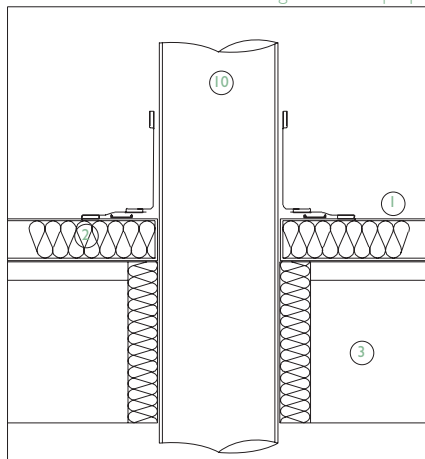


Sections 1:10. Mechanical fastening method. Roof fold



Sections 1:10. Mechanical fastening method.
Junctions of external wall and roof slab

Section 1:10. Mechanical fastening method. Pipe penetration



Details

- | | |
|------------------------|-------------------------|
| 1. Waterproof membrane | 7. Rainwater outlet |
| 2. Thermal insulation | 8. Opening for overflow |
| 3. Concrete deck | 9. Balustrade |
| 4. Paving slabs | 10. Pipe or duct |
| 5. Smooth pebbles | 11. External wall |
| 6. Parapet coping | 12. Rooflight |

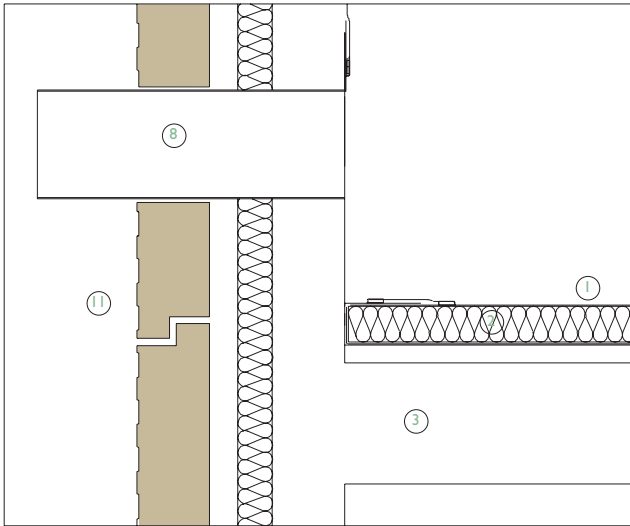
that for the mechanically fixed system. The membrane can either be bonded directly to the concrete deck to form a concealed membrane, or be in the exposed configuration discussed here. When bonded directly to the concrete deck, a felt backing layer is usually used to overcome any roughness in the substrate that would puncture the material. In the exposed membrane configuration the vapour barrier is usually bitumen-based and is bonded to the deck. Joints between the vapour barrier sheets are lapped to avoid any risk of vapour passing through the roof structure from inside the building. The thermal insulation is then bonded to the vapour barrier. Insulation can also be mechanically fixed with pressure plates to the concrete deck

beneath. The membrane is then bonded to the insulation with a continuous layer of bonding adhesive on its underside. Some systems still bond the membrane at points only rather than across the entire surface of the membrane, but this is dependent upon the wind load and the proprietary system used.

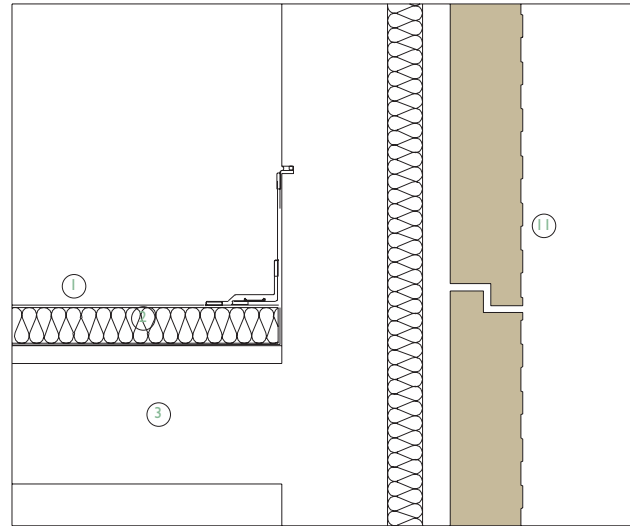
Bonded membranes have a visually smooth appearance, making it suitable where the roof surface is seen from points around the building. It can be more difficult to achieve the bonding required for high wind uplift conditions, but this is a matter of individual design. This fixing method still requires mechanical fixing at the edges, and around openings such as rooflights.

Parapets and upstands

Membranes can be bonded or mechanically fixed to parapet upstands. The fixing method that is used on the main area of roof is usually continued on these vertical areas. With mechanical fixing the pressure plate can be fixed either to the upstand or to the flat roof area. The pressure plate forms a junction between the membrane sheet forming the upstand and the membrane sheet of the roof. Intermediate pressure plates are applied horizontally on the upstand when its height exceeds around 500mm, depending on the specific material used.



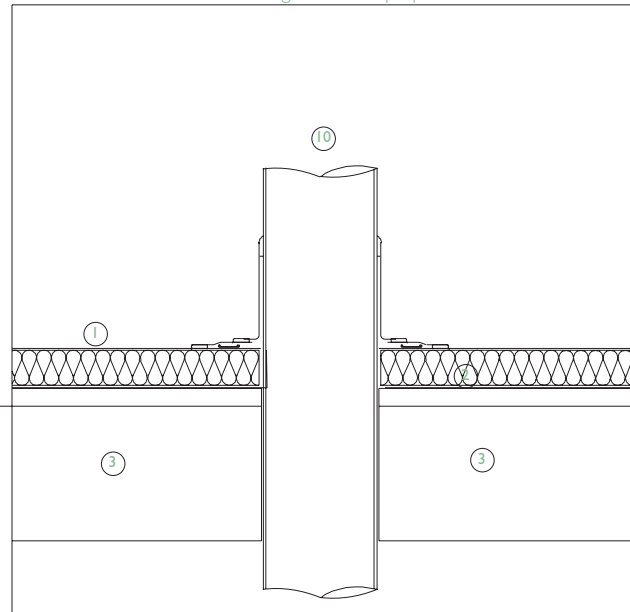
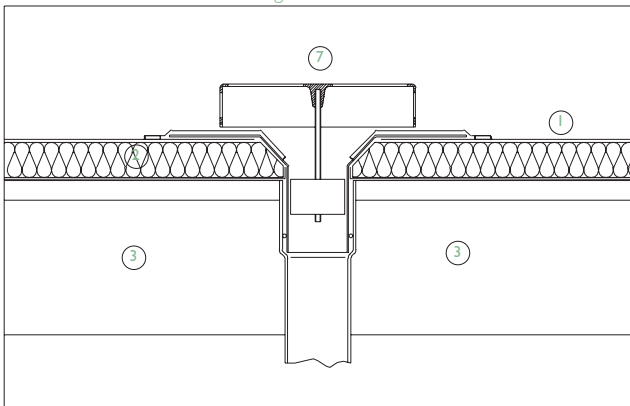
Section 1:10. Mechanical fastening method. Roof overflow



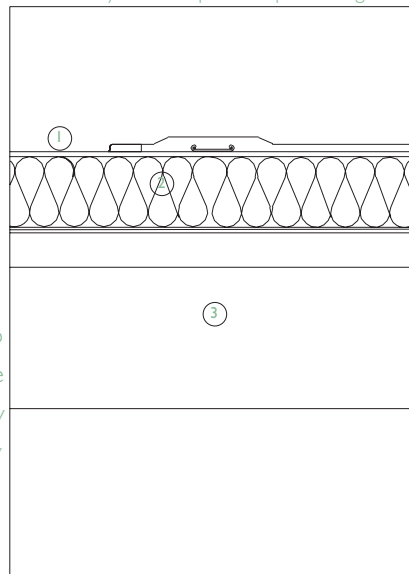
Section 1:10. Mechanical fastening method. Junctions of external wall and roof slab

Section 1:10. Mechanical fastening method. Pipe penetration

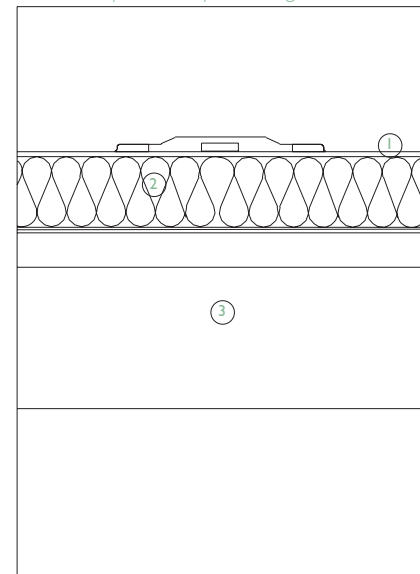
Section 1:10. Mechanical fastening method. Rainwater outlet



Section 1:5.
Mechanically fastened pressure plate fixing



Section 1:5.
Mechanically fastened point fixing

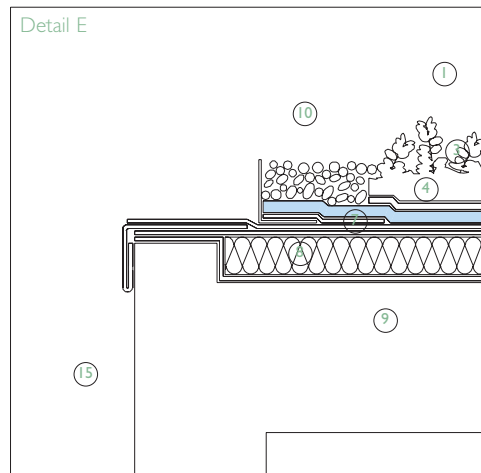


Ballasted roofs

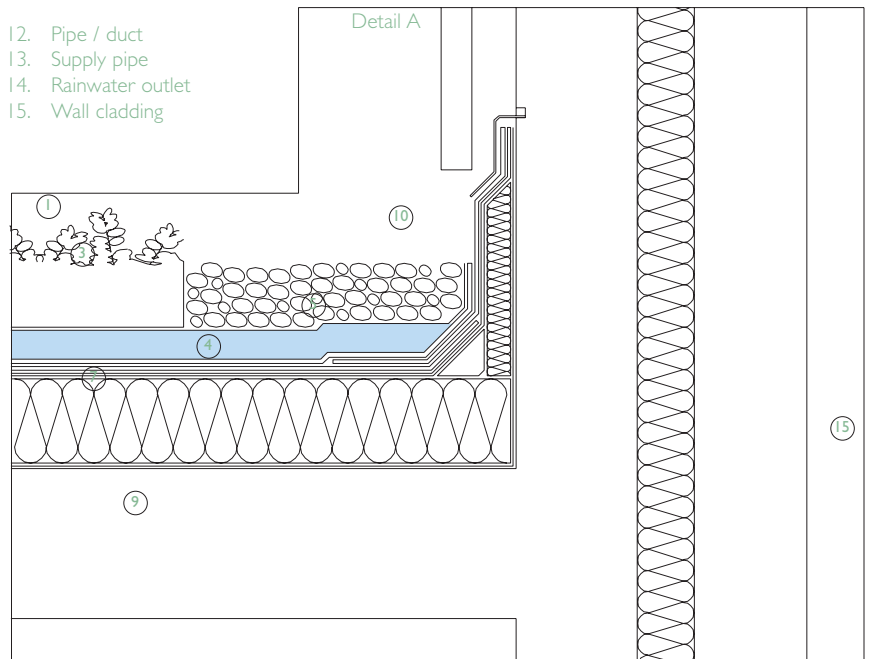
Concealed membranes which are ballasted use a top layer to weigh down the membrane and insulation rather than use mechanical fixing or bonding methods. A typical build-up consists of a single layer membrane welded together to form a continuous sealed sheet, which is loose laid onto a concrete deck. A backing felt is used where the concrete is considered to be too roughly finished for the membrane to be laid directly on top. Thermal insulation is loose laid onto the membrane with a filter layer set onto the insulation. Smooth pebbles are spread on top, to a depth dependent upon both the weight required to avoid wind uplift as well as to satisfy visual requirements.

Details

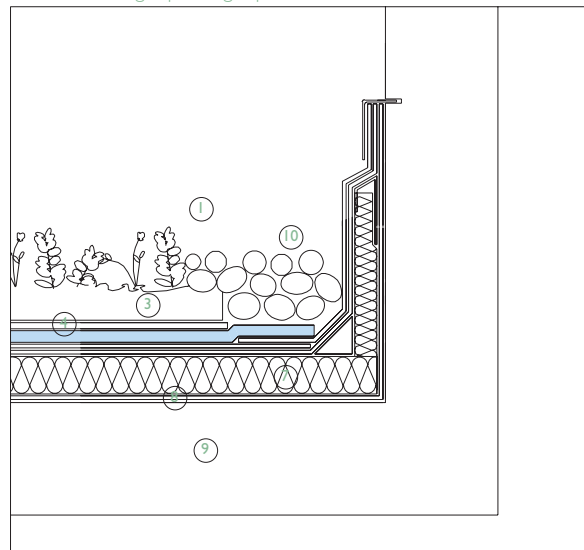
- | | | |
|--------------------------|------------------------|----------------------|
| 1. Light vegetation | 6. Waterproofing layer | 12. Pipe / duct |
| 2. Heavy vegetation | 7. Thermal insulation | 13. Supply pipe |
| 3. Soil / growing medium | 8. Vapour barrier | 14. Rainwater outlet |
| 4. Filter sheet | 9. Concrete deck | 15. Wall cladding |
| 5. Drainage layer | 10. Smooth gravel | |
| | 11. Coping | |



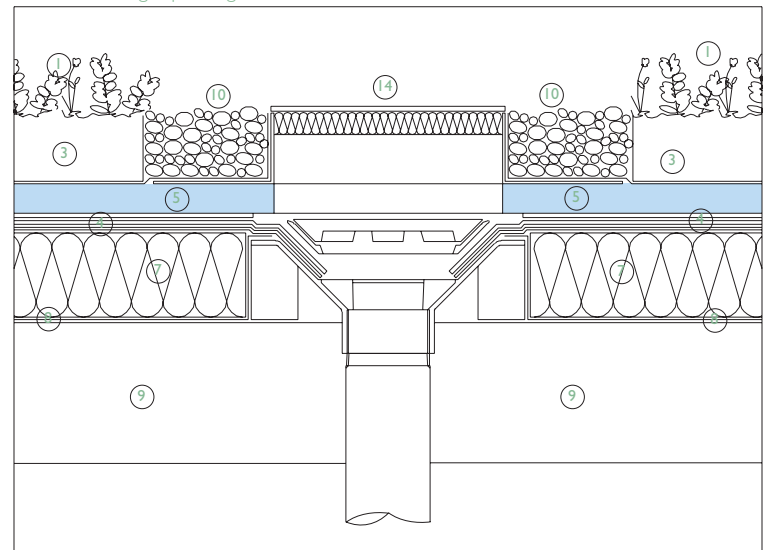
Section 1:10. Light planting. Eaves and parapet junctions.



Section 1:10. Light planting. Upstand.



Section 1:10. Light planting. Rainwater outlet.



Concrete decks used for planted areas can be waterproofed with either a concealed membrane or an exposed membrane as discussed in the previous sections. Planted roofs are of two types: light planted and heavy planted. Unlike other concrete roof types, planted roofs are not always insulated as they often form the roof of underground structures such as car parks, providing a planted roof at ground level.

Light planted roofs have resilient plants that require little or no irrigation, and that will grow in a thin layer of soil or organic growing medium. They are not usually used on a roof accessible to building users, but are seen from vantage points around the building. Light planted roofs have plants and flow-

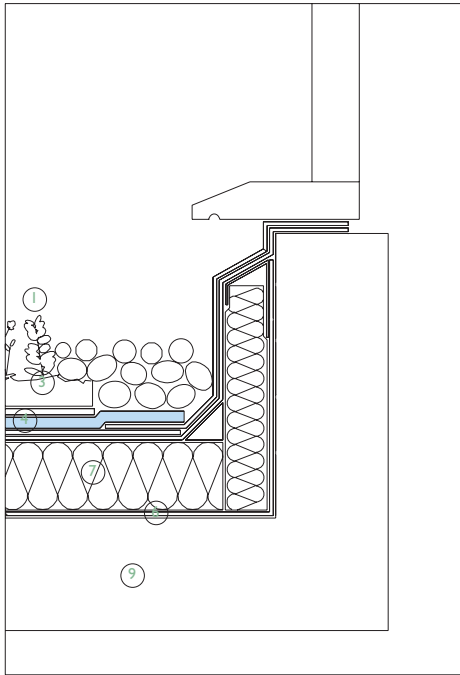
ers that require little maintenance and do not usually have an irrigation system to supply water at controlled times, relying on rainwater and modest amounts of watering during maintenance at specific times of the year. These lightweight planted roofs suit a lightweight deck, such as a thin concrete shell, although profiled metal decks are commonly used as substrates. Maintenance access is provided by the pebble strips at the roof edges or by individual paving slabs that avoids the need to walk across the planting.

Heavy planted roofs permit a wide variety of plants, shrubs and trees to grow on a concrete roof deck. Due to the size and intensity of the planting they require an automated irrigation system, usually from

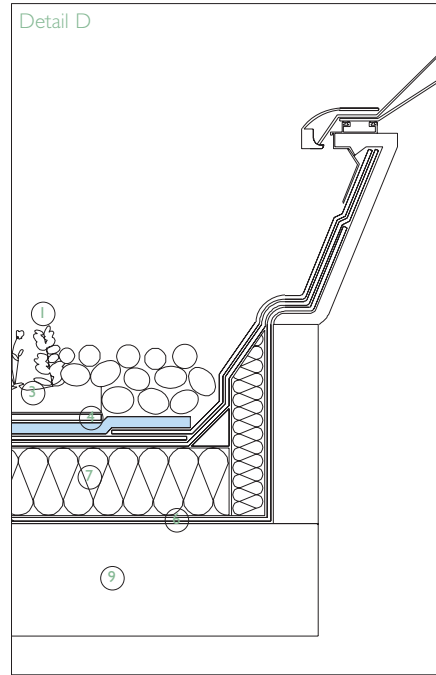
pipes set into the soil that provide a trickle water feed to the soil at specific times which may vary during the course of the year. Heavy planted roofs require regular maintenance, provided by paved paths or by areas of grass.

Both light planted and heavy planted roofs have drainage layers beneath the growing medium that hold water and release it back to the plants when required. This allows the soil depth to be much less than that which would be required for older landscaping methods, where the soil was expected to hold all the water. The reduced depth of soil allows planting to be considered for concrete roof structures that would require no significant strengthening to receive the

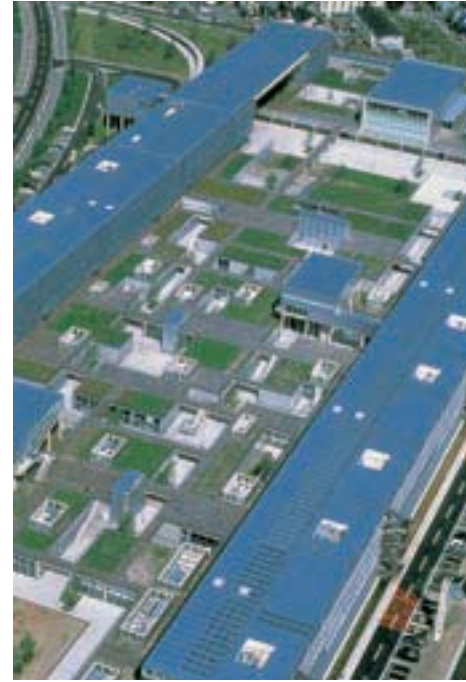
Section 1:10. Light planting. Cill junction.



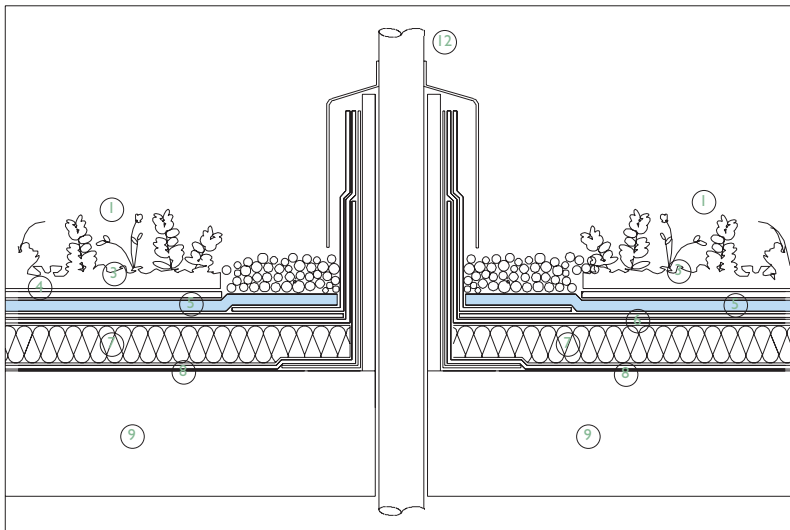
Section 1:10. Light planting. Rooflight upstand.



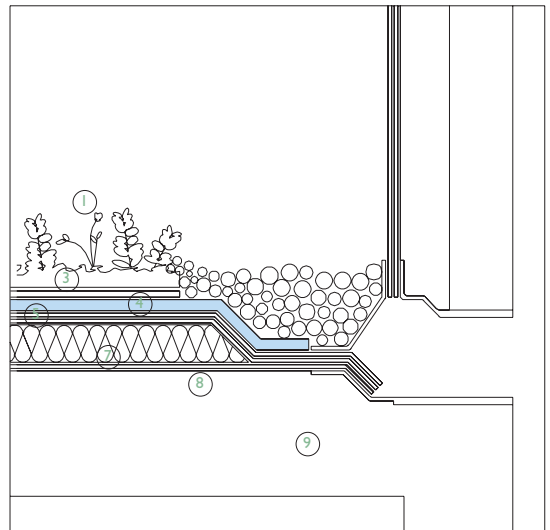
Prefectural University, Tokyo, Japan.
Architect: Riken Yamamoto and Field Shop.



Section 1:10. Light planting. Pipe penetration.



Section 1:10. Light planting. 2-way outlet.



added weight of soil. In terms of drainage it is estimated by manufacturers of proprietary systems that 50% to 90% of rainfall is retained in planted roofs, but this varies considerably with local climate conditions and rainwater drainage provision.

Planted roof components

Both light planted and heavy planted roofs have a similar build-up, comprising typically a top layer of planting, with a growing medium or soil beneath. A filter layer is set underneath, and below this, a drainage layer and moisture mat. Beneath this lowest layer is set thermal insulation if required. Although planted roofs provide a limited amount of thermal insulation from the soil, in practice

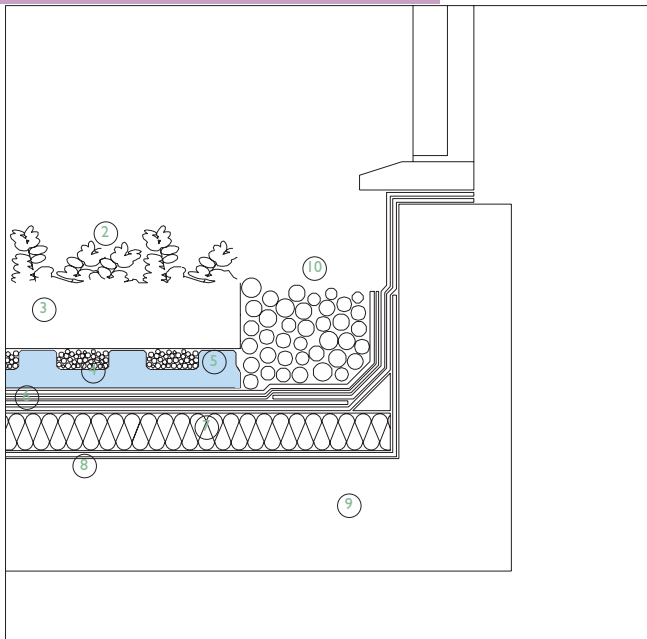
this is reduced due to the varying amounts of water held within the soil. A root barrier is set beneath the insulation to protect the waterproof membrane, which forms the bottom layer, which is bonded to the concrete roof deck. The root barrier is sometimes bonded to the waterproofing layer, usually when the complete build-up is a single proprietary system.

The essential requirements for stabilising and maintaining plant growth in planted roofs are the provision of nutrients in the growing medium, water retention, soil aeration and drainage. Soils used are aimed to be relatively low in weight but are balanced to suit the nutrients, soil porosity, vapour permeability (from the drainage layer below)

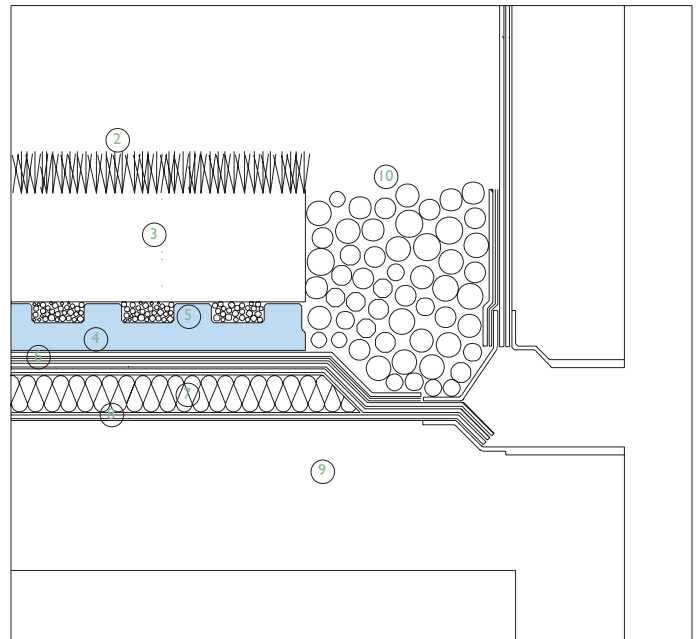
and pH values required by the plants chosen. Both the soil mix and the soil depth determine the amount of plant growth that can be expected on a planted roof.

To prevent the passage of organic matter and fine particles into the water drainage system, a filter sheet is set underneath the planting. This sheet is lapped up the sides of the planting, where it meets an upstand, to the level of the planting.

The drainage layer beneath the filter sheet retains water that drains through the planting. Water is retained in profiled troughs in a typically polystyrene egg-crate shaped tray that releases water back to the planting. This method also performs satisfactorily on sloping concrete roofs. Excess water is

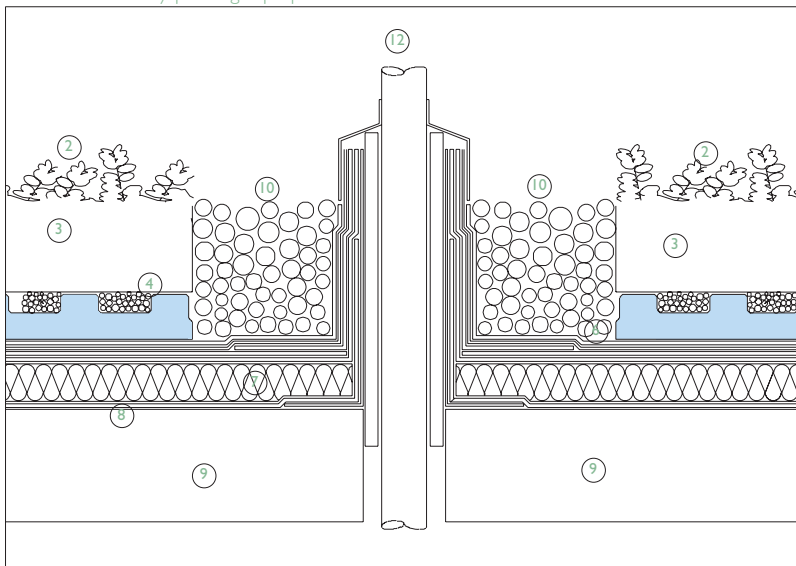


Section 1:10. Heavy planting. Cill junction. Detail B

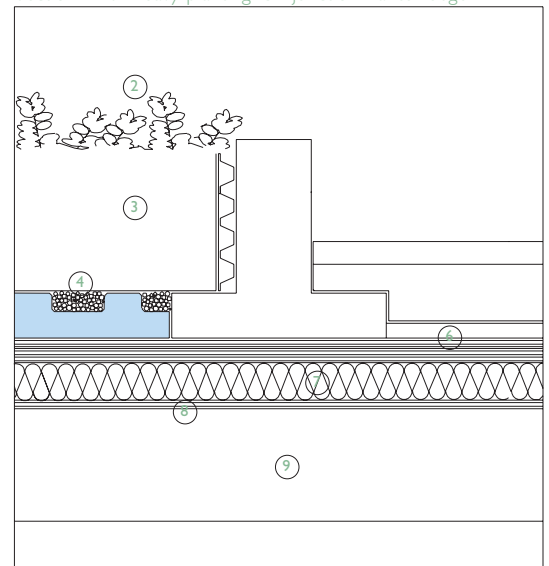


Section 1:10. Heavy planting. 2-way outlet.

Section 1:10. Heavy planting. Pipe penetration.



Section 1:10. Heavy planting. Cill junction. Planter edge.



drained away through gaps between the drainage trays. The egg-crate form allows aeration, permitting the soil to absorb the water stored here. In drier months, water diffuses up through the soil to the plant roots. A moisture mat is often set under this layer to catch water that runs off the drainage layer. The mat is made from a durable fibre that retains moisture and nutrients as well as serving as protection to the root barrier beneath. It is not used in inverted roof configurations. In inverted roofs, a root barrier is set immediately below the insulation to protect the waterproof membrane forming the lowest layer. This layer prevents planting roots from damaging the waterproofing. In warm roof construction,

the waterproof membrane is set on top of the thermal insulation, positioning the insulation within the building envelope. A vapour barrier is set between the thermal insulation and the concrete deck. In this configuration a moisture mat is set between the waterproof membrane and the drainage layer above.

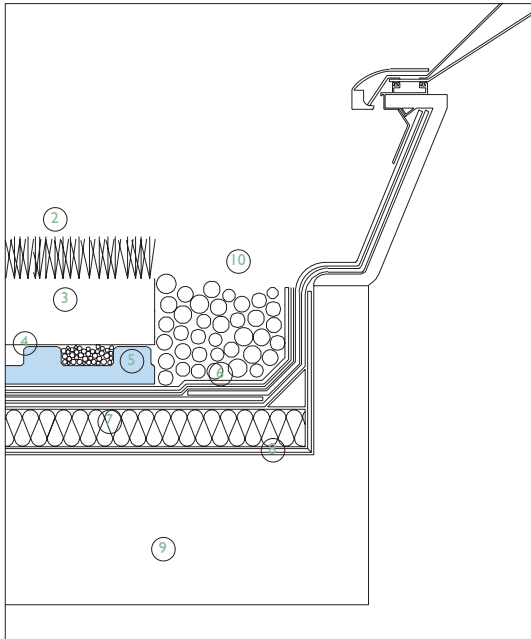
Soil depth

The soil depth in light planted roofs ranges from 50mm to around 150mm, weighing a minimum of around 70kg/m² of roof area. Water is stored in the growing medium and drainage layer, making it efficient in mild, temperate climates. Light planted roofs can be grown on both nominally flat roofs and on sloping roofs with a pitch up to

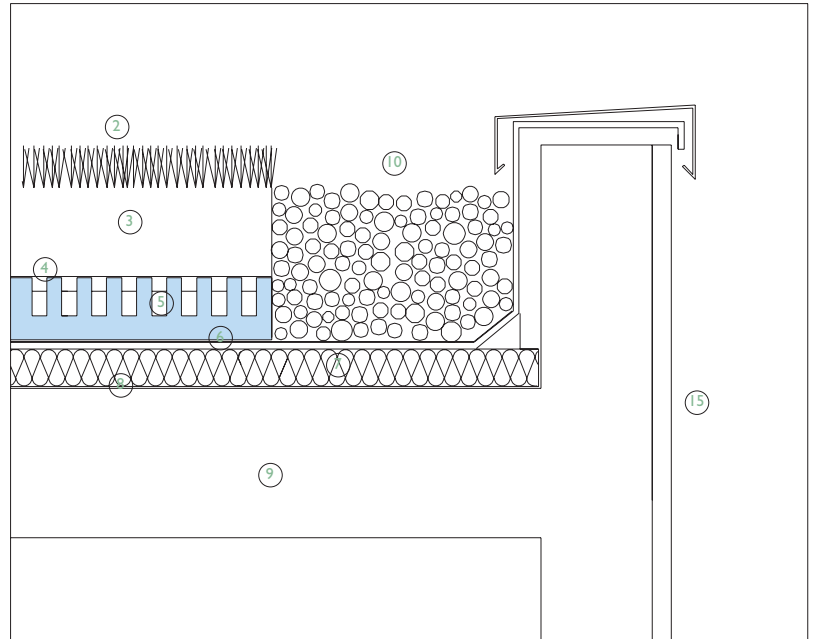
25° to 30°. Heavy planted roofs have a deeper drainage layer to provide greater water storage. The soil depth, in excess of 150mm, requires an automatic irrigation system to provide a reliable water supply coverage of the complete roof.

In inverted roof configurations, the weight of soil and vegetation is made sufficient to avoid wind uplift and the possibility of the insulation floating on the water during rainfall. Although the ponding is often considered by proprietary waterproofing manufacturers not to affect the waterproofing layer, it can cause lightweight planted roofs to 'float' during rainstorms if this layer is not properly secured.

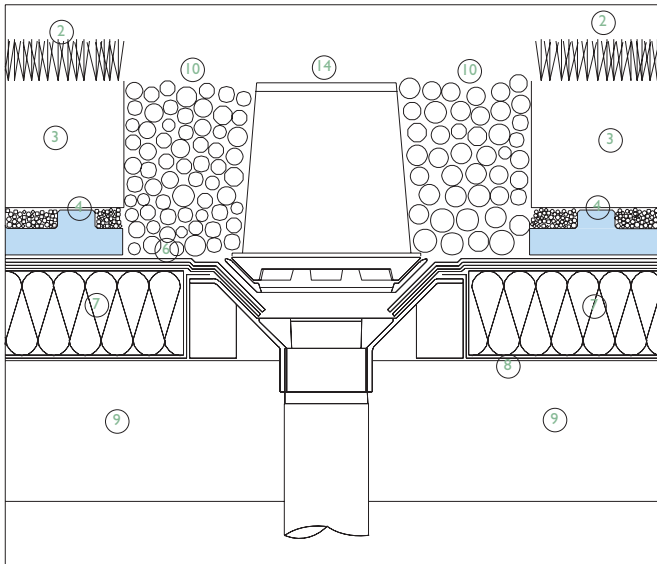
Section 1:10. Heavy planting. Rooflight upstand.



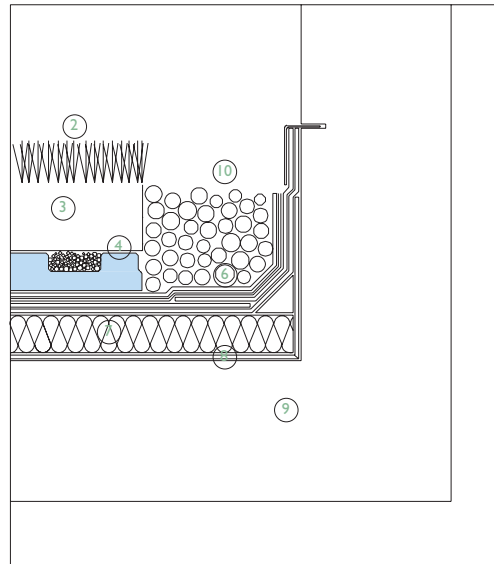
Section 1:10. Heavy planting. Low parapet.



Section 1:10. Heavy planting. Rainwater outlet. Detail F



Section 1:10. Heavy planting. Upstand. Detail C



Details

1. Light vegetation
2. Heavy vegetation
3. Soil / growing medium
4. Filter sheet
5. Drainage layer
6. Waterproofing layer
7. Thermal insulation
8. Vapour barrier
9. Concrete deck
10. Smooth gravel
11. Coping
12. Pipe / duct
13. Supply pipe
14. Rainwater outlet
15. Wall cladding

Overflows

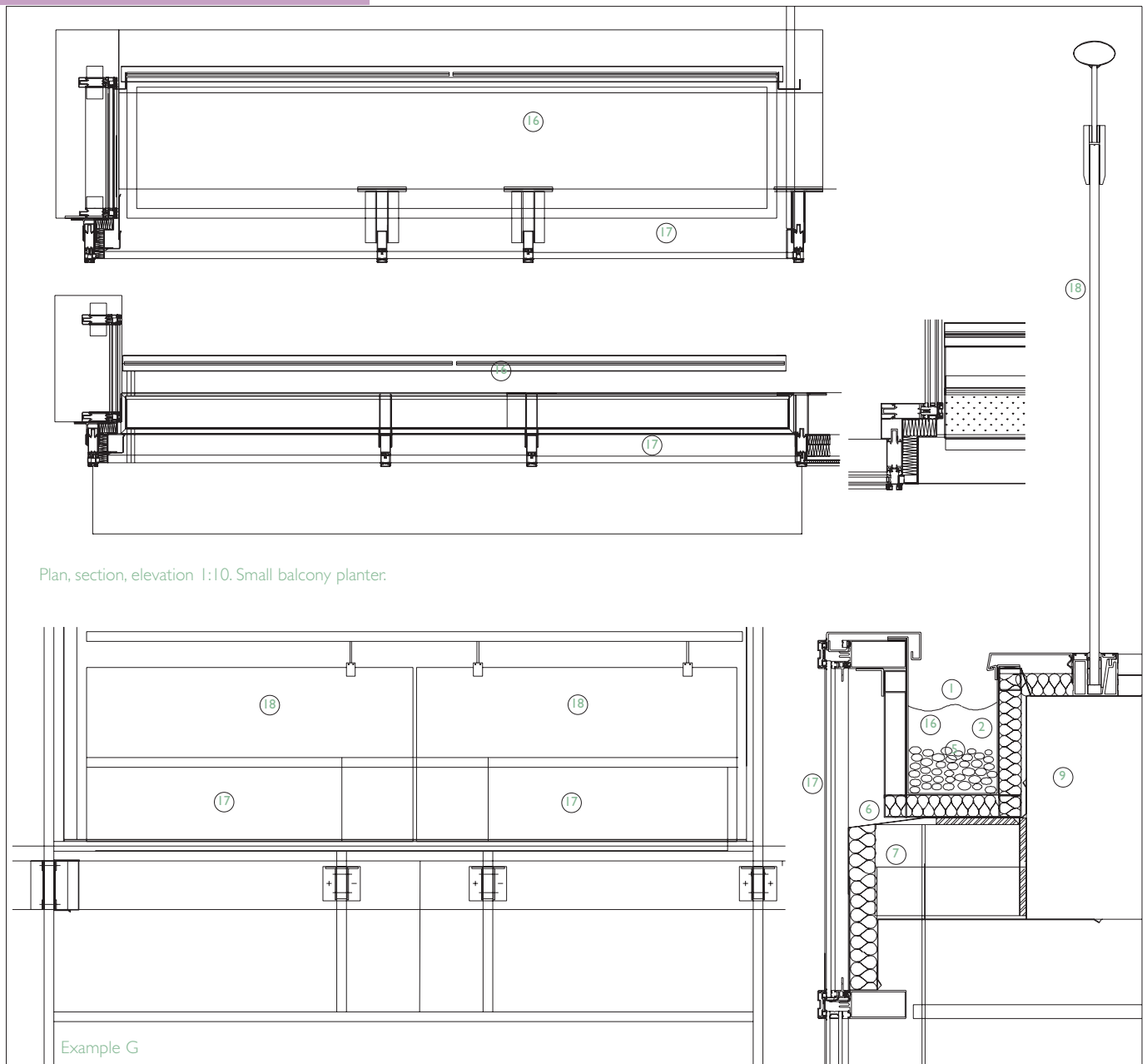
Irrigated heavy planted roofs are usually provided with overflow outlets so that, in the event of the rainwater outlets being blocked, a high rainfall or failure of the irrigation control equipment does not cause the roof to flood with water. Overflows are set typically at a height between 50mm and 150mm above the planting level to avoid flood damage to both the planting and to the interior of the building. When the roof is laid to fall, some overflows are set at the level of the highest finished roof level in order to avoid planting being damaged should flooding result in landscaping being temporarily submerged in water:

Roof junctions

At upstands and eaves the same principles apply to planted roofs as discussed in the previous sections on concealed membranes and exposed membranes. The waterproofing extends a minimum of 150mm above the level of the planting, providing a continuity from the roof membrane to the flashing at the top of the upstand or to the adjacent wall construction. Upstands for parapets and door sills, high walls and rooflights shown in details (A), (B), (C) and (D) respectively are formed by extending the waterproof filter sheet and root barrier up to a minimum of 150mm above the level of the soil or growing medium. The visible membranes and sheets are concealed with

thermal insulation, and typically either paving turned on edge (the same paving used for adjacent access paving) or a metal sheet to match that of the parapet coping where a metal coping is used.

Eaves can be formed by metal edge trims, usually from a minimum 3mm thick folded aluminium sheet or stainless steel angle. The filter sheet is folded up the inside face of the angle to avoid organic matter and fine particles from being washed down into the drainage layer. The waterproof membrane is bonded to the base of the metal angle as shown in (E), where the edge is terminated by a paving slab. Smooth pebbles can be used, provided there is no risk of them being pushed over the edge, particular-



ly during maintenance work. Many planted roofs have low parapet or eaves edges so that the roof can be experienced visually from the outside of the building. A fall arrest system is provided, such as harnesses worn by maintenance personnel, which is attached by a safety line to an anchor point or a latch way cable. Balustrades are provided for building users in conditions with low parapets.

Vegetation barriers are provided at roof perimeters, upstands, duct penetrations and rainwater outlet points to avoid damage to the adjacent construction that would be caused by plants. Pebbled strips with a minimum width of 300mm are used, with river washed pebbles of 16mm to 32mm diameter.

Rainwater outlets

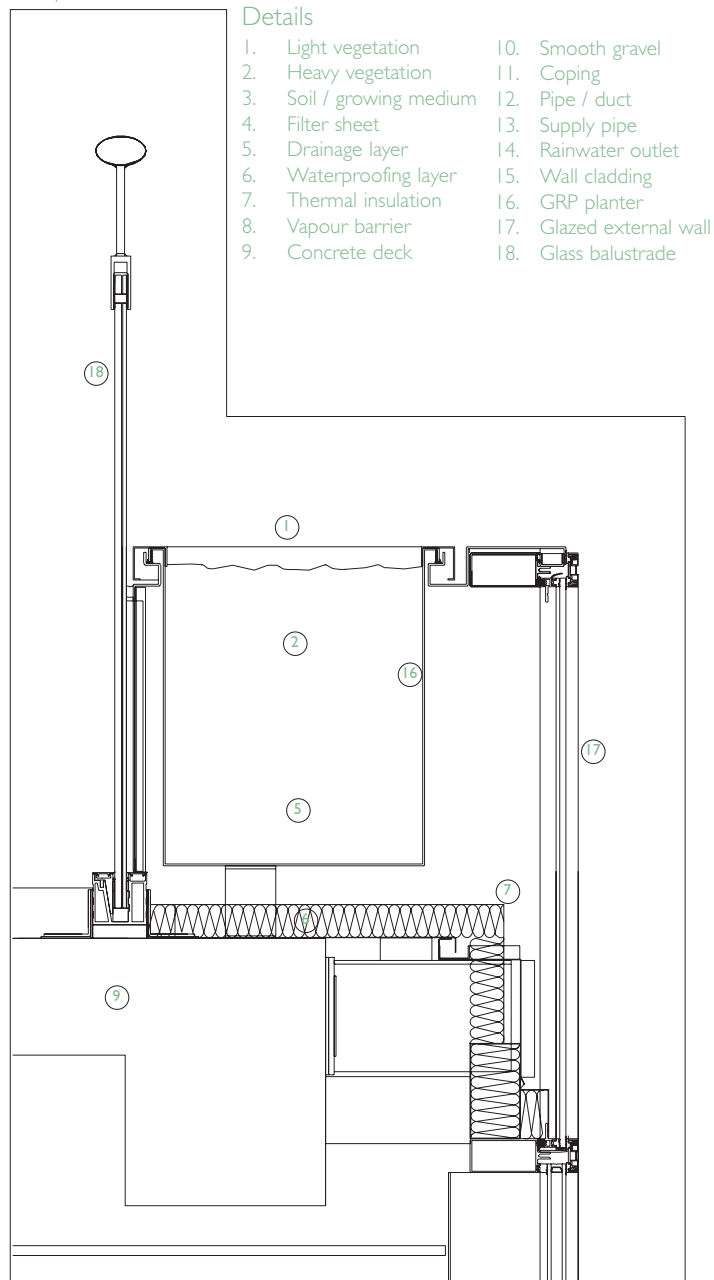
The filter layer is dressed up around the vertical edges of the rainwater outlets as (F). An access cover is provided for maintenance purposes. Water drains at the level of the waterproof membrane, which is dressed into the base of the outlet.

Balcony planters

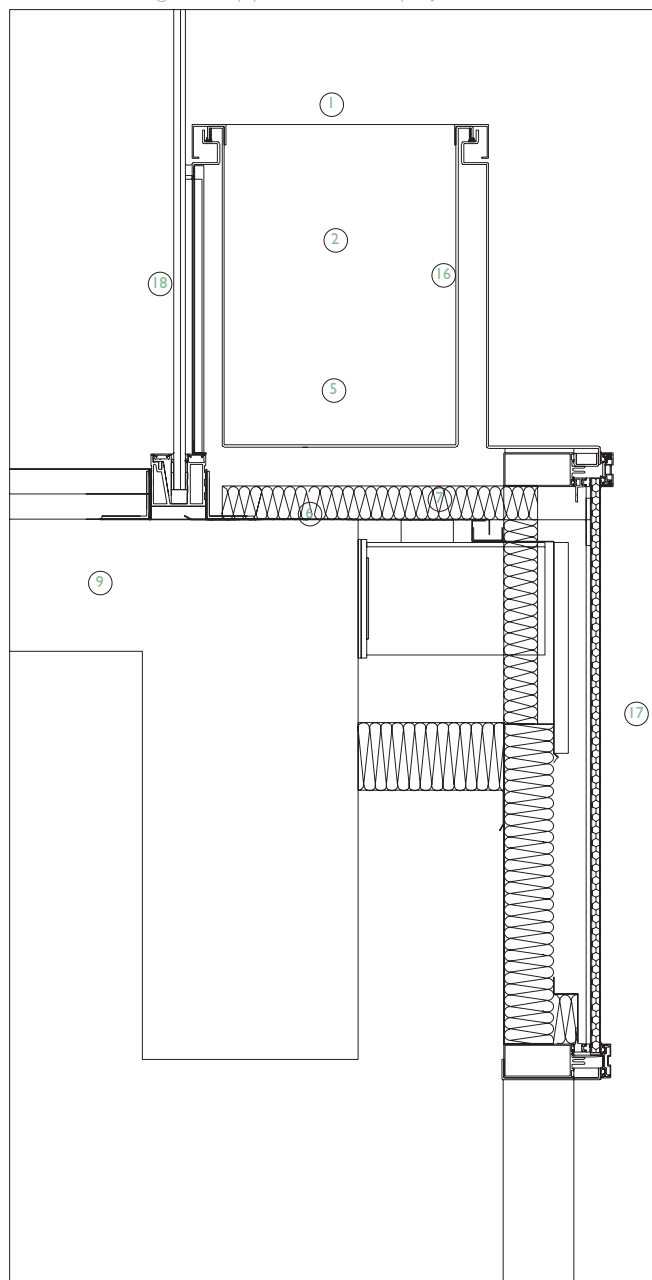
Planting troughs with automatic irrigation and a drainage system can be incorporated at roof level into curtain wall facades, as shown in (G), (H) and (J). In (G) a small planter is integrated into a balcony. The planter is sealed, but should any water leak either from the planter (as a result of damage) or if water penetrates the seals around

its top edges, then the water is drained by an internal waterproof tray into the transom below, where it drains to the outside. The curtain wall system, which is drained and ventilated internally, allows any water that penetrated these planter seals to drain through its pressure equalisation chambers. A glazed balustrade is shown behind the planters, indicating that the planter would be maintained from the facade cleaning system, typically cleaning cradle. In (H) and (J) larger versions of this planter are shown that are suitable for much larger plants. The planters are drained internally in the same way. In all planters water is supplied at one end, typically by a water supply pipe of small diameter set into the roof finishes. The drainage

Example H



Sections I:10. Large balcony planters. Example J



pipe is typically of 50mm diameter for such installations, and is set either within the facade panels or directly in front of the facade. Planter boxes are made from glass reinforced polyester (GRP) which is moulded to form a single, sealed shell. This material is very resilient and can be moulded by hand to suit individual project requirements. Planter boxes made from thermoplastics are much more expensive to manufacture, requiring large numbers to be fabricated at the same size to make them economic. The boxes are set into a metal frame provided within the curtain walling system and are sealed with silicone around their edges. In this example, a metal strip is set on top of the planter to conceal the GRP from view.



Prefectural University, Tokyo, Japan. Architect: Riken Yamamoto and Field Shop.

4

TIMBER

(1) Flat roof 1: Mastic asphalt coverings

Warm and cold roofs

The material

Warm roof build-up

Solar protection

Upstands

Eaves and verges

Penetrations

Gutters and rainwater outlets

(2) Flat roof 2: Bitumen-based sheet membranes

The material

Roof build-up

Solar protection

Fixing methods

Parapet upstands

Junction with tiled roof

Eaves and verges

(3) Pitched roof : Tiles

Plain tiles

Interlocking tiles

Ventilation

Eaves

Ridges

Verges

Hips and valleys

Abutments

(4) Pitched roof : Slates

Roof folds

Vents

Monopitch ridges

Dormer windows

Abutments

(5) Pitched roof : Metal

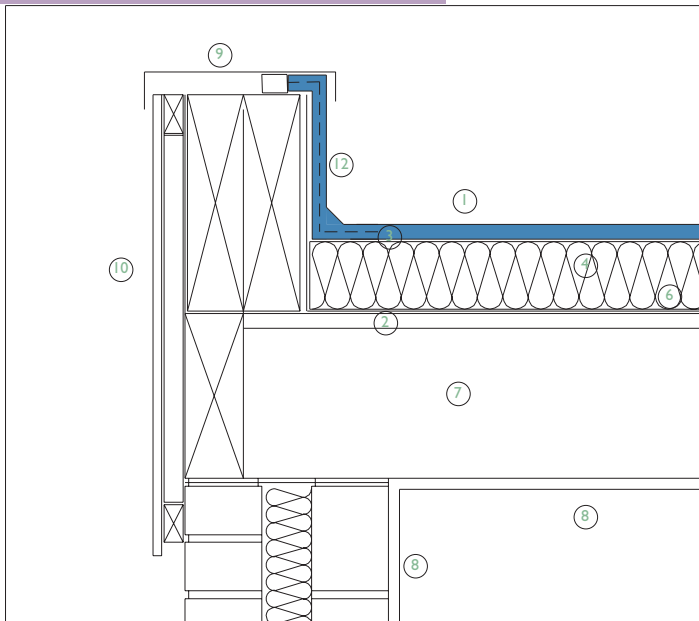
Standing seam cold roofs

Eaves and valley gutters

Ridges and abutments

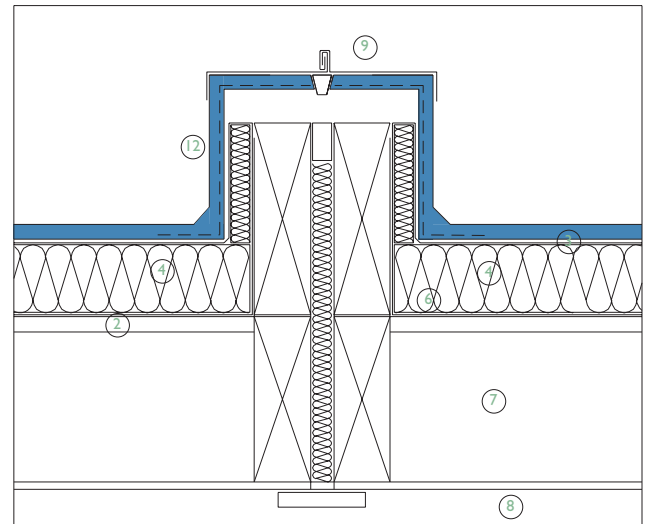
Penetrations

Metal tiled roofs



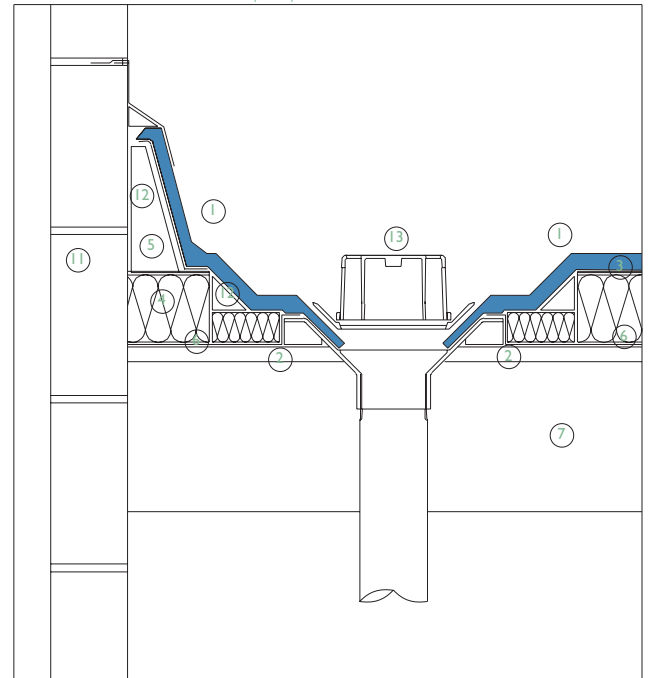
Section I:10. Eaves

Saltwater Pavilion, Neeltje Jans, Holland. Architect: Oosterhuis Associates.



Section I:10. Expansoin joint

Section I:10. Drain outlet at parapet wall



Warm and cold roofs

Flat timber roofs are described as being in either 'warm' roof or 'cold' roof configuration. In the warm roof as (A), thermal insulation is set on top of the timber deck, which is protected by a waterproof layer set onto its upper face. A vapour barrier is set between the thermal insulation and the timber deck. The roof build-up is not required to be ventilated as the timber structure is maintained at near internal temperature conditions. In the cold roof configuration, as (B) the waterproof layer is set directly onto the timber deck. Thermal insulation is set beneath the timber deck, in the voids between the timber joists and air is allowed to circulate in the void to provide ventilation

that avoids the possibility of rot forming in the timber. A vapour barrier is set beneath the insulation, on the warm (in winter) side of the insulation, with a dry wall or internal lining board set below this. In both warm and cold roofs, the vapour barrier avoids the passage of damp air up into the thermal insulation where interstitial condensation can form that might damage the internal construction of the roof.

In a mastic asphalt waterproofed warm roof, thermal insulation is set on top of the timber deck, with an asphalt layer on top of this. A separation layer is set between the asphalt and the thermal insulation. A vapour barrier is set between the thermal insulation and the timber deck. In the mastic asphalt

cold roof configuration, the asphalt is set directly onto the timber deck, with a separating layer beneath the asphalt.

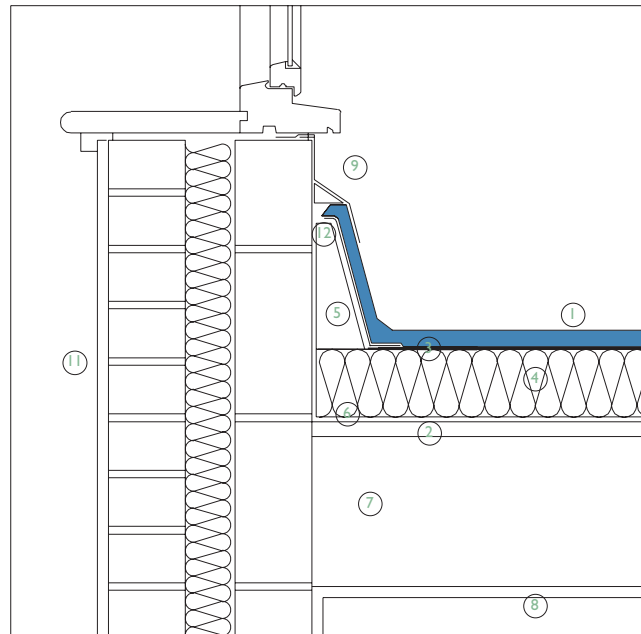
The material

Asphalt is manufactured from bitumen which is blended with limestone powder and fine limestone aggregate. 'Lake' asphalt is used in some parts of the world, which is a naturally occurring material from Trinidad. Mastic asphalt, used to form a continuous waterproof covering on flat or sloping roofs, has polymer additives in some types to provide stability at the relatively high temperatures experienced when exposed to the effects of the sun, as well as providing flexibility of the material at low temperatures,

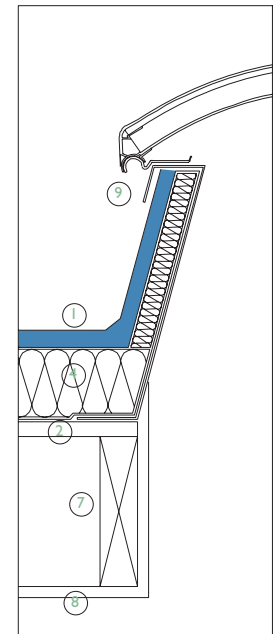
Details

1. Mastic asphalt
2. Plywood sheet or timber boards
3. Separating layer
4. Rigid thermal insulation
5. Freestanding timber upstand
6. Vapour barrier
7. Softwood joists
8. Dry lining/drywall internal finish
9. Metal flashing
10. Fascia board
11. External wall
12. Expanded metal lathing
13. Rainwater outlet

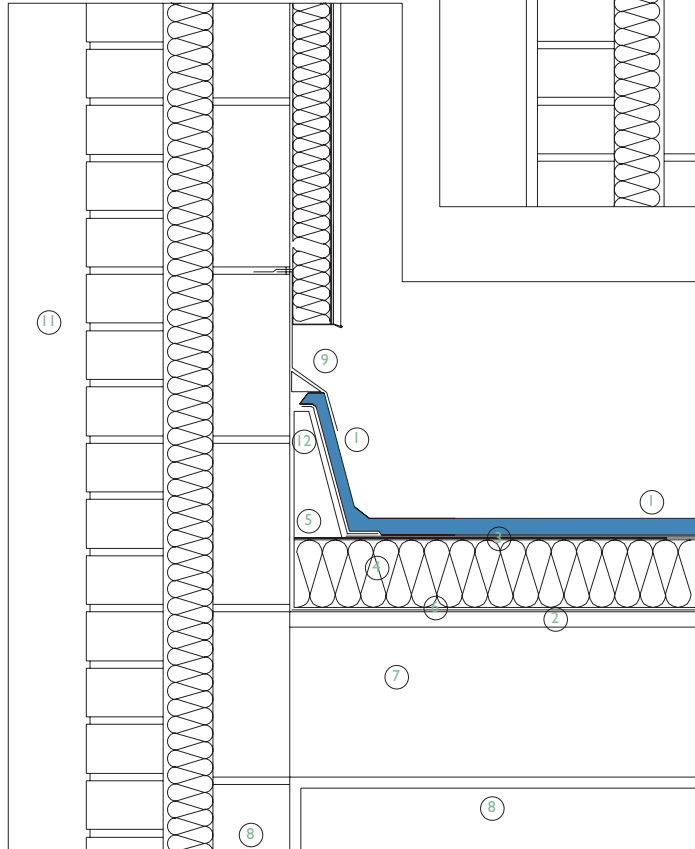
Section 1:10. Low parapet wall



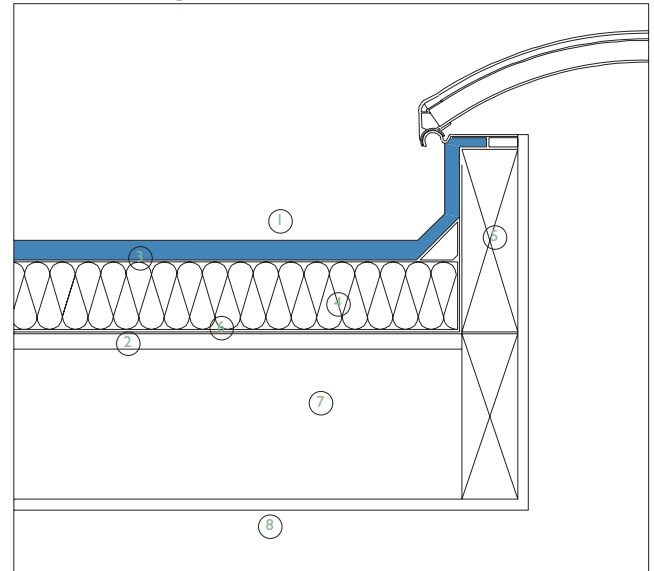
Section 1:10. Rooflight



Section 1:10. High parapet wall



Section 1:10. Rooflight



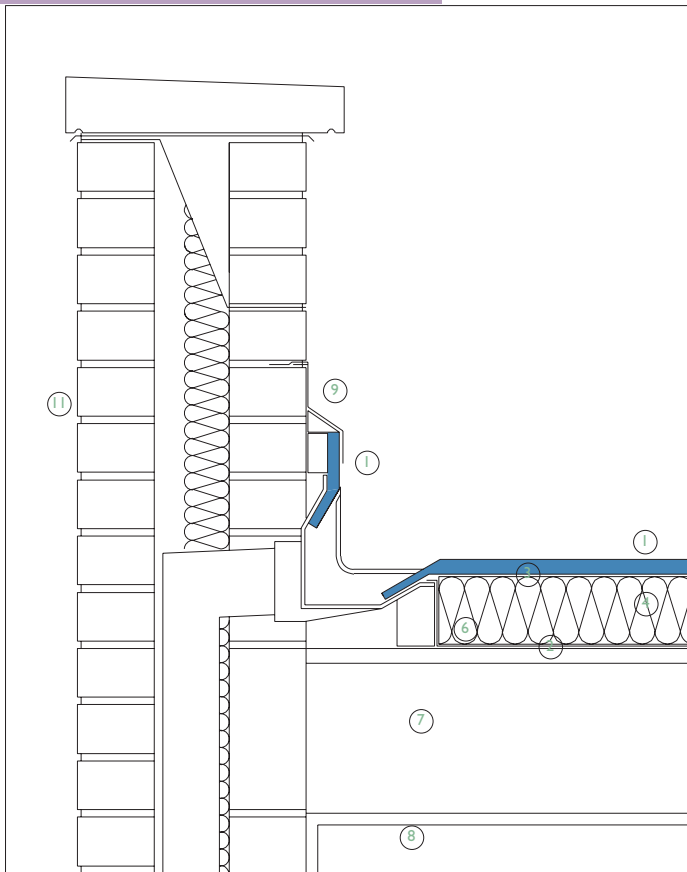
which allows it to take up movements in the substrate. Asphalt is applied in a hot liquid form on site, allowing it to form a homogeneous material at complex junctions such as at upstands, roof penetrations and changes in level. It was used more commonly 25 years ago, and its popularity is being challenged by single layer sheet membranes, which have greater strength, flexibility, a higher melting point and UV resistance. However, the use of this material is set to continue, mainly a concealed membrane, but its use as an exposed membrane is discussed here since this application is much more common in timber construction. Mastic asphalt is laid on rigid substrates, typically reinforced concrete decks, but its use as an exposed membrane on a

timber deck is set to continue, particularly as a result of additives which make the material more flexible than was previously the case.

The essential difference for timber decks between a mastic asphalt covering and those in sheet materials is at upstands, where a separate upstand fixed to the roof deck rather than the wall, is often formed between the roof and supporting wall in order to better accommodate the relative lack of flexibility in the mastic asphalt. This is done where slight lateral movement in the roof deck is expected that cannot be accommodated by the asphalt. The junction between the top of the asphalt upstand and the external wall is sealed by a metal flashing fixed into the upstand or onto its surface.

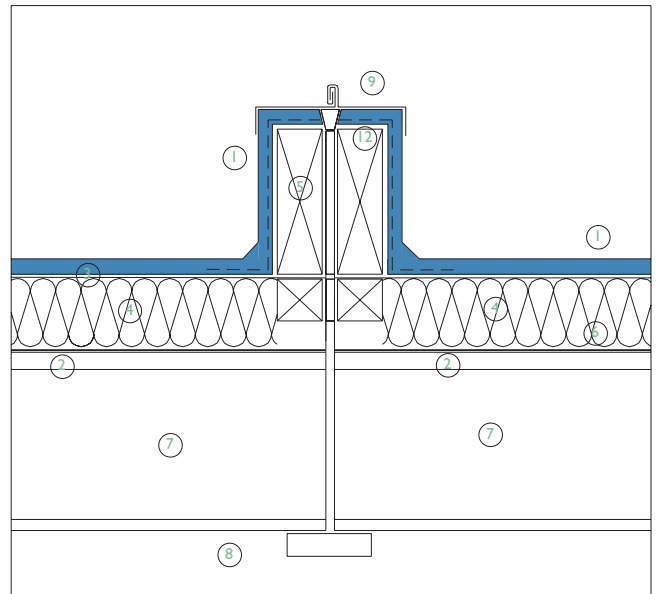
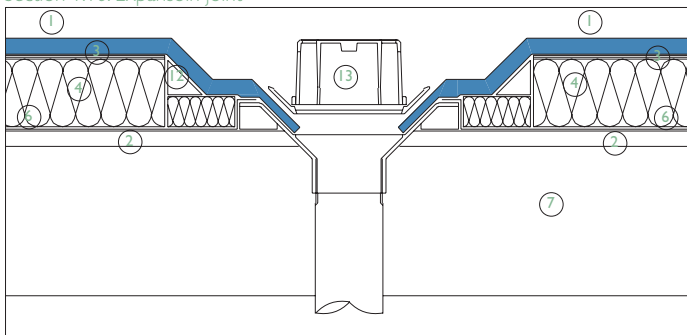
Warm roof build-up

Where timber boards are used instead of plywood sheet, the boards are usually tongued and grooved and around 19mm thick to provide as rigid a substrate as possible. Plywood decks are usually WBP grade and at least 19mm thick. A minimum fall of 1:50 (2%) is used to avoid ponding and to keep the roof clear of standing water. Although completely flat roof decks are used for single layer membranes, this has not been a part of the traditional use of exposed asphalt roof coverings, so the minimum 1:50 fall is still observed as a rule. Falls are formed by either tilting the supporting timber joists beneath the deck, or setting flat or angled strips, called furring pieces, on top of the



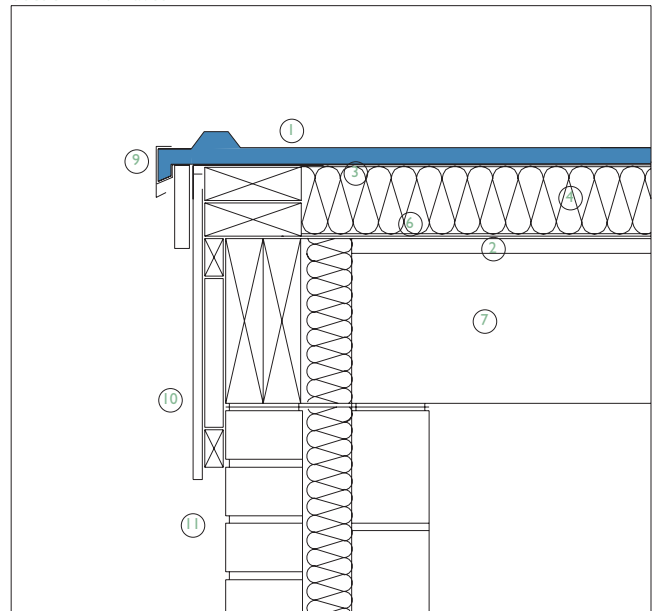
Section 1:10. 2-way drain outlet

Section 1:10. Expansion joint



Section 1:10. Rainwater outlet

Section 1:10. Eaves



joists. The profiled shape of the fitting pieces is dependent on the direction of the fall in relation to the direction of the structural joists. Thermal insulation which is pre-formed in the factory to a sloping angle, sometimes called 'tapered' insulation, is offered by some manufacturers as an alternative method of creating a roof fall.

A vapour barrier is provided on the underside of the thermal insulation, on the warm (in winter) side. Roofing felt is commonly used, or else a proprietary metal lined sheet with metal foil tape to seal the joints. All laps and joints are fully sealed to avoid the passage of water vapour through the barrier. An alternative vapour barrier is of a layer of asphalt, around 12mm thick, set on a glass

fibre underlay.

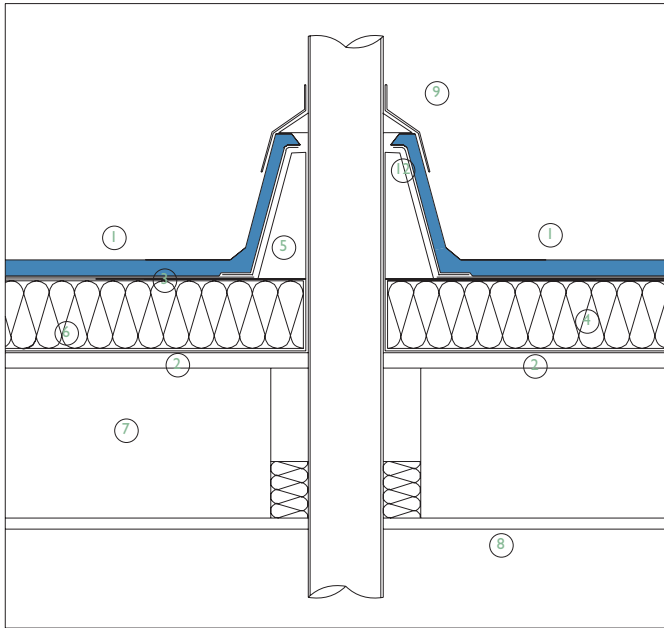
Thermal insulation is usually provided to give a minimum U-value of 0.25W/m²K. In the warm roof configuration, the thermal insulation is of a type suitable for having hot liquid-applied mastic asphalt laid onto it. As mastic asphalt retains a high temperature for a comparatively long period after being laid, the insulation materials used are those which are both compatible and which maintain dimensional stability under such conditions. Polyisocyanate foam materials and cork sheet are commonly used for this reason, typically in a proprietary composite sheet form as a composite of cork board with polyurethane foam. Extruded polystyrene is also used in the warm roof configuration as

an alternative insulating material. In order to achieve a U-value of 0.25 W/m²K, an insulation thickness of 100mm - 150mm is expected, varying slightly between the materials used.

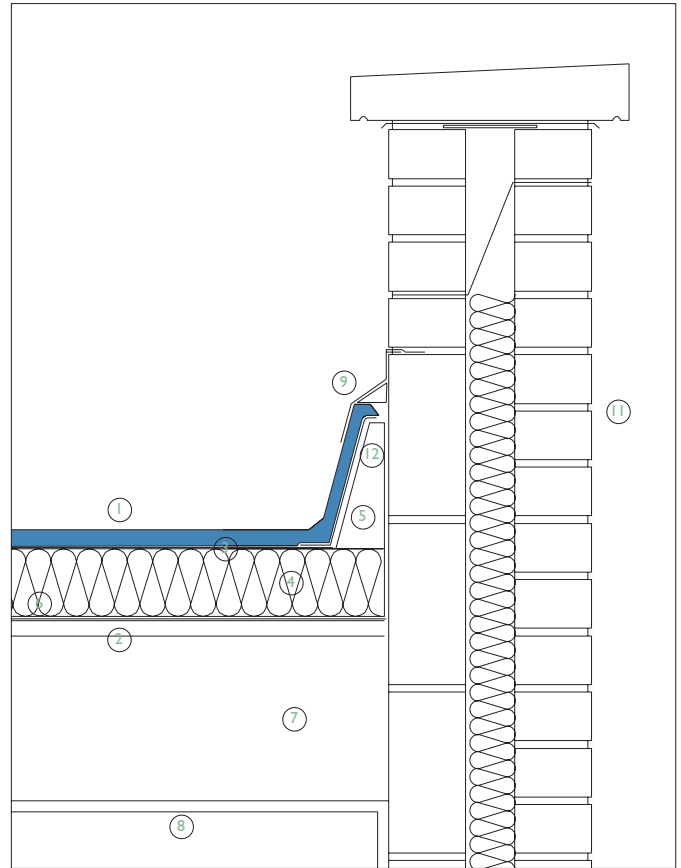
A separating layer is laid onto the thermal insulation layer in order to isolate the asphalt from movement, mainly at joints, in the substrate or structural deck. It also helps to restrain the asphalt in cold temperatures. Sheathing felt is used typically, loose laid with laps around 50mm between sheets.

Asphalt is usually applied in two coats to an overall thickness of around 20mm, set on a separating layer. In the exposed membrane configuration the slope if the roof does not exceed around 5°. When asphalt is laid

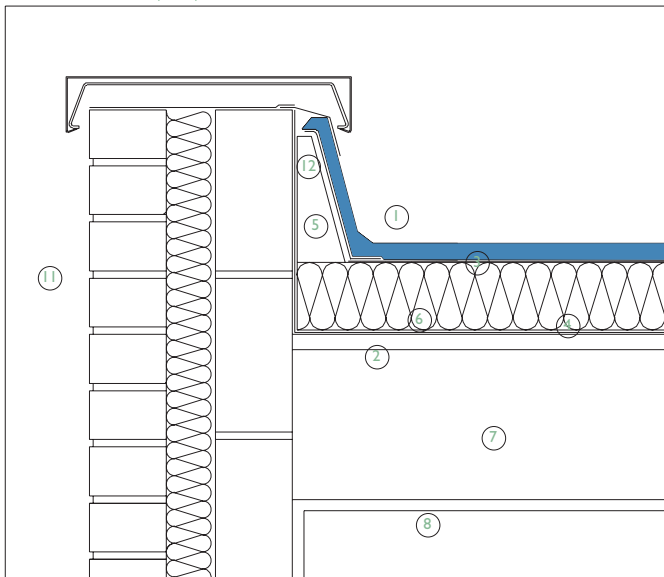
Section 1:10. Pipe penetration



Section 1:10. High parapet wall



Section 1:10. Low parapet wall



Details

1. Mastic asphalt
2. Plywood sheet or timber boards
3. Separating layer
4. Rigid thermal insulation
5. Freestanding timber upstand
6. Vapour barrier
7. Softwood joists
8. Dry lining/drywall internal finish
9. Metal flashing
10. Fascia board
11. External wall
12. Expanded metal lathing
13. Rainwater outlet

directly onto concrete, in a concealed or inverted roof configuration discussed in the Concrete chapter; the roof slope can go up to around 30°, also laid in two coats to an overall thickness of around 20mm. When the asphalt has been laid, sand is rubbed into the finished top surface while it is still hot in order to break up the top surface of the bitumen. This helps to reduce the effect of gradual crazing of the surface caused by the effects of the sun.

Solar protection

In warm roof construction, a protective surface is usually applied to all exposed areas with a solar reflective paint, stone chippings or thin paving slabs which are bedded into

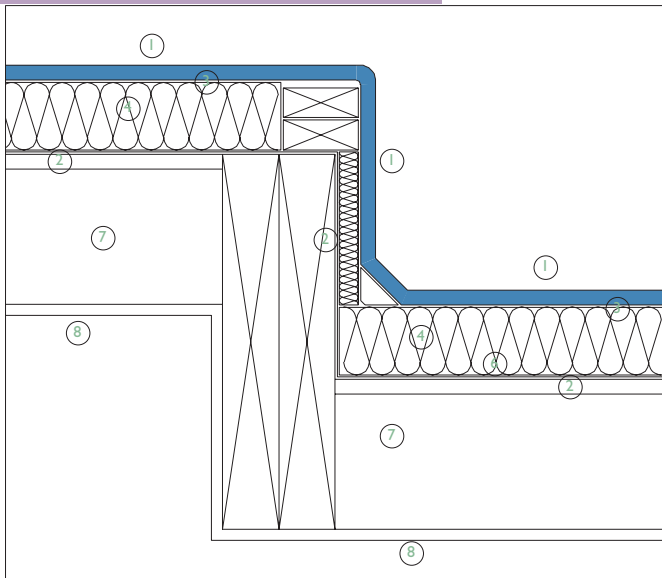
the asphalt surface with a proprietary adhesive. A single layer of 10mm - 14mm stone chippings are used as permanent surface protection for asphalt. The chippings are usually bonded to the asphalt after the asphalt has cooled, with a bitumen solution to provide only a limited bond. This allows the chippings to be removed easily at a later date for repair and maintenance work.

Upstands

At upstands, where the asphalt is usually set vertically, or at a steep slope, the material is laid in three coats. The first coat is very thin in order to key in the substrate, then two further separate coats are applied to give an overall thickness of around 20mm. In

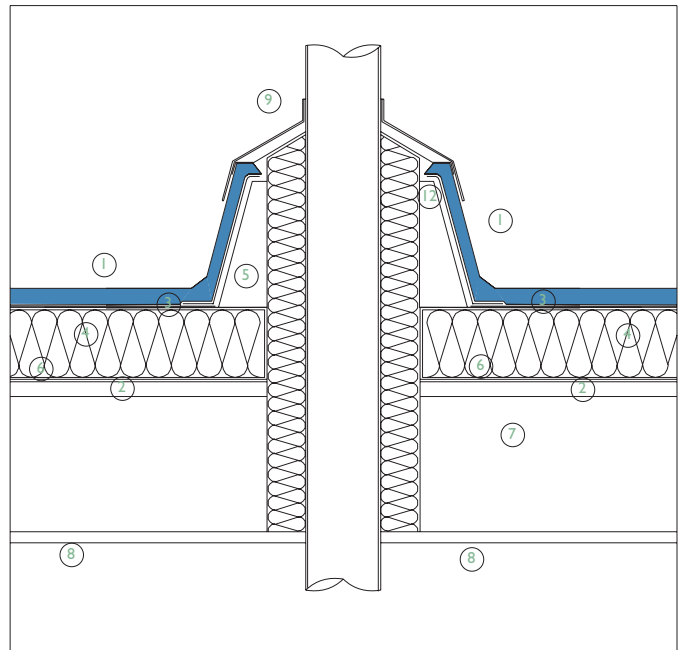
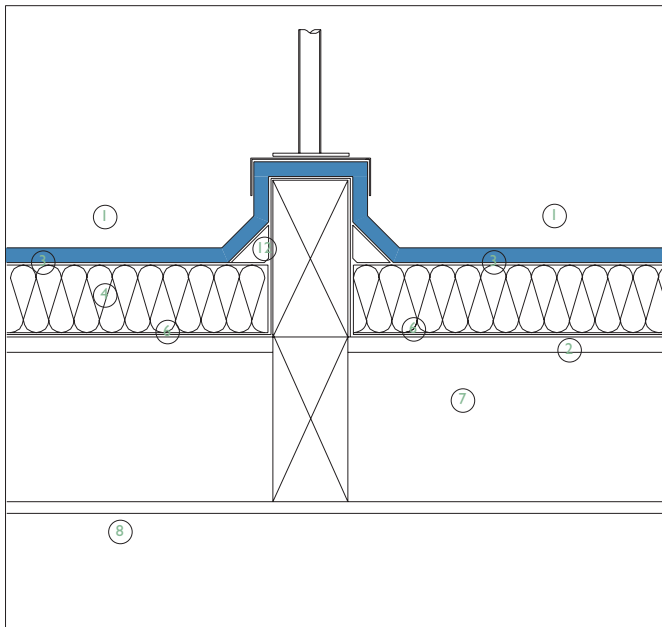
forming an upstand, sheathing felt is fixed to the substrate, often a separate upstand fixed to the roof, as mentioned earlier. Expanded metal lathing, typically at 150mm centres, primed in bitumen, is fixed to the face of the sheathing layer, which provides a 'key' to which the asphalt will bond. Where the upstand is formed in lightweight concrete block, the surface is faced with either a sand cement render, or metal laths and sheathing felt is used as described.

As with upstands in other materials, the asphalt extends a minimum of 150mm above the finished roof level. If the upstand is formed directly against concrete blockwork, then the thickness is usually only around 13mm. If the upstand to be waterproofed in



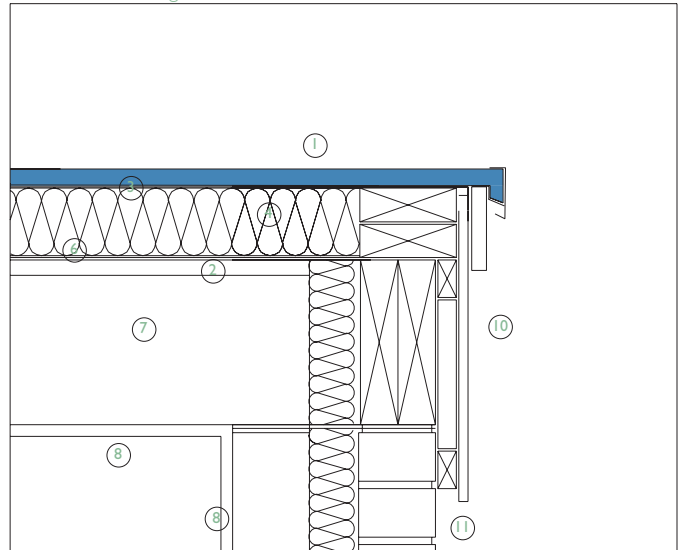
Section 1:10. Step in roof

Section 1:10. Balustrade



Section 1:10. Pipe penetration

Section 1:10. Rooflight



asphalt is higher, then the material increases to 20mm, as used on the general areas of roof. The junction of wall and roof, or upstand and roof, is formed with an angle fillet, where the material folds through two 45° folds. A single 90° internal fold can result in a failure of the material. The 45° angle fillet formed also strengthens the junction, allowing it to absorb more movement between wall and roof deck. In masonry walls, the top of the asphalt is turned into a chase, or horizontal groove, between blockwork courses, or is formed by a groove being cast into a reinforced concrete upstand. Where a timber upstand is used which is separate from the main upstand (discussed earlier) the adjacent thermal insulation on the roof deck is set

25mm away from the upstand. This is to provide a slot for additional asphalt in order to strengthen the junction of vertical and horizontal areas of asphalt. Upstands to rooflights are formed to a height of 150mm above the finished roof level. The asphalt is continued up and across the top of the upstand. The asphalt is usually bedded in expanded metal lathing fixed over sheathing felt, as used with other forms of upstand.

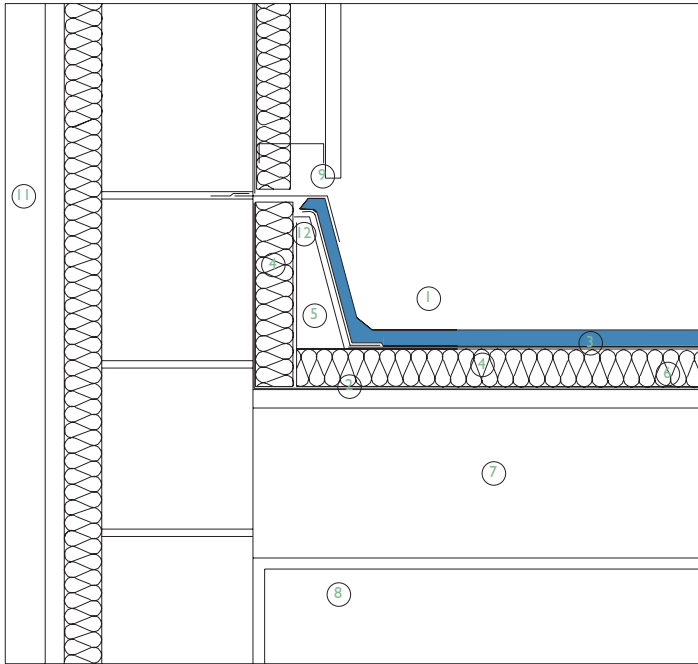
Eaves and verges

Trims to verges and eaves are formed with a GRP or aluminium trim in order to support the bottom edge of the asphalt. Some installations use no trim at all, but the edge becomes vulnerable to damage and

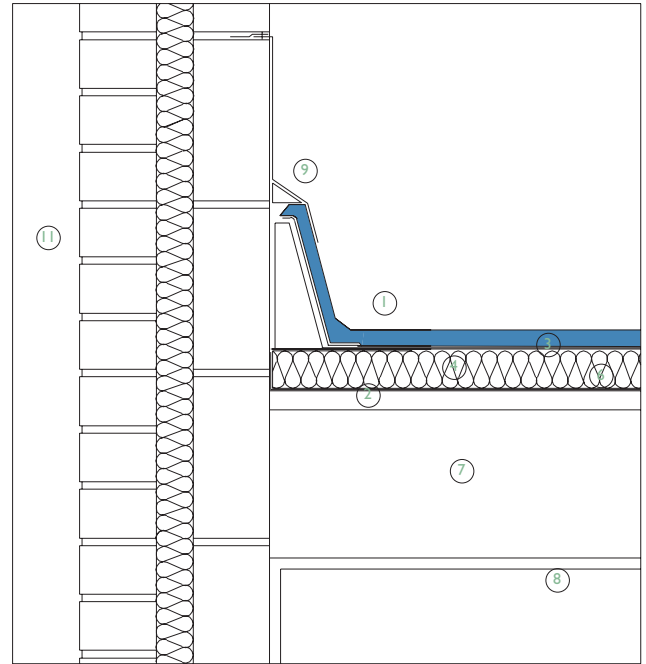
can result in a visually uneven appearance. When the asphalt edge is terminated by a gutter, a metal flashing can be set under the bottom of the asphalt. Alternatively, an aluminium or GRP edge trim can be used.

Verges can be formed by creating an asphalt upstand as shown in (C), built to a height of around 50mm to suit the expected flow from the roof. An alternative detail is to stop the asphalt at the edge of the roof and terminate in a metal strip so that the asphalt cannot be seen from below, but in practice it can be difficult to achieve a reliable seal between the asphalt and the metal trim. At the junction with a timber or metal-clad wall set on the roof, an upstand is formed on the roof as shown in (D) so that the upstand is

Section I:10. Parapet



Section I:10. Parapet



Details

1. Mastic asphalt
2. Plywood sheet or timber boards
3. Separating layer
4. Rigid thermal insulation
5. Freestanding timber upstand
6. Vapour barrier
7. Softwood joists
8. Dry lining/drywall internal finish
9. Metal flashing
10. Fascia board
11. External wall
12. Expanded metal lathing
13. Rainwater outlet

Saltwater Pavilion, Neeltje Jans, Holland. Architect: Oosterhuis Associates.



supported by the roof only, in order to avoid the possibility of rainwater penetration as a result of structural movement between the roof and the wall.

A verge or fascia can also be formed by creating a low upstand in timber sections which are fixed down to the structural timber deck, as (E). The asphalt is dressed up across the top of the low upstand, bedded in expanded metal lathing with sheathing felt beneath. The insulation is separated from the timber sections in order to allow the asphalt to dip down to the level of the deck to provide additional strength to the joint. An edge trim is usually introduced on the edge of the roof to terminate the asphalt and provide a visually crisp edge as seen from below.

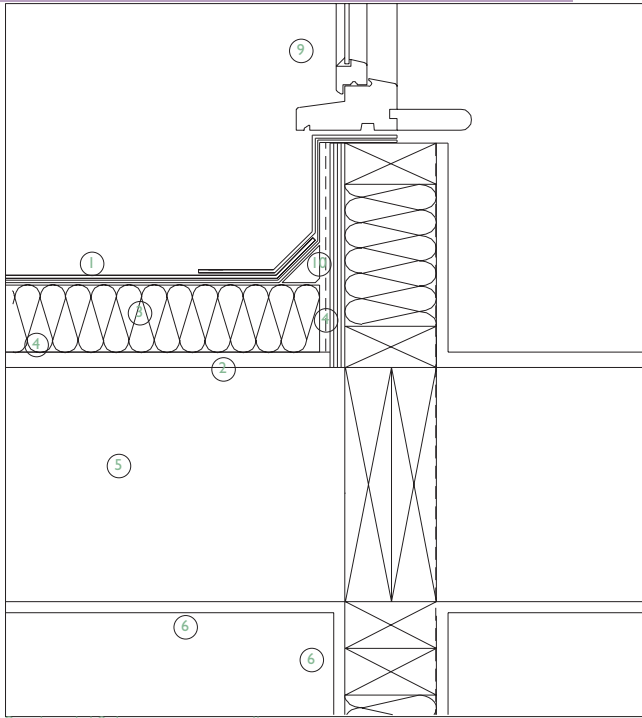
Penetrations

Penetrations through an asphalt covered roof are formed by extending the asphalt by 150mm to create a collar round the material. The top of the asphalt collar has an apron flashing around it to protect the top of the asphalt. An alternative method of sealing a roof penetration is to form a complete upstand around the penetration which can be insulated to the top of the opening. An insulated metal panel can then be mechanically fixed and sealed, or bonded, to the duct or pipe creating the penetration. An additional secondary seal, formed typically with either EPDM or metal sheet, forms a secondary seal to this penetration.

Gutters and rainwater outlets

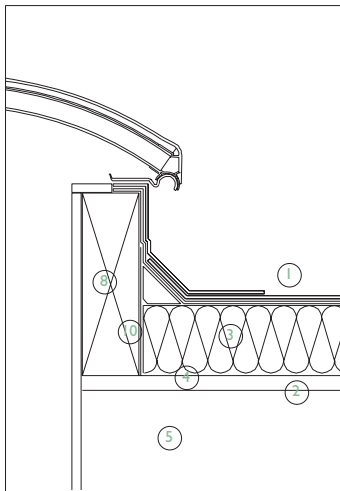
Gutters can be formed to any shape created within the timber deck since asphalt can be laid to suit a complex geometry without the need for joints in the material. Where the gutter is formed as a parapet gutter at the base of the tiled roof, the asphalt is carried up over the tilting fillet of the tiled roof.

Rainwater outlets are formed by setting the outlet at the level of the structural deck. The asphalt is stepped down with 45° folds down into the rainwater outlet, and the metal grating and cover is fixed down onto this. The sheathing felt extends up to the edge of the rainwater outlet.



Section 1:10. Low parapet wall

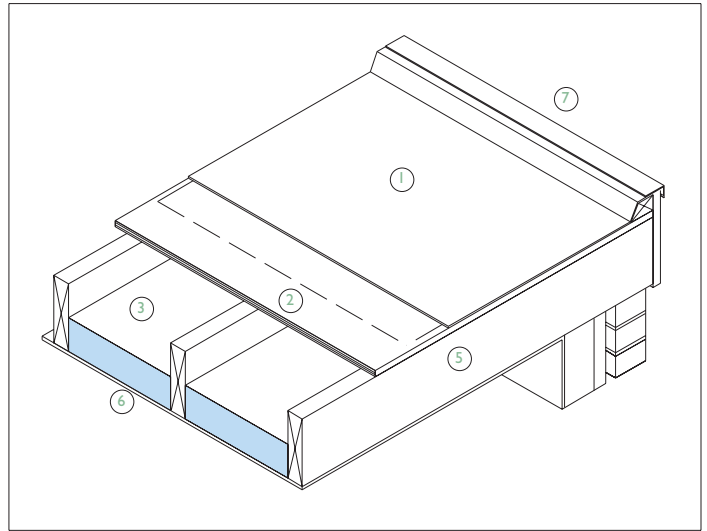
Section 1:10. Rooflight



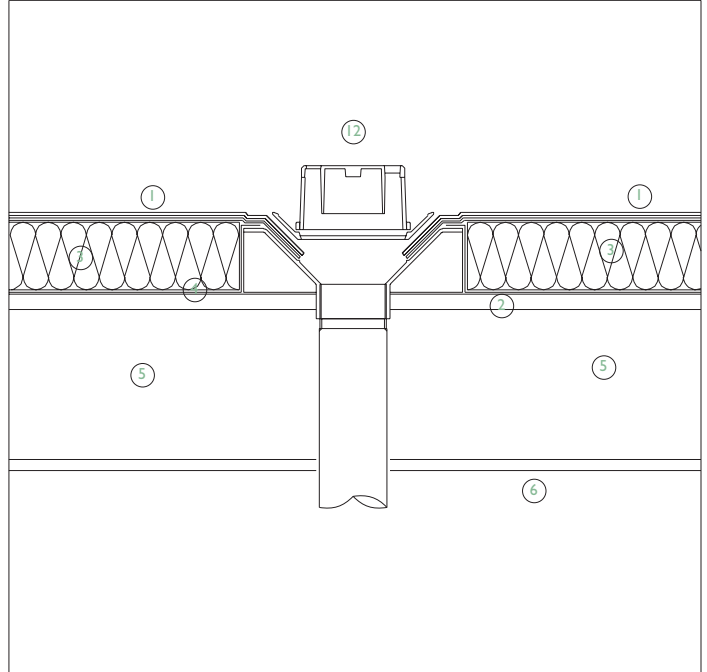
Details

1. Bitumen-based sheet
2. Plywood sheet
3. Rigid thermal insulation
4. Vapour barrier
5. Softwood joists
6. Dry lining/drywall internal finish
7. Metal flashing
8. Timber upstand
9. External wall
10. Angle fillet
11. Proprietary skirt flashing
12. Rainwater outlet
13. Paving bonded to bitumen-based sheet

Isometric view of assembly



Section 1:10. Rainwater outlet



This section discusses flat timber roofs that use a bitumen sheet-based membrane as a waterproofing layer in a warm roof, which is a common combination. Although other membrane materials are used on flat timber roofs as both warm and cold roofs, typically formed in elastomeric and thermoplastic membranes, their application is discussed as Exposed Membranes in the Concrete chapter. The principles of detailing in that section can be similarly applied to timber roofs. Bitumen-based sheet can also be used in 'inverted roof', or concealed membrane configuration as described in the Concrete Chapter where the detailing is similar, but bitumen-based sheet is generally less robust than the membranes described in that section. Mem-

branes applied to concrete decks are usually laid in hot liquid form and are reinforced to suit the specific conditions of folds and joints occurring within the structural deck. In this section the material is considered as an exposed and visible material on a relatively lightweight deck.

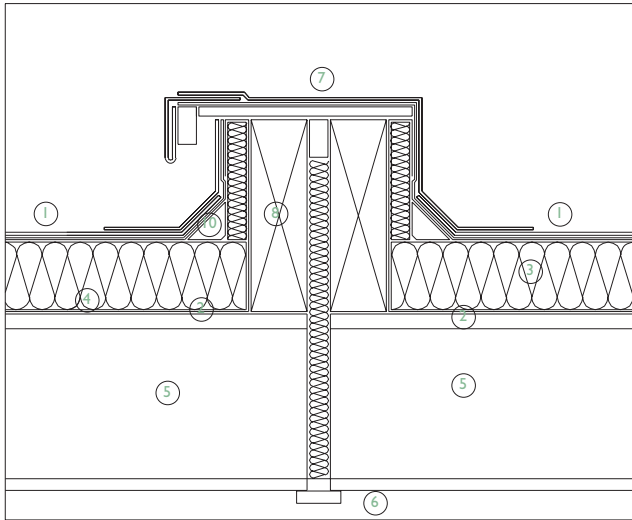
Bitumen sheet membranes are economic, and are often used with timber roof decks, which together provide an economic roof design for relatively small-scale applications, or designs with a complex geometry of low pitched roofs, as is often used in housing and in school buildings. Bitumen-based membranes have developed over the past 25 years to compete with the newer elastomeric and thermoplastic materials by

increasing their flexibility and making them thinner, requiring less material, which helps to reduce their overall cost. Bitumen-based membranes can also be used with concrete and metal decks, and the principles here can be applied in a similar way to those roof deck types.

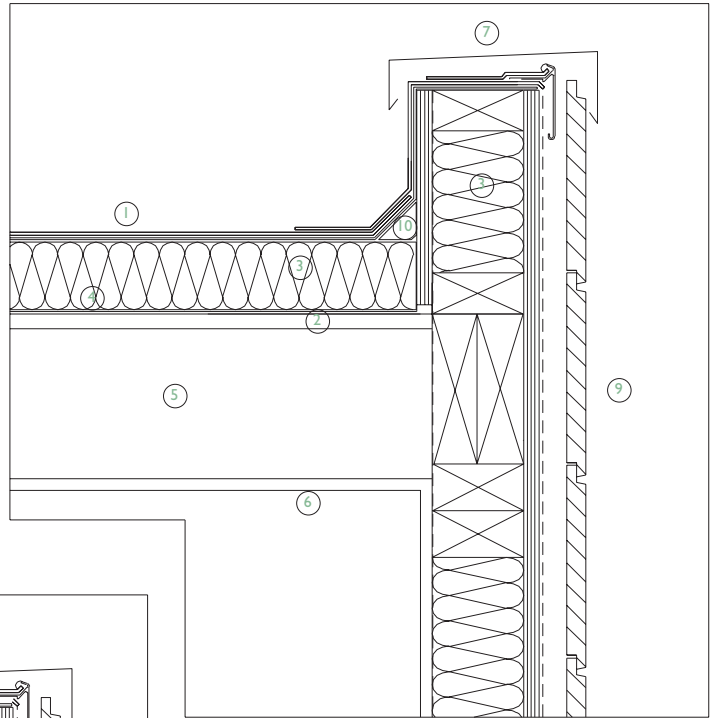
The material

Bitumen-based sheet is manufactured in roll form in widths of around 1000mm, is black in colour, and is typically mixed with SBS (styrene-butadiene-styrene) polymers or with TPO (thermoplastic polyolefin) polymers. The addition of these polymers raises the melting point which ensures stability in hot weather as well as increasing the flexibili-

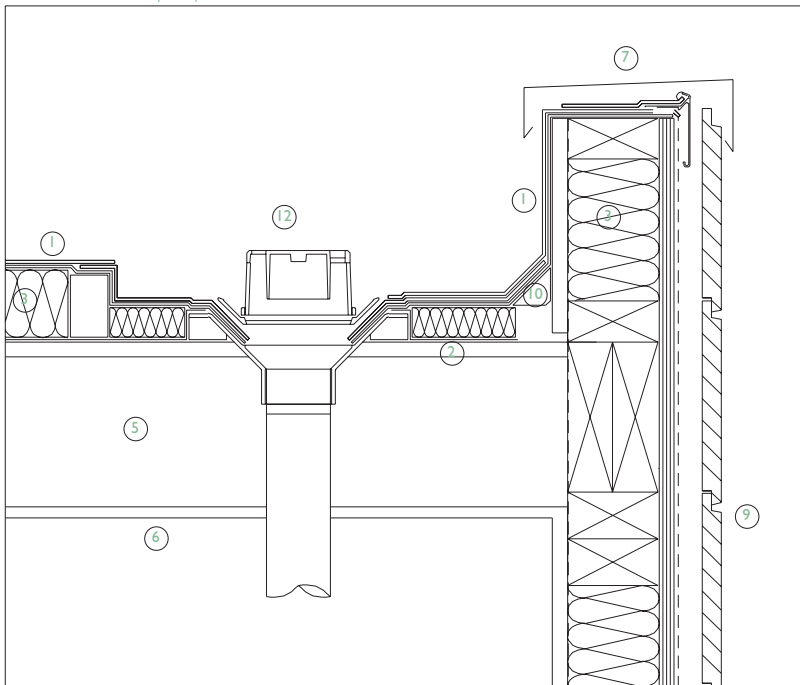
Section 1:10. Expansion joint



Section 1:10. Low parapet wall Detail A



Section 1:10. Low parapet wall with drain outlet



Pavilion, Burgundy, France. Architect: Dirk van Postel.



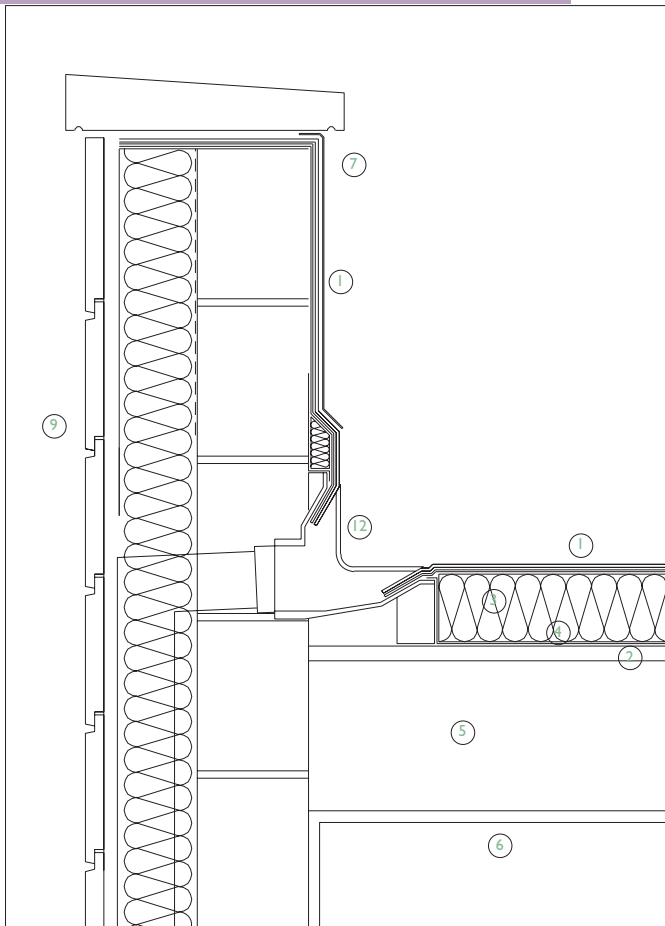
ty of the material at low temperatures (usually in winter in temperate climates) and enhancing the fire resistance of the material. Bitumen-based sheet often has a glass fibre reinforced upper face to provide greater dimensional stability and resistance to accidental damage, as well as a polyester reinforced core to increase tensile strength. These sheet materials are typically around 4mm thick, depending on the proprietary system used. Even with these additives, bitumen-based sheet is slowly oxidised by heat, making the material gradually more brittle which eventually results in cracks. The polymer additives reduce this effect, particularly the TPO additives which help to increase the life of the material, which can now be up to

around 25 years. TPO-modified sheet can be exposed to the effects of the sun, requiring no additional solar protection, since the material provides better UV resistance than older-type bitumen-based membranes. SBS-modified sheet is usually covered with stone chippings or solar reflective paint to protect them from the effects of the sun.

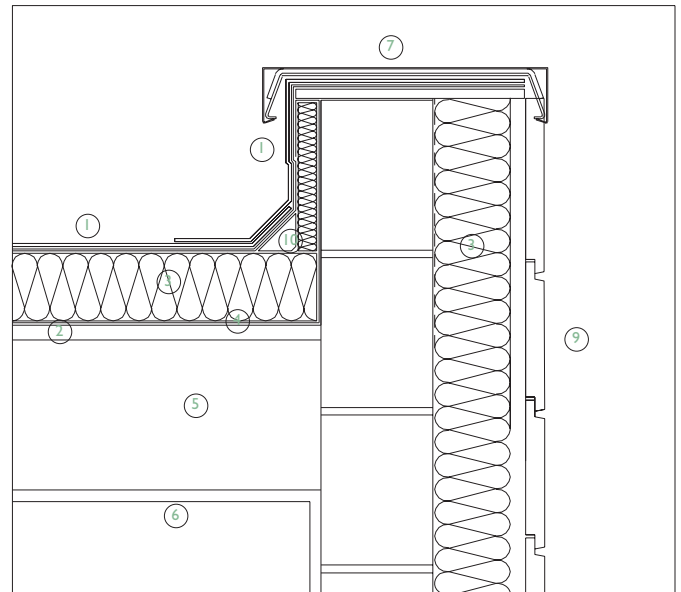
Roof build-up

Where plywood is used to form the structural deck of a timber roof, the joints between plywood boards are usually taped to provide a continuously smooth surface. On timber boarded decks, where this is not as practical a method, a thin layer of bitumen is laid onto the deck, applied typically in thick

liquid form to seal the joints between the boards, the bitumen setting to form a smooth substrate. A vapour barrier is set onto the prepared timber deck, the barrier being often bitumen-based as part of a proprietary system. Rigid closed cell insulation such as polyurethane is bedded in hot bitumen onto the vapour barrier to hold the insulation securely in place. A loose laid perforated isolating layer is set onto the thermal insulation which is used to allow the membrane and thermal insulation to release gases into the isolating layer which are formed as a result of bonding the bitumen to the insulation. The bitumen-based membrane is then bonded to the thermal insulation through the holes in the isolating layer:

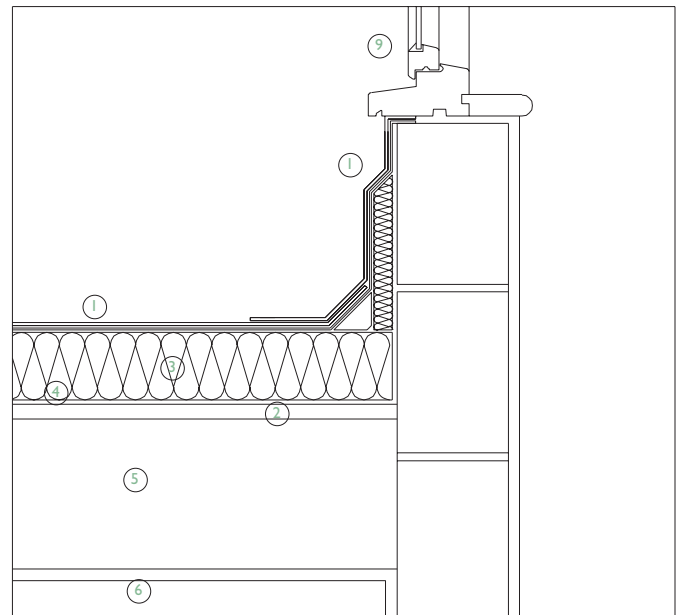


Section 1:10. Section 1:10. 2-way drain outlet Detail C



Section 1:10. Low parapet wall Detail B

Section 1:10. Door threshold



Details

- | | |
|--|---|
| 1. Bitumen-based sheet | 8. Timber upstand |
| 2. Plywood sheet | 9. External wall |
| 3. Rigid thermal insulation | 10. Angle fillet |
| 4. Vapour barrier | 11. Proprietary skirt flashing |
| 5. Softwood joists | 12. Rainwater outlet |
| 6. Dry lining/drywall
internal finish | 13. Paving bonded to
bitumen-based sheet |
| 7. Metal flashing | |

Solar protection

Resistance to UV radiation is provided by either a coating of fine stone chippings or by aluminium solar reflective paint applied to the visible surface of the bitumen-based sheet. As a result of providing this additional UV protection, these coatings have the additional benefit of reflecting heat, which has the effect of reducing the surface temperature of the roof below that which would otherwise be the case. Solar reflective paint gives the roof a metal appearance, which provides a visual alternative to the characteristic black colour of bitumen-based sheet. Membranes can also be provided with a solar protection layer during manufacture as part of a proprietary bitumen-based membrane system.

Fixing methods

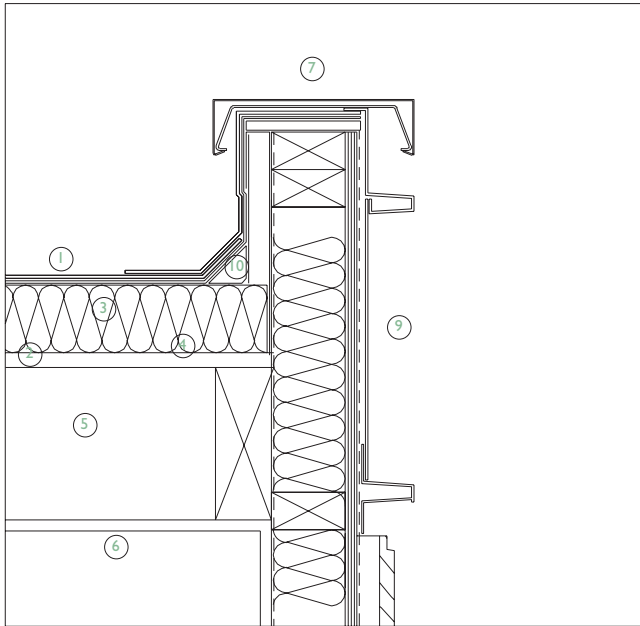
Bitumen-based membranes are fixed typically by either torching, bonding or mechanical fixing methods. With torching, a flame is used to melt an adhesive layer on the underside of the sheet so that the membrane adheres to the substrate. Sheets are lapped by around 100mm to ensure a water tight seal. Torches are usually gas fuelled, supplied from a small canister as part of a hand-held tool, or are supplied from a large gas cylinder set onto the roof to a variety of tools, either hand-held or wheeled, for larger scale applications.

In the bonded method, the sheet is applied cold onto the substrate, the adhesive being either poured and spread in place or

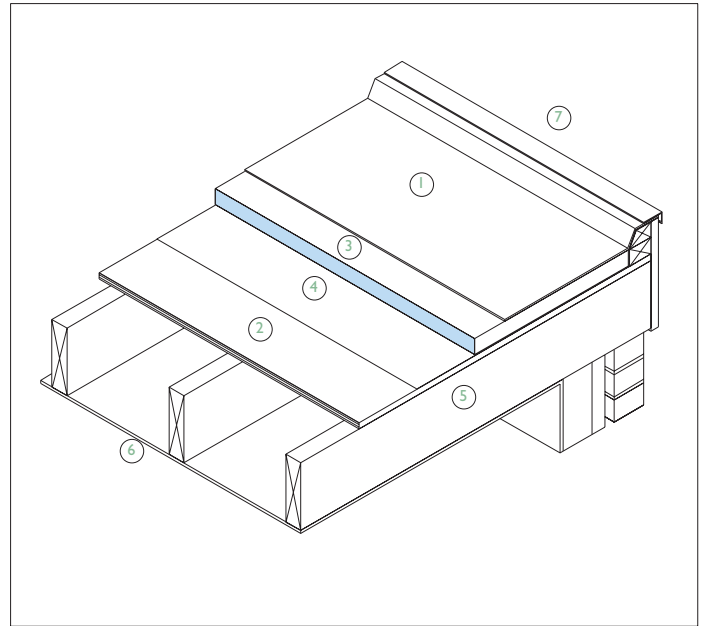
spray applied to the substrate / structural deck. Bitumen-based sheet is laid on top and is rolled into place. Laps are sealed with adhesive, but torching is sometimes used to seal the laps of bonded membranes to allow them to be installed more quickly. Like elastomeric and thermoplastic membranes, the hot air welding of laps and joints is being introduced. A tool that provides hot air to the edge of the material is used that allows the material to melt locally and be sealed together. The use of bonding avoids the need for a flame that can damage adjacent finished work.

With the mechanical fixing method no adhesive is required, the membrane being fastened through the insulation layer into the

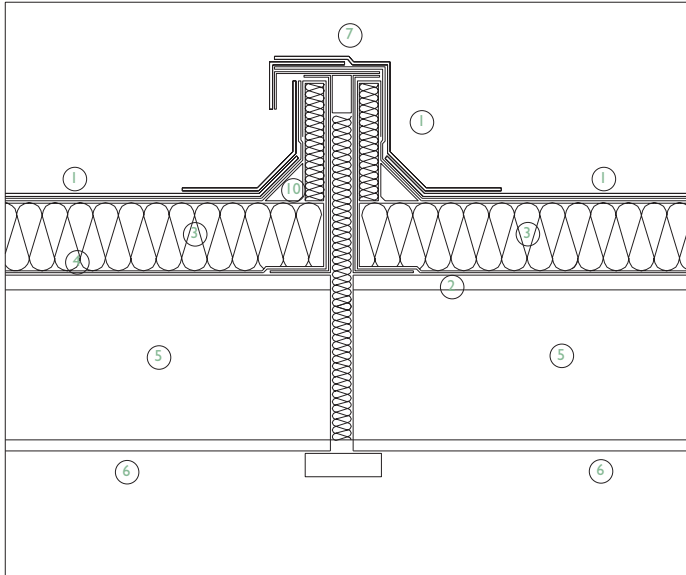
Section 1:10. Low parapet wall



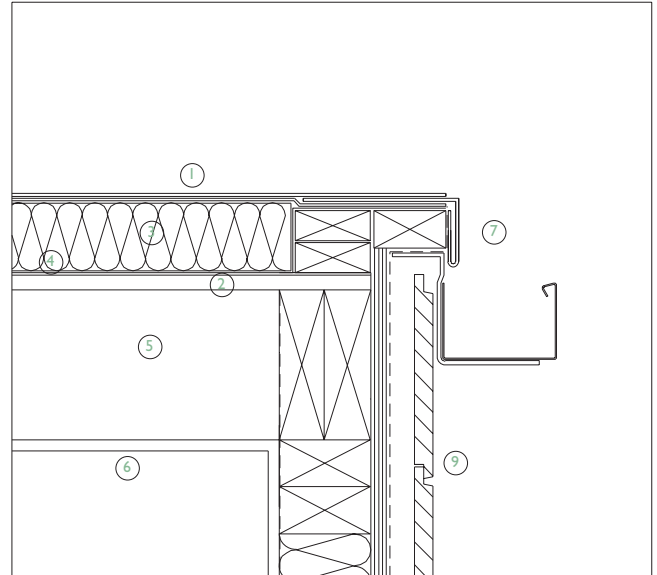
Isometric view of assembly



Section 1:10. Expansion joint



Section 1:10. Eaves Detail D



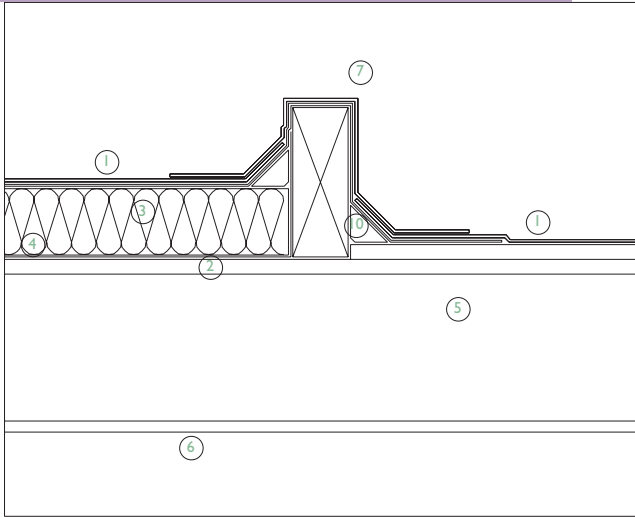
timber deck with disc-type fasteners. Laps between sheets are usually torch sealed to a width of around 150mm. A vapour barrier, with sealed laps, is laid onto the structural deck or substrate with the insulation set on top. The insulation is mechanically fixed to the deck, with the bitumen-based sheet laid onto the insulation. The mechanical fasteners are fixed within the area of the lap in the sheet through the insulation into the deck beneath. Mechanical fixings are covered by strips or are lapped over the top of the fixings, the laps being sealed by torching, then pressed in place with a roller tool.

Parapet upstands

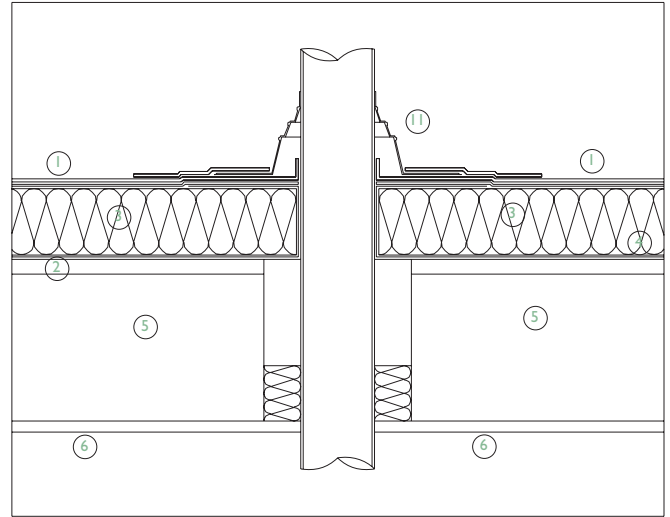
Upstands in bitumen-based sheets are

formed by either fixing the sheet to the plywood face of a timber framed upstand as (A), or to the face of the thermal insulation as (B), depending on the configuration of the external wall. Where a timber roof deck meets a masonry wall, as (B) where a concrete block wall is clad in timber rainscreen panels, the bitumen-based sheet is shown fixed to the face of the upstand. With a low upstand, the membrane continues up the full height and extends across the top of the wall underneath the coping. The roof membrane is made continuous with the waterproof seal of the external wall, with the membrane as shown in (B) terminating against the bitumen paint finish of the external face of the blockwork wall. The coping

can be made from any impervious and durable material. A pressed metal coping is shown in (B), overhanging on both sides to provide added protection to the membrane as it folds over the top of the wall. Upstands to high parapet walls can be formed by terminating the membrane 150mm above the finished roof level. Above this level the wall is waterproofed with a different method, as shown in (C). Typically, concrete walls are waterproofed with bitumen paint and an external panel-based finish, or render. The top of the membrane is protected with a folded metal flashing such as aluminium, which is either bedded into a groove formed in the joint between courses of blockwork, or the metal strip is sealed against the wall

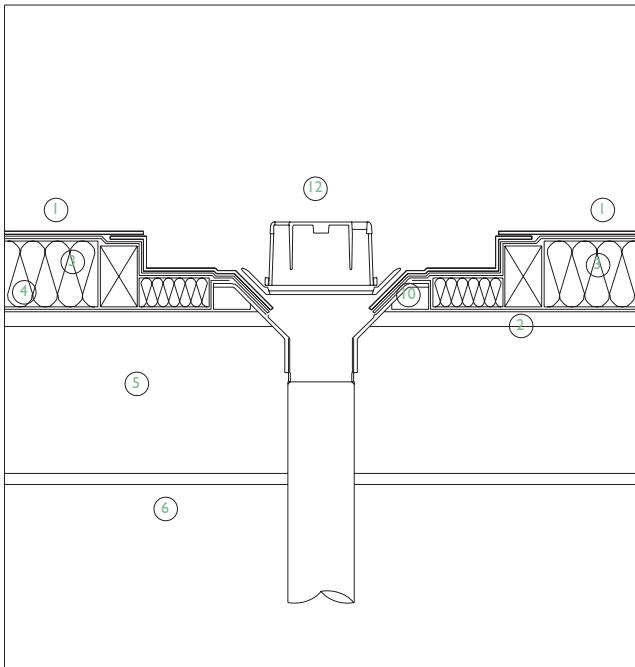


Section 1:10. Step in roof



Section 1:10. Pipe penetration

Section 1:10. Rainwater outlet



Pavilion, Burgundy, France. Architect: Dirk van Postel



with silicone if a concrete wall is used. The vapour barrier continues up the full height of the membrane. A 45° angle fillet is used to avoid turning the bitumen-based sheet through a full 90° fold in a junction where significant structural movement can be expected.

Upstands for perforations and movement joints are formed in the same way as other upstands, but the membrane continues over the top of the upstand. Where an expansion joint is formed, the membrane is separated on one side of the movement joint to open and close as a result of structural movement.

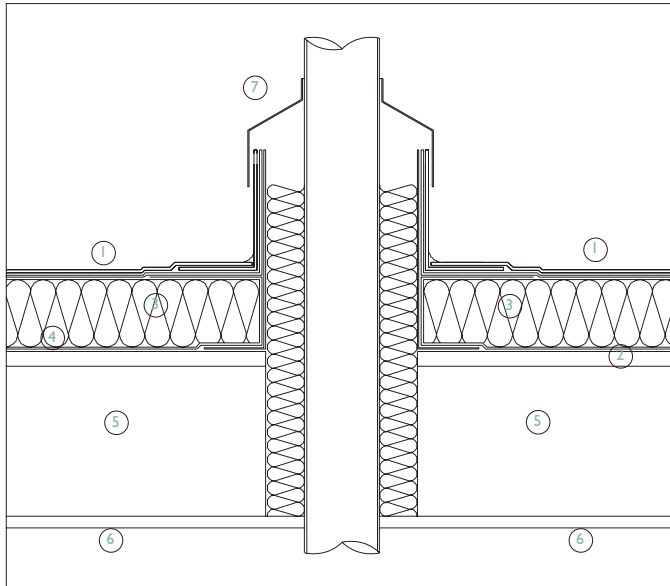
Junction with tiled roof

The junction of a flat roof and a tiled

pitched roof is formed by extending the base layer and membrane up 150mm above the finished roof level, with an additional reinforcing layer to strengthen the junction. The roofing felt, or breather membrane, of the tiled pitched roof extends down over the top of this membrane to provide a complete weather tight seal across the roof. The bottom top row of tiles are kept clear of this junction in order to avoid the possibility of damage and to ensure that rainwater running down the tiles cannot run back up the gap between the tile and the roof membrane by capillary action. Where a bitumen-based membrane forms a waterproof covering to an area of flat roof at the top of the pitched roof, the membrane is folded at the

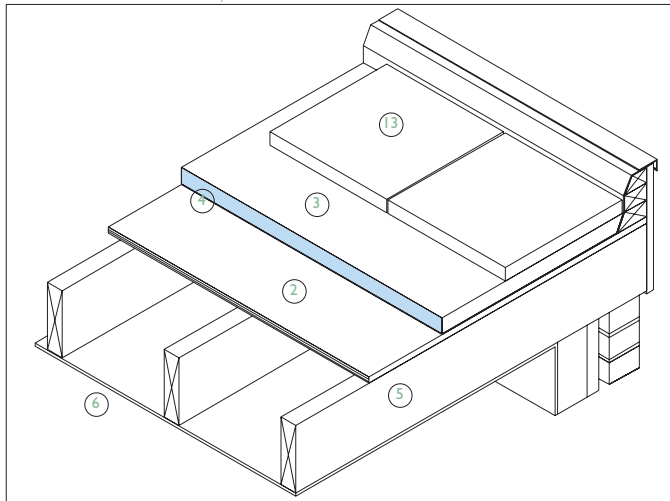
edge to form a drip, so that rainwater cannot track up into the roof construction. A metal drip is sometimes used to give a visually sharper edge to the roof. The vapour barrier beneath the thermal insulation is turned up so that it terminates against the edge of the membrane drip to provide a continuous barrier. A metal flashing extends down from the vapour barrier and is lapped over the top of the tiling to provide a complete seal from bitumen-based membrane the roof tiles beneath. The roofing felt or breather membrane under the roof tiling is terminated against the underside of the upper timber deck. Where the membrane meets a rooflight upstand the bitumen-based sheet is taken over the top of the timber

Section I:10. Pipe penetration



- | | | | |
|-----------------------------|-----------------------|--|------------------|
| Details | | 5. Softwood joists | 10. Angle fillet |
| 1. Bitumen-based sheet | 6. Dry lining/drywall | 11. Proprietary skirt flashing | |
| 2. Plywood sheet | 7. Metal flashing | 12. Rainwater outlet | |
| 3. Rigid thermal insulation | 8. Timber upstand | 13. Paving bonded to bitumen-based sheet | |
| 4. Vapour barrier | 9. External wall | | |

Isometric view of assembly



upstand to form a continuous seal with the vapour barrier on the inside of the building, where required, as well as the vapour barrier beneath the thermal insulation. The rooflight is fixed to the top of the sealed upstand, typically with a continuous timber glazing bar or metal strip that seals the gap between glazing and upstand. The edge of the rooflight typically includes a drip to avoid water running back up into the joint between upstand and rooflight.

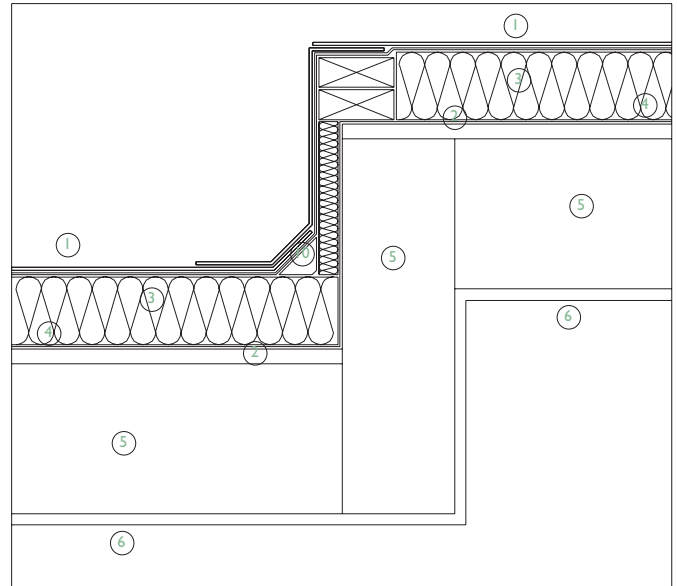
Eaves and verges

The eaves detail shown in (D) is formed with a folded drip formed in the same way as described for the junction with the top of a pitched roof. The gutter is tucked up

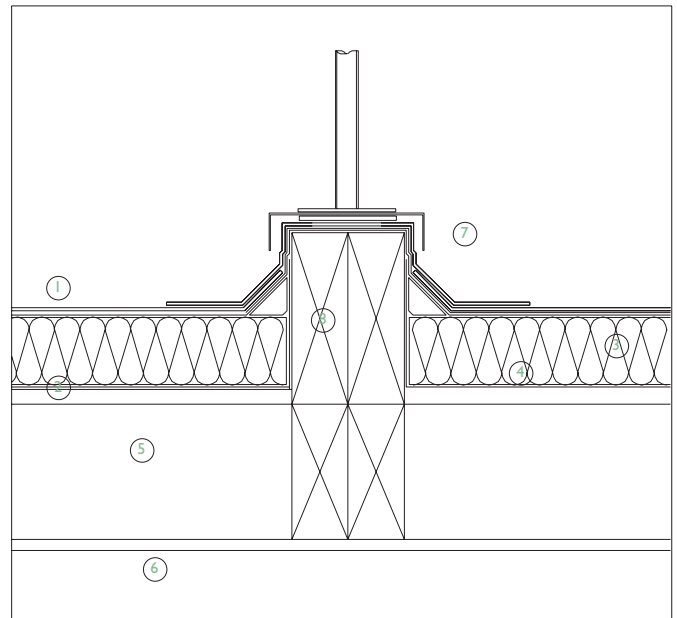
behind the drip to ensure that all rainwater running off the edge of the eaves is collected by the gutter; and that no water is allowed to run behind the gutter and down the face of the wall below, where staining can occur from the dust washed off the flat roof. The vapour barrier under the thermal insulation is continued to the edge of the roof to ensure that the timber sections forming the edge of the eaves are kept dry and ventilated within the roof void beneath. The thermal insulation is kept continuous between wall and roof to avoid thermal bridging that reduces the thermal insulation value of the external envelope.

Verges typically extend along the edge of shallow slopes of bitumen-based roofs, and

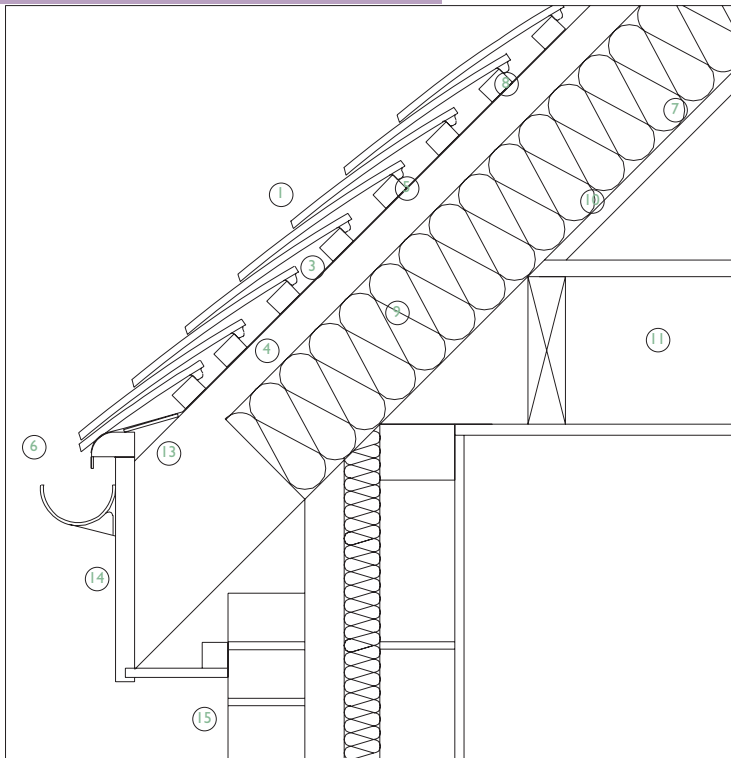
Section I:10. Step in roof



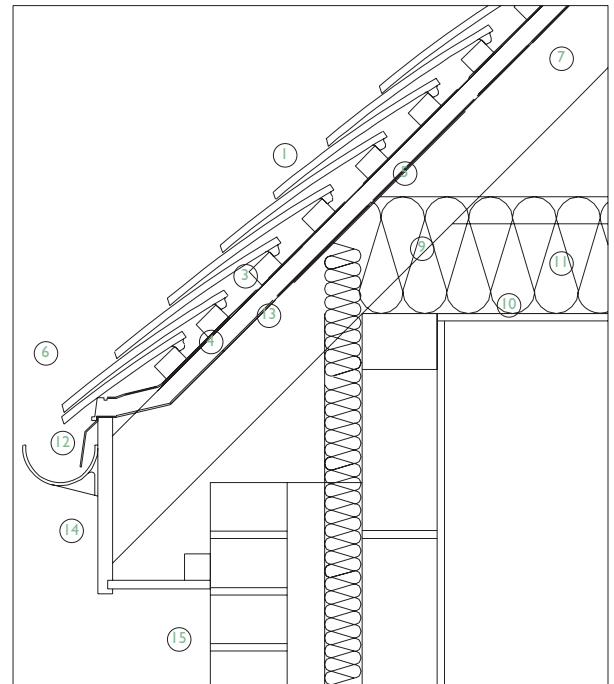
Section I:10. Balustrade



are formed with a low upstand that prevents rainwater from running over the edge of the verge. The membrane is continued up over the top of the upstand. A GRP or metal edge trim is set at the edge to terminate the membrane as well as forming a drip at the top of the external wall. An additional sealing strip of membrane is lapped over the edge trim to provide a complete water tight barrier, as well as providing reinforcement to strengthen the joint. The vapour barrier extends up the side of the timber upstand but it is not necessary to extend it to the edge of the roof due to the extra layer of bitumen-based membrane that provides a full seal.

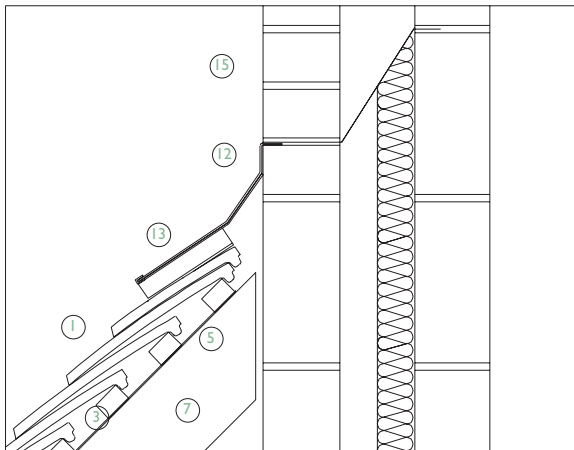


Section 1:10. Plain tiles. Eaves Detail E

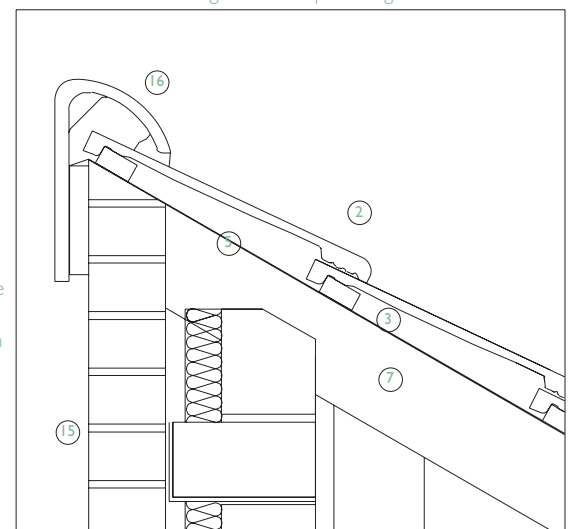


Section 1:10. Plain tiles. Eaves Detail B

Section 1:10. Plain tiles. Abutment



Section 1:10. Interlocking tiles. Monopitch ridge



Details

1. Plain tile
2. Interlocking tile
3. Softwood battens
4. Softwood counter battens
5. Roofing felt
6. Gutter
7. Softwood rafter
8. Vapour permeable membrane
9. Thermal insulation
10. Vapour barrier
11. Softwood joist
12. Metal flashing
13. Ventilator
14. Fascia board
15. External wall
16. Ridge capping

Clay tiles for roofs are most commonly made from clay or concrete. In the clay type natural clay is mixed with additives such as quartz, mica, iron oxide and crystalline aluminium oxide. Clay tiles are fired in a kiln at around 1100°C to make the material both rigid and resistant to moisture penetration. Plain tiles are used on pitched roofs ranging from vertical tile hanging to pitches as low as around 35° above the horizontal. Interlocking tiles, with grooves and complex laps can be used in down to a minimum pitch of 22.5° above the horizontal. Concrete tiles are made from aggregate and Portland cement which are mixed together and then cured in temperature-controlled chambers in the factory. Their appearance tends to imitate those of tradi-

tional clay tiles in both shape and variety of colour, but large interlocking tiles are available in sizes that are difficult to achieve in clay. In common with clay tiles, concrete plain tiles are used in roof pitches down to 35° above the horizontal. An advantage of concrete tiles over clay tiles is that some concrete interlocking tiles can be used for pitches as low as 12.5° above the horizontal.

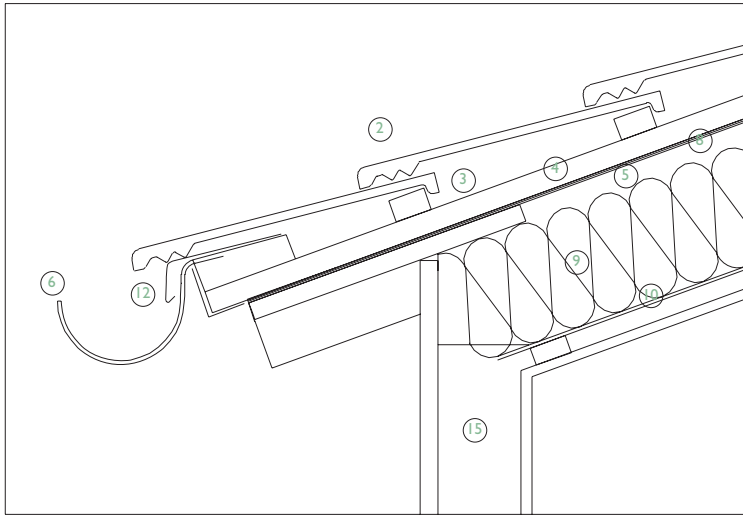
Both tile types are fixed to timber battens set horizontally, that is, at right angles to the direction of the slope. The battens are fixed onto roofing felt, which forms a second line of defence and full weathertight barrier to the roof. The roofing felt is set on timber rafters (sloping timbers) or full timber trusses. The tiles provide the first line of defence

against rainwater penetration as well as protecting the roofing felt from direct wind-blown rain, the effects of the sun, as well as protecting the felt from accidental damage. Many tile shapes and profiles are available which have been developed from historical examples. The design life for tiled roofs in both clay and concrete types is around 30 years but they are actually expected to last for around 100 years.

Plain tiles

Plain tiles are made in a variety of sizes, the most common being around 260mm x 160mm. Tiles are lapped by a minimum of around 35mm on their top edge, called the 'head lap', when hung vertically, and are head

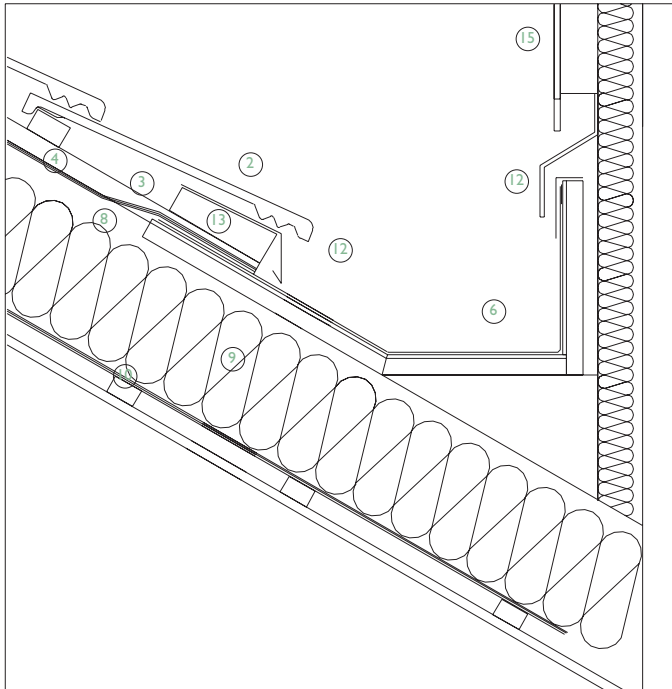
Section 1:10. Interlocking tiles.Eaves Detail F



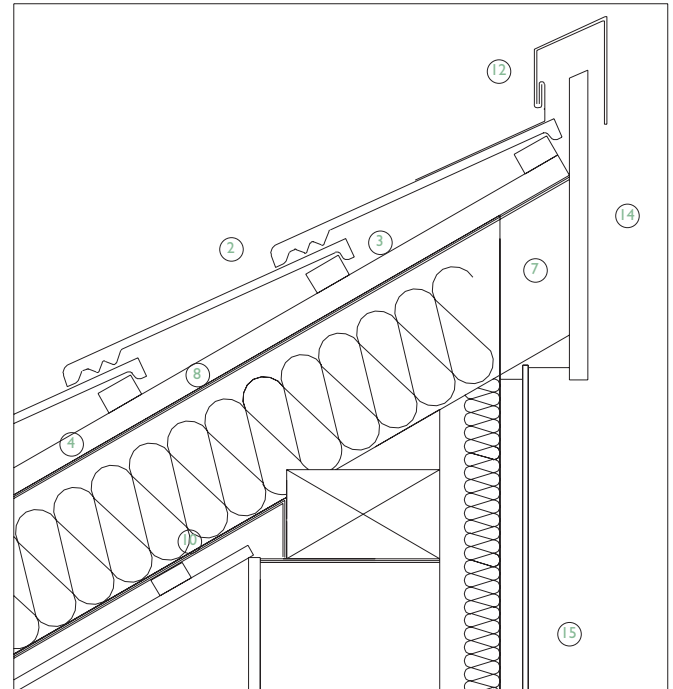
Nara Centennial Hall, Japan. Architect: Arata Isozaki



Section 1:10. Interlocking tiles.Valley gutter



Section 1:10. Interlocking tiles. Monopitch ridge



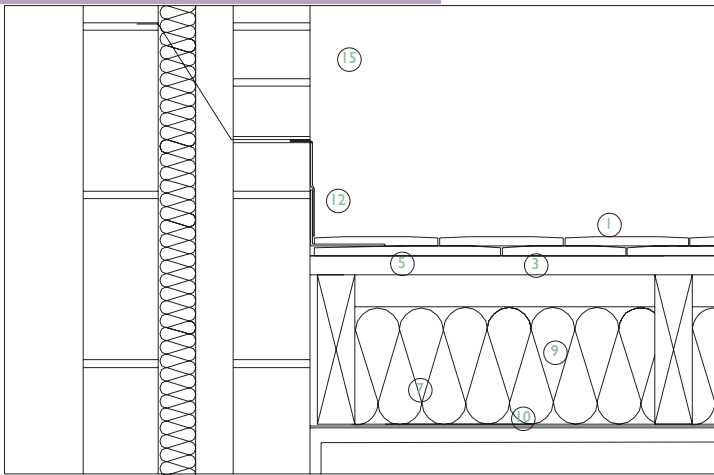
lapped by a minimum of around 65mm when hung on any slope down to 35° above the horizontal. The maximum head lap for all conditions is around 90mm, so that tiles are always lapped with three tiles set over one another, as (A). Tiles are butted up to one another on their sides, with joints staggered over one another to avoid rainwater penetration by draining water that penetrates the outer tile onto the middle of the tile beneath, where it runs on down the roof. With the maximum head lap, the smallest size of visible tile is around 170mm x 160mm, giving a shape to each tile approximating to a square. Tiles are fixed to battens with nails fixed through two holes at the top of the tile, which are covered by the two

tiles that lap over it. Tiles have two nibs (brackets) on their underside which hook over the battens to both support the weight of the tile and to align them on the battens, which are set out accurately to ensure that the required arrangement of tiles is achieved.

Interlocking tiles

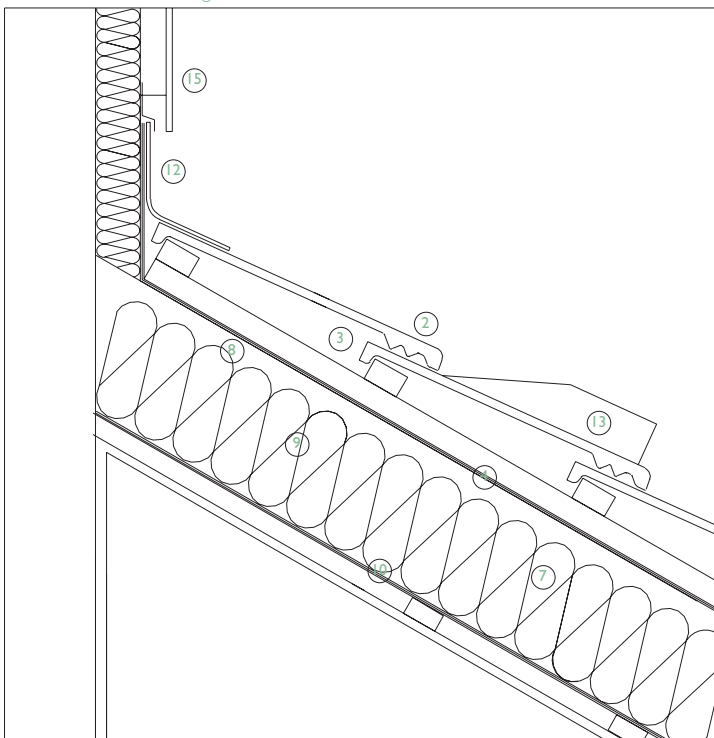
Interlocking tiles in both clay and concrete are also made in different profiles and sizes, with a typical size of around 400mm x 300mm. This tile type has a longer head lap of around 100mm which accommodates grooves in the bottom of the top tile. These grooves serve as drips to avoid the passage of rainwater up through the tile by capillary

action. Tiles are also lapped at their sides, again with grooves set into the tiles, usually on both faces of the tiles that lap. Again rainwater is drained down these grooves onto the centre of the tile below, which has the overall effect of draining the tile on all four sides. This interlocking of tiles, together with the provision of drainage grooves, avoids the need for three tiles to always lap one another, as is required for plain tiles. As tiles lap only at their edges, only one tile thickness is required, with any water that passes through the joint from windblown rain being drained down the roofing felt to the bottom of the roof. The typical 100mm head lap and 30mm side lap give a typical visible tile size of 300mm x 270mm which, like plain tiles, has a



Section I:10. Plain tiles. Abutment Detail P

Section I:10. Interlocking tiles. Abutment Detail N



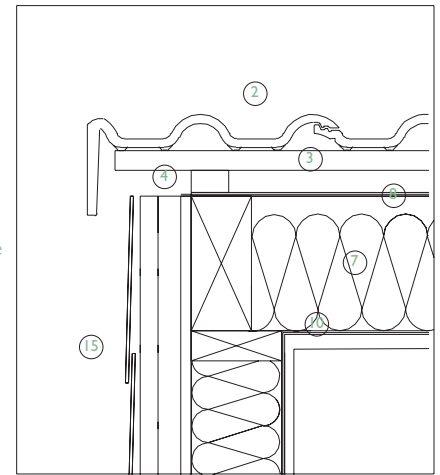
square-like size. This is often not perceived due to the rolled or wavy profiles typical of traditional designs, but is visually dominant in flat, modern designs. Like plain tiles, the interlocking types have nibs on their underside to hang and align the tile, and are fixed with nails which are usually larger than those used for plain tiles in order to secure the larger sized tiles.

Ventilation

Like flat roofs, pitched roofs are formed as either warm roofs or cold roofs. In the cold roof as (B), horizontal joints are insulated, and the void is ventilated to ensure that any condensation forming in the roof void can escape, which avoids damage to both the

timber and the thermal insulation. In recent years it has become more common to use a vapour permeable membrane or 'breather' instead of waterproof roofing felt. This is done to avoid ventilating the roof void, which can become very damp in temperate climates during winter. Any vapour in the roof void escapes through the breather membrane, but in practice the ceiling has to be completely sealed to avoid any vapour passing from the space below into the roof void. While a vapour barrier between the thermal insulation and the dry wall lining beneath is standard, in all roof constructions, the barrier must be completely sealed around roof hatches, pipes and ducts as well

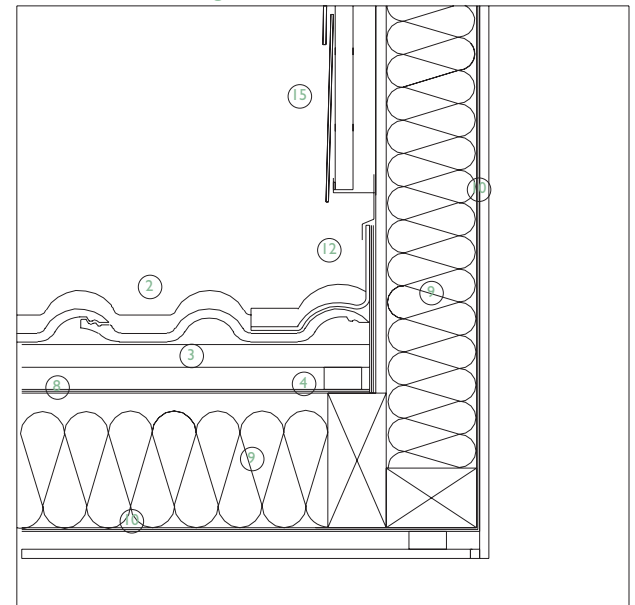
Section I:10. Interlocking tiles. Verge



Details

1. Plain tile
2. Interlocking tile
3. Softwood battens
4. Softwood counter battens
5. Roofing felt
6. Gutter
7. Softwood rafter
8. Vapour permeable membrane
9. Thermal insulation
10. Vapour barrier
11. Softwood joist
12. Metal flashing
13. Ventilator
14. Fascia board
15. External wall
16. Ridge capping

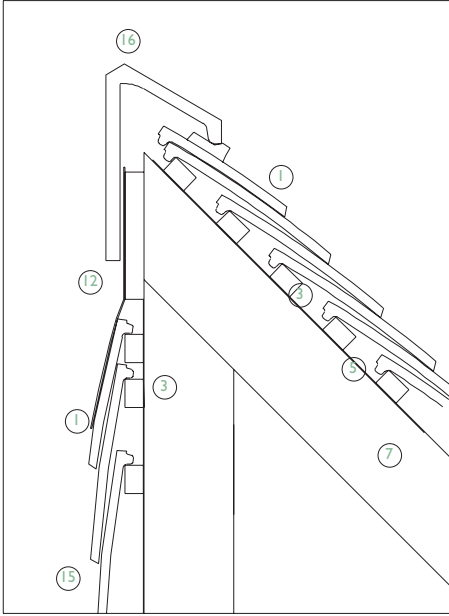
Section I:10. Interlocking tiles. Abutment Detail Q



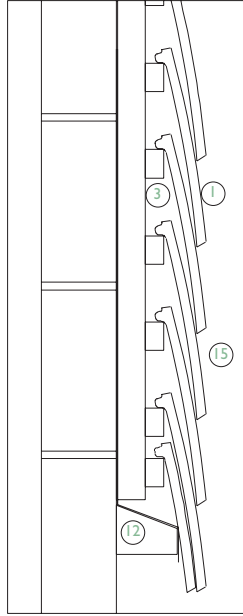
as at its edges for this to work. In practice, most cold roofs are still ventilated at the ridge and at the eaves even when a breather membrane is used as an underlay to the tiling. These principles apply equally to monopitch roofs as (C) and roof spaces which are divided.

In the warm roof, the sloping rafters are filled with thermal insulation in order to allow the internal space of the roof void to be used, as (E). As with the cold roof, a vapour barrier is set between the thermal insulation and the internal dry wall lining. A vapour permeable membrane is set on the outside face of the sloping rafters as an underlay to the tiling. If the insulation completely fills the void between the rafters, then

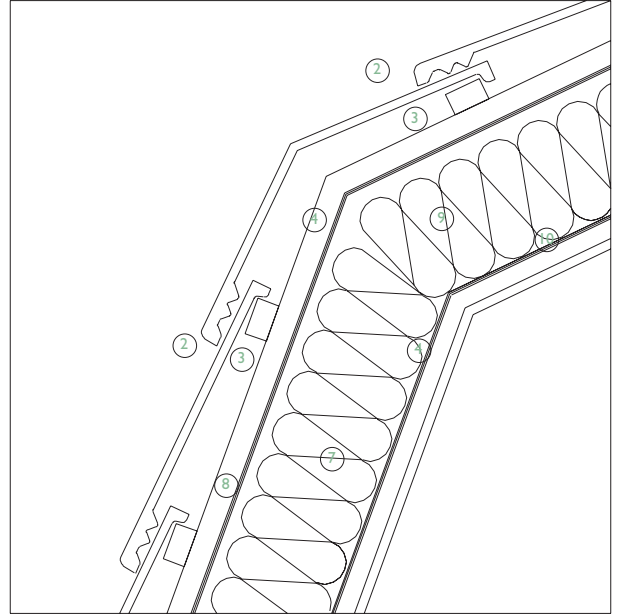
Section I:10.Plain tiles.Monopitch ridge Detail C



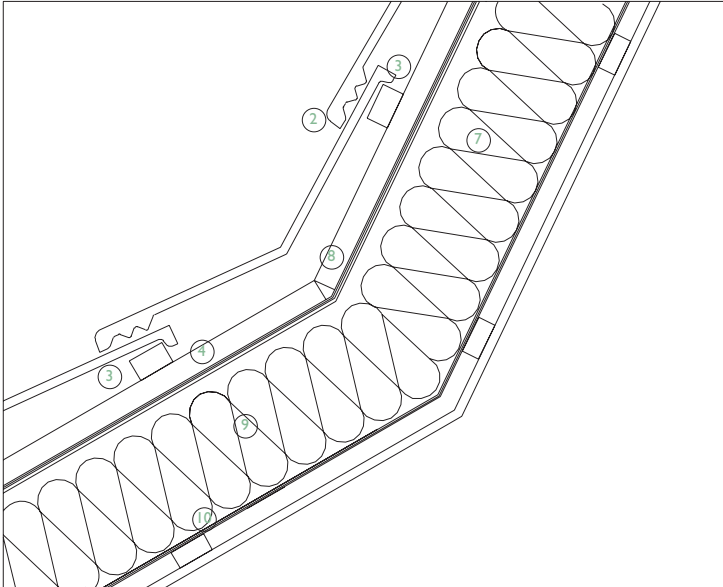
Section I:10.Vertically hung tiles



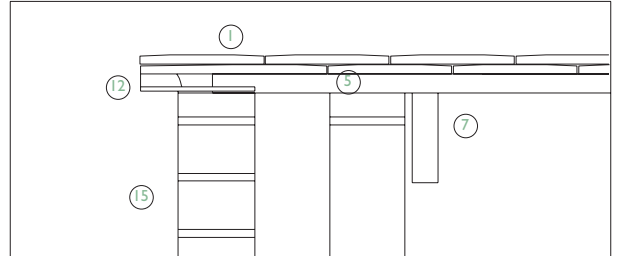
Section I:10.Interlocking tiles.External fold



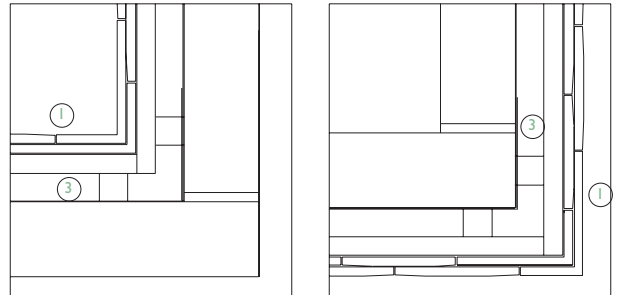
Section I:10.Interlocking tiles.Internal fold



Section I:10.Plain tiles.Verge Detail H



Plan I:10.Vertically hung tiles at internal and external corners



this breather membrane serves to allow moisture trapped within the construction to escape. If the thermal insulation does not fill the void, and is set against the internal dry lining, then the void between the insulation and the breather membrane is ventilated at the ridge and at the eaves. Where a breather membrane is used, the cavity between the outside face of the membrane and the tiles is increased from 25mm to 50mm to allow the air within the void to move more freely, ensuring that vapour being released to the outside can be dispersed easily. The increased gap if formed by battens set perpendicular to the tiling battens, called counter battens, which are set in the direction of the rafters, and are fixed down to

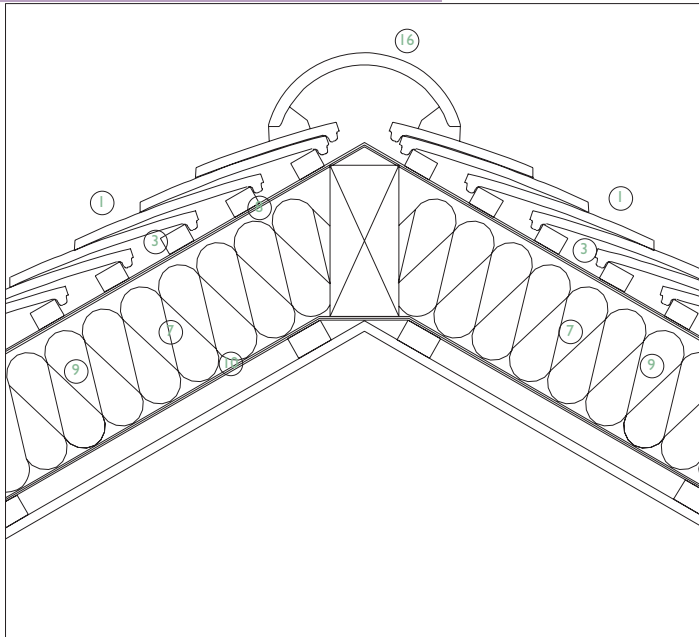
them through the underlay.

Eaves

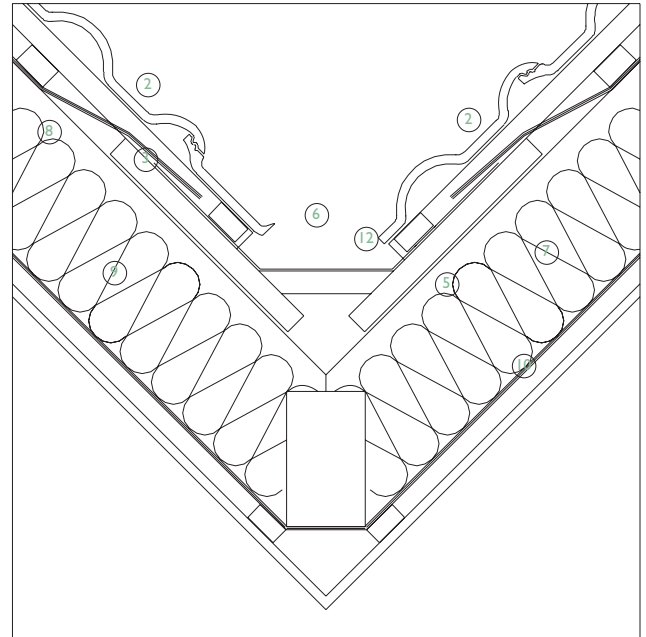
Both plain tiles and interlocking tiles are terminated at their base with a gutter. In order to maintain a constant pitch of tiles down to the gutter; the bottom row of battens is raised up on a wedge-shaped timber profile called a tilting fillet. This allows the underlay to meet the underside of the bottom tile, and drain both rainwater running down the tiles as well as any moisture running down the underlay, into the gutter. A ventilator; typically in PVC-U, is set between the bottom tile to ventilate either the roof void in a cold roof, or the cavity between the underlayer and the tiles in a warm roof

configuration.

In the cold roof version the proprietary ventilator is set beneath the underlayer as shown in (F). Fresh air is allowed to flow into the ventilator set beneath the bottom tile and is released into the roof void without affecting the thermal insulation of the roof at ceiling level, which is continuous between wall and roof. In the warm roof version, a ventilator set between the bottom tile and the felt underlay introduces air into the void between the tile and the breather membrane. The thermal insulation either continues to the fascia board, then returns horizontally back from a continuity with the wall insulation, or alternatively the wall insulation continues vertically until it reaches the slop-

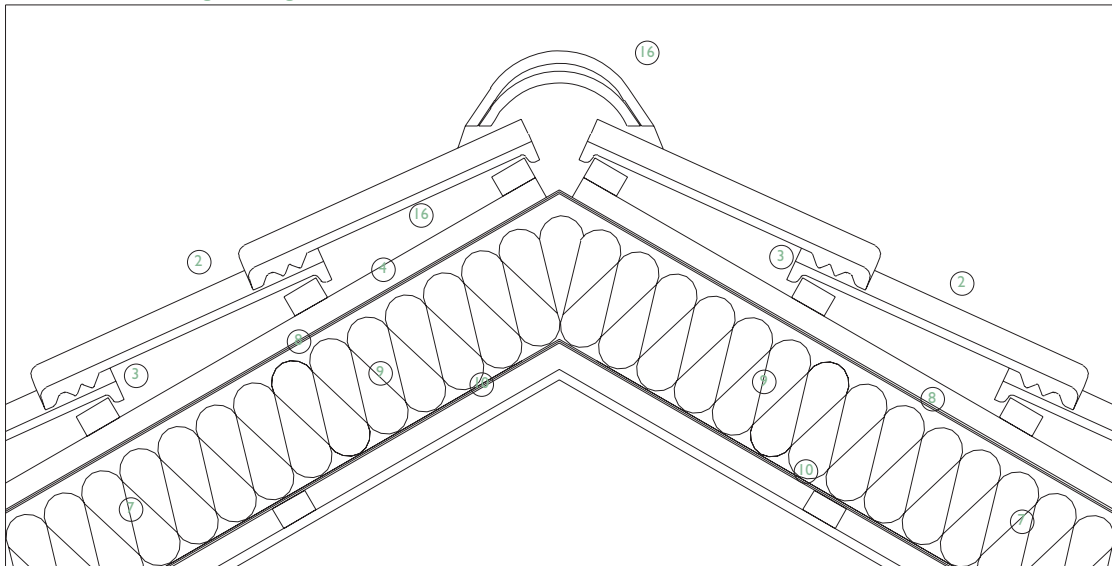


Section 1:10. Plain tiles. Ridge Detail A



Section 1:10. Interlocking tiles. Valley gutter

Section 1:10. Interlocking tiles. Ridge Detail G



Details

1. Plain tile
2. Interlocking tile
3. Softwood battens
4. Softwood counter battens
5. Roofing felt
6. Gutter
7. Softwood rafter
8. Vapour permeable membrane
9. Thermal insulation
10. Vapour barrier
11. Softwood joist
12. Metal flashing
13. Ventilator
14. Fascia board
15. External wall
16. Ridge capping

ing insulation set between the rafters. In the second version, the void forming the fascia and soffit immediately beneath it is in 'cold' roof configuration and is required to be ventilated in order to avoid damp, stagnant air from damaging the timbers.

Ridges

Where a sealed ridge is required, ridge tiles are either bedded in a sand cement mortar, as (G), or are dry fixed with metal screws, typically stainless steel, where a rapid installation is required. For ventilated ridges, proprietary fixings usually made in PVC-U with ventilation slots are used to ventilate either the batten cavity between the underlay and the tiles, in a warm roof, or the roof

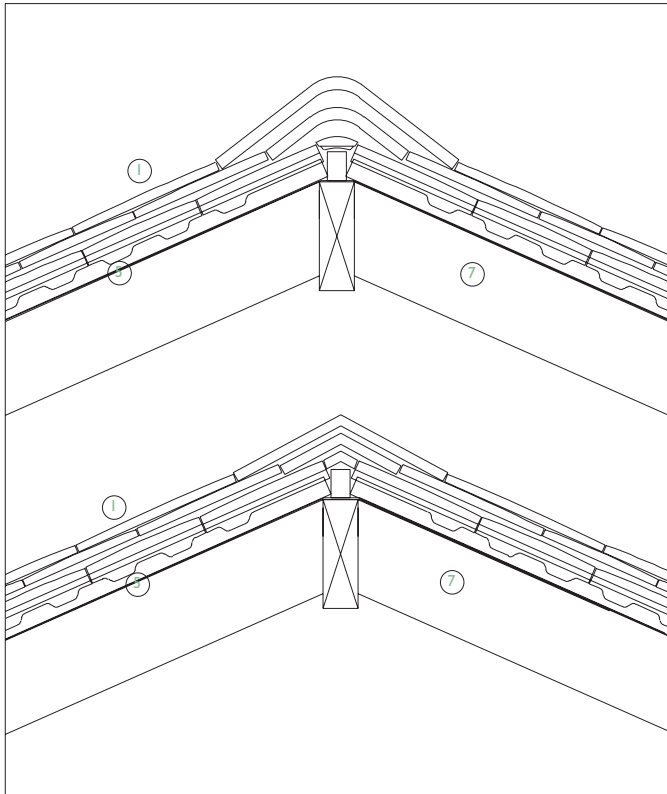
void in a cold roof configuration. Where the batten cavity is ventilated the cavity is sealed across the ridge. Air is allowed to pass through a gap between the bottom of the ridge tile and the roof tile immediately beneath, the gap being formed by the PVC-U ventilator. The ridge tile itself is mechanically fixed to a ridge batten which is secured back to the counter battens beneath with metal clips, usually in stainless steel. Where the complete roof void is vented to the outside in a cold roof, a gap of around 10mm in the underlay is formed at the ridge. The underlay is turned up the side of the top row of battens on each side of the ridge to ensure that rainwater is not blown up the batten cavity and down into the roof void

beneath. The ridge tile is fixed in the same way in the warm roof version, with a PVC-U ventilator set below the ridge tile.

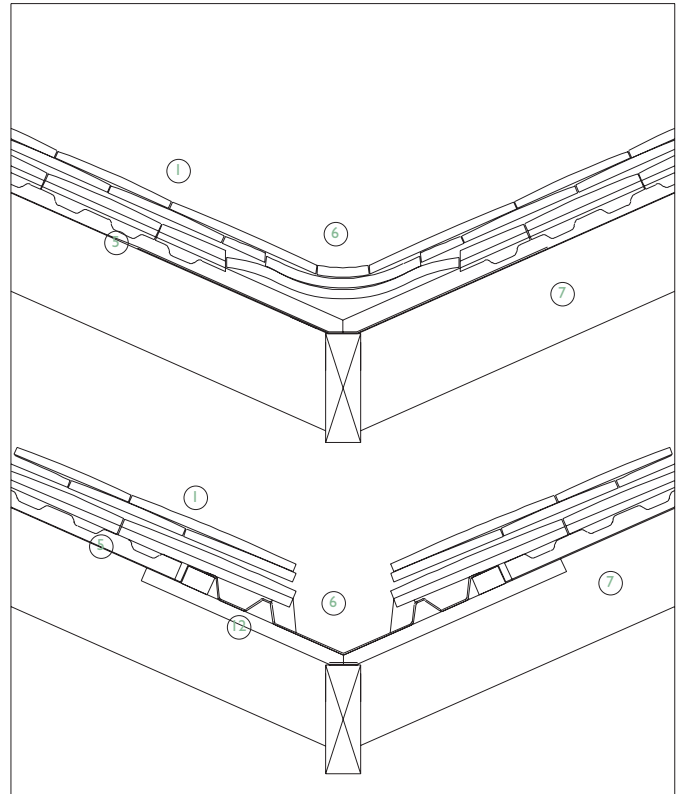
Verges

Verges, or gable ends, are closed with a sand cement mortar seal between the underside of the tiles and the fascia board beneath, as (H). Metal clips, usually in stainless steel, are used to restrain the edge tile. Proprietary systems of interlocking tiles often have special verge tiles, as (J), where the tile forms a straight vertical face. The verge tiles are clipped together to hold them in place to resist wind uplift. The void enclosed by the timber fascia board and soffit board beneath is usually ventilated in

Sections 1:10. Plain tiles. Hips Detail K



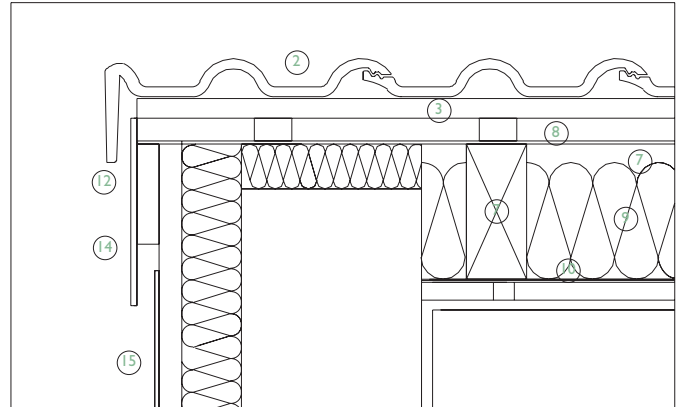
Sections 1:10. Plain tiles. Valleys Detail M



Nara Centennial Hall, Japan. Architect: Arata Isozaki



Section 1:10. Interlocking tiles. Verge Detail J



order to keep it dry. The vents, as at the eaves, have bird mesh or insect mesh to prevent the voids from being used as nesting areas.

Hips and valleys

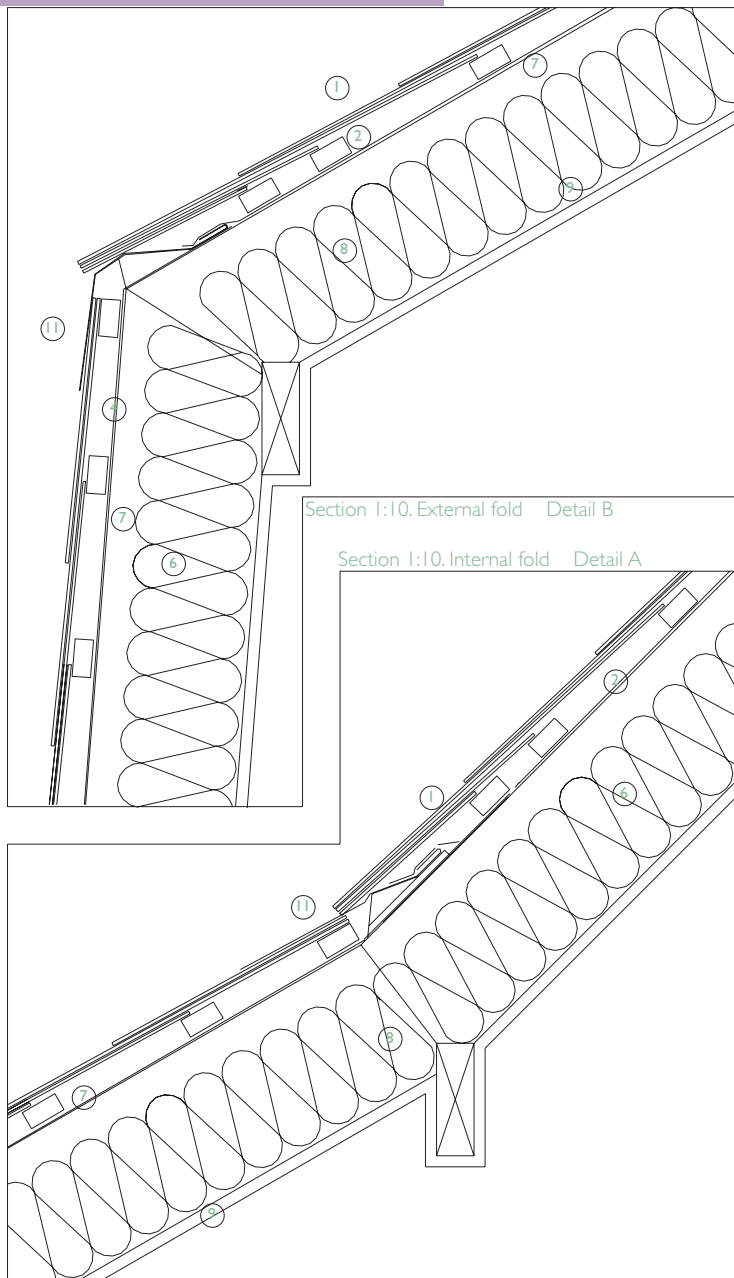
Hips and valleys in plain tiles are formed with either specially folded hip tiles or by cutting the tiles to create a mitred corner. Specially folded hip tiles, as (K) form part of manufacturers' ranges of tiles, but usually they suit only 90° corners in plan, and only certain roof pitches. More complex folds in the roof can be formed with cut tiles that meet at the fold line, with the open joint being closed by a metal flashing beneath the fold line, as (L). Hips in interlocking tiles are

often made using the same method as at the ridge in order to suit the individual shape of the tile used.

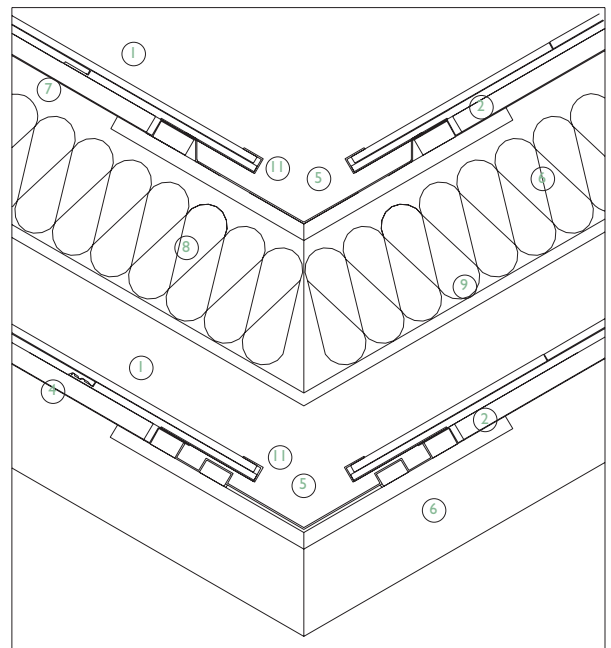
Valleys are formed in the same way, with either folded tiles or mitred tiles. When a large amount of rainwater is collected in the valley, a full gutter can be formed by introducing a metal or GRP strip, as (M). The edges of the gutter are folded up the adjacent battens and are made continuous with the felt underlay. The gutter is usually supported by timber boards or plywood sheet set between the rafters as shown in (M). An additional layer of underlay is sometimes set beneath the gutter as a second line of defence against rainwater penetration at folds and junctions in the gutter.

Abutments

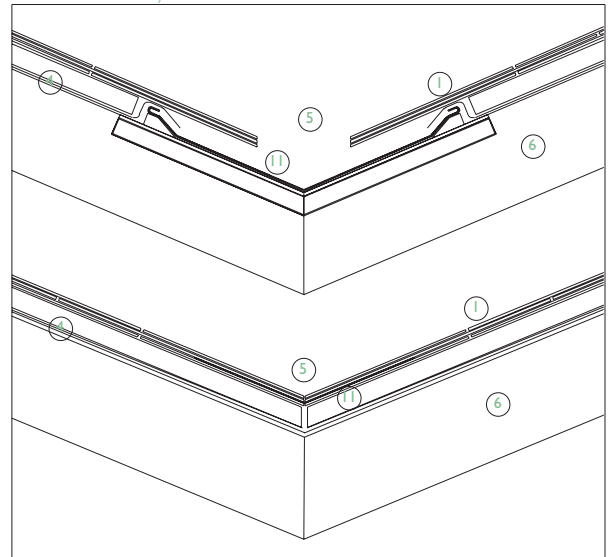
Where a tiled roof meets a vertical wall at the ridge, a proprietary ventilator is set onto the top tile, as (N), which is clipped onto the tile itself. A gap between the vertical wall and the top tile is maintained to allow the free passage of air, while the gap between ventilator and wall is closed with a metal flashing that is set into the vertical wall and folded over the top of the PVC-U ventilator, to which it is bonded or mechanically fixed. A side abutment requires no ventilation and the metal flashing folds into the gap below the top tile as (P) or is formed into the slope of the interlocking tile as (Q).



Section 1:10.Valleys



Section 1:10.Valleys



Roofing slates are made in either natural cut stone, as reconstituted stone or as fibre cement tiles which imitate the appearance of the natural material. All these slate types are made in a similar size to tiles, at around 450mm x 350mm, but are also available in a wider range of sizes, from 600mm x 300mm down to 400mm x 200mm, depending on the manufacturer. Natural slate is used as a flat material that is fixed in the same way as tiles, as discussed in the previous section. Reconstituted slates are made from typically 50% to 60% recycled waste slate (from the quarrying of slate) which is mixed with resin and glass fibre reinforcement, then pressed to shape. Reconstituted slate are usually made with an interlocking profile to enhance their

performance in reducing rainwater penetration. Fibre cement slates are cement-based imitations of natural slates which are more economic than the natural material.

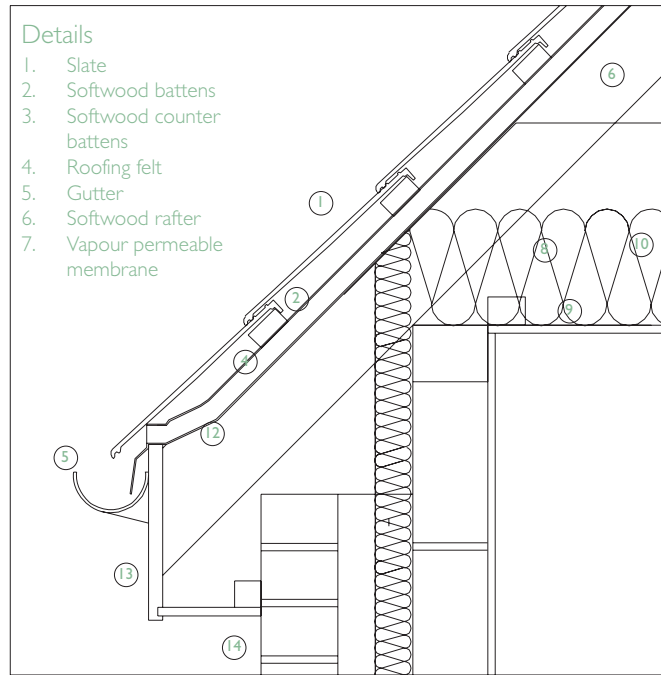
All these slate types can be used in roof pitches from vertically hung to usually 22.5° above the horizontal. All slate types require a head lap (discussed in the previous section on tiles) ranging from 60mm to around 120mm depending on the roof pitch. Both natural slate and fibre cement types are laid in a way that maintains a minimum thickness of two layers of slate to ensure a weather tight roof covering. Reconstituted slate is often formed with profiled edges that interlock to reduce the possibility of capillary action from rainwater being drawn up into

the lap between the slates. This improved jointing allows the material to be used in a single thickness rather than as two layers.

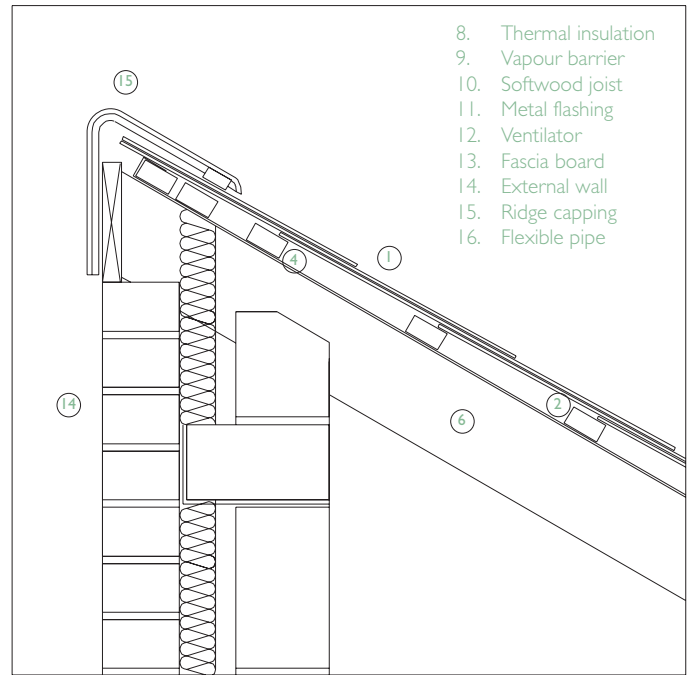
Natural slate is sorted into at least three groups on site, based on the material thickness, which varies in the splitting of the natural material. When fixed, slates used on any course (row of slates) are of similar thickness. The thickest slates are used at the base of the roof, and the thinnest are used at the top of the roof, with slates in between varying progressively from thick to thin. Fibre cement slates are of constant thickness and do not require any sorting on site.

The ventilation of slate roofs follows the principles set out in the previous section on tiled roofs, with both warm and cold roof

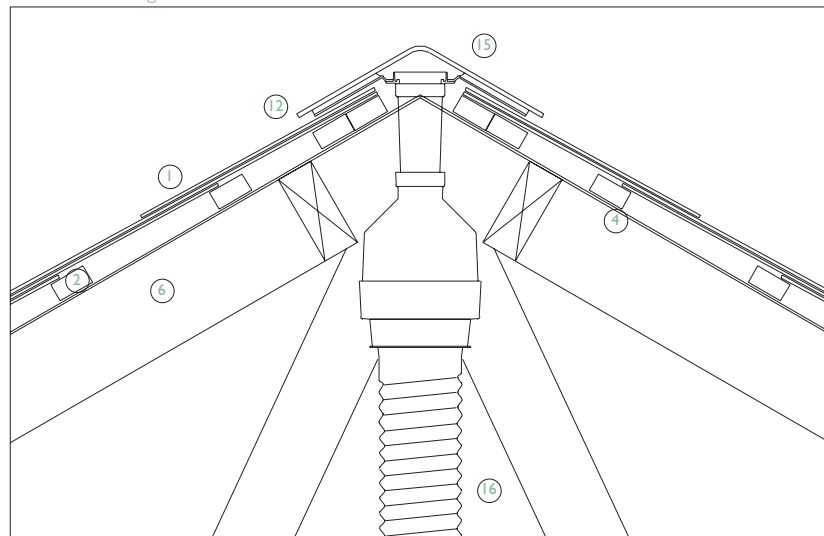
Section 1:10. Eaves



Section 1:10. Monopitch ridge



Section 1:10. Ridge with vent extract Detail C



Tateyama Museum of Toyama, Japan. Architect: Arata Isozaki & Associates.



configurations being detailed in the same way. The detailing of eaves, ridges, verges, hips and valleys follows the same principles of rainwater drainage, ventilation and thermal insulation as set out in the section on tiled roofs.

Roof folds

Changes of roof pitch that form a fold line are formed by reducing the lap at the head of the tiles, or head lap, to a minimum. In (A) the roof pitch forms an internal fold, where the upper tile is butted up to the lower tile. A metal flashing is set beneath the upper slate and is lapped over the outer face of the lower slate to ensure that rainwater is directed down the slope and not onto the

underlay beneath. In (B) the external fold is formed by projecting the upper slate out slightly to form a drip, ensuring that rainwater does not run back up the metal flashing beneath, which is positioned in the same way as in (A).

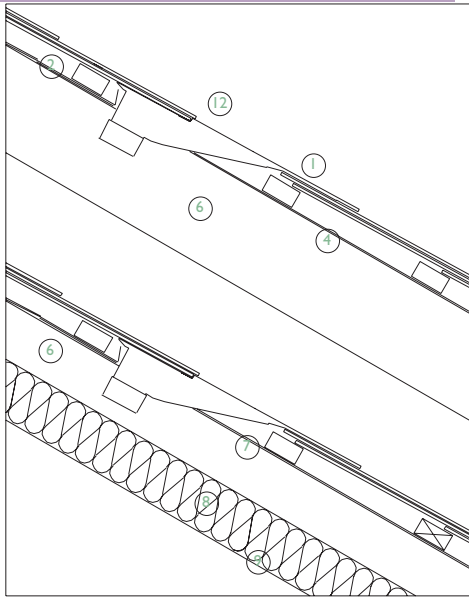
Vents

Extract points for mechanical ventilation ducts can be integrated into a vent at the ridge as well as on the general area of pitched roof without requiring a projection above the roof that would be visible from below. The ridge vent in (C) uses a similar vent as that required for a ventilated ridge, as described in the section on tiled roofs. The top of the flexible duct has a connector,

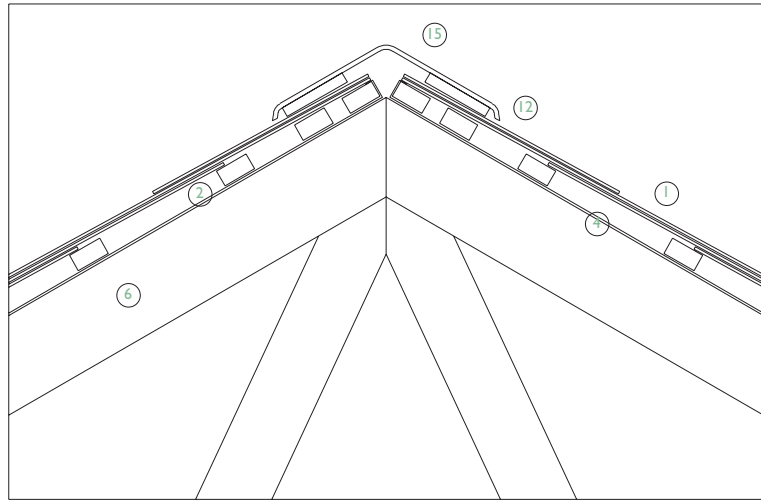
usually in PVC-U as part of a proprietary system. The connector is closed around the base of the roof vent and is sealed where it penetrates the underlay to ensure that rainwater cannot find its way into the roof void. A ventilator set into the pitch of the roof, as (D), can have a flexible duct connected to it in the same way.

Monopitch ridges

As with apex ridges, a monopitch ridge is formed with a specially formed ridge slate or clay tile. The ridge slate or tile is mechanically fixed to the timber structure beneath to either allow the ridge to be ventilated or closed against the sloping slates on one side, and a timber board on the vertical face.

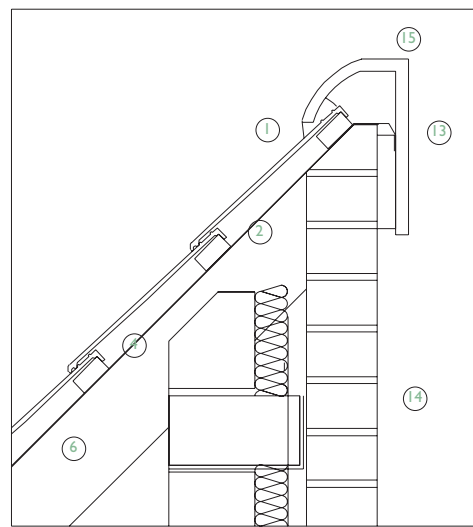
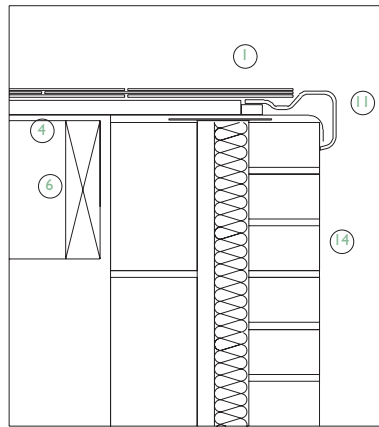
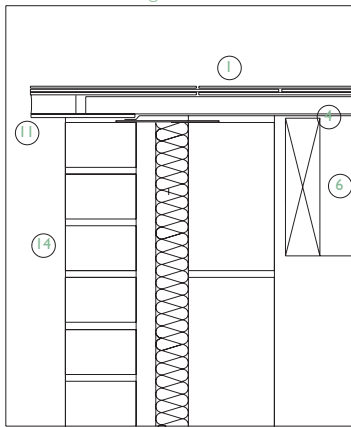


Section I:10.Ventilators Detail D



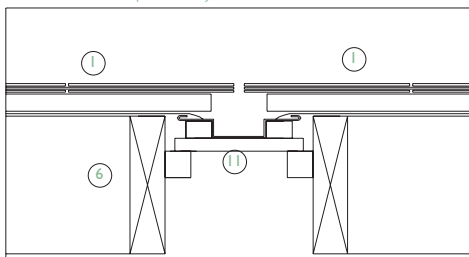
Section I:10.Ridge

Sections I:10.Verges

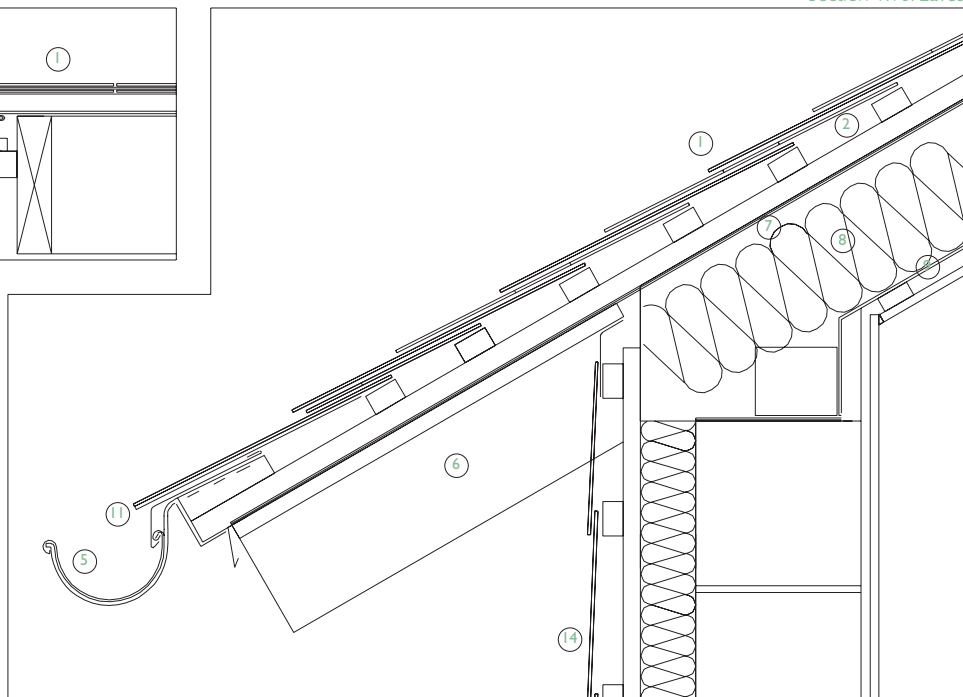


Section I:10.Monopitch ridge

Section I:10.Expansion joint



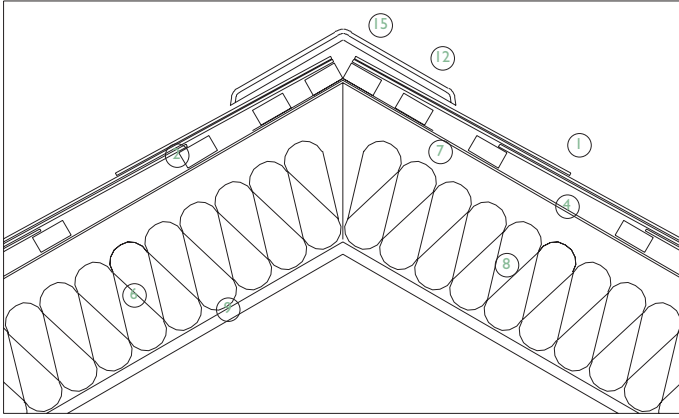
Section I:10.Eaves



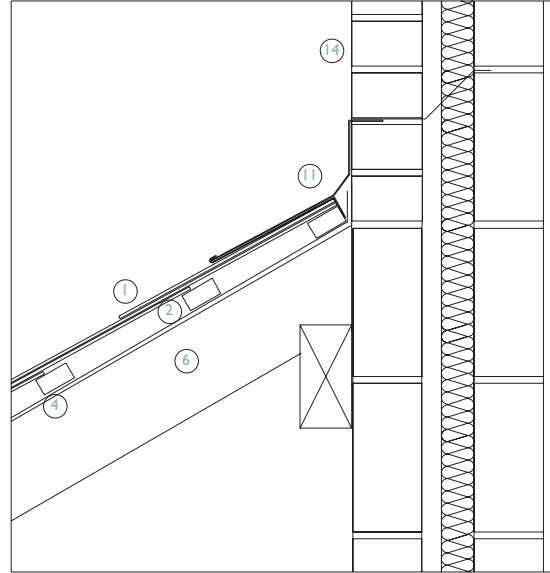
Details

1. Slate
2. Softwood battens
3. Softwood counter battens
4. Roofing felt
5. Gutter
6. Softwood rafter
7. Vapour permeable membrane
8. Thermal insulation
9. Vapour barrier
10. Softwood joist
11. Metal flashing
12. Ventilator
13. Fascia board
14. External wall
15. Ridge capping
16. Flexible pipe

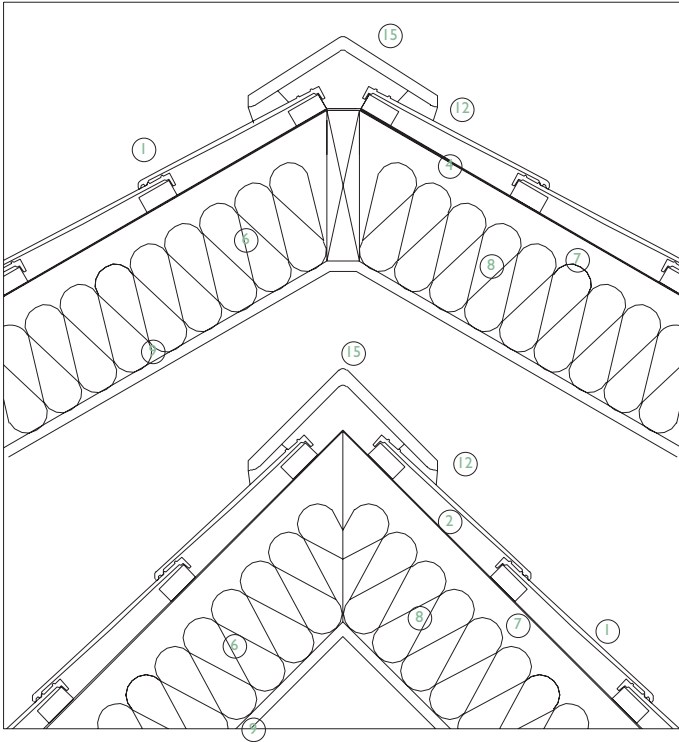
Sections 1:10. Ridges



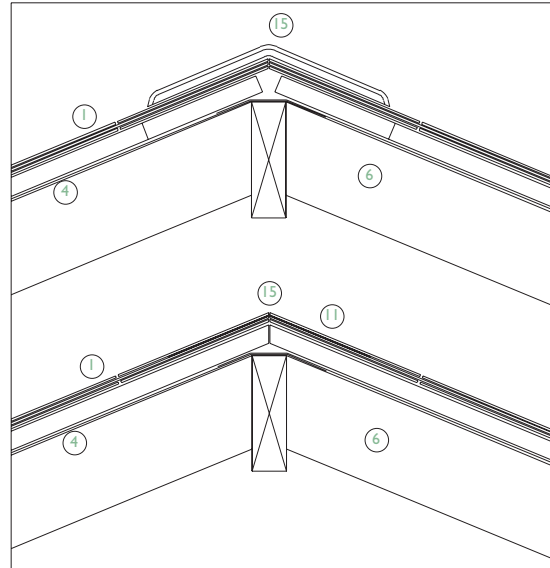
Section 1:10. Abutment Detail J



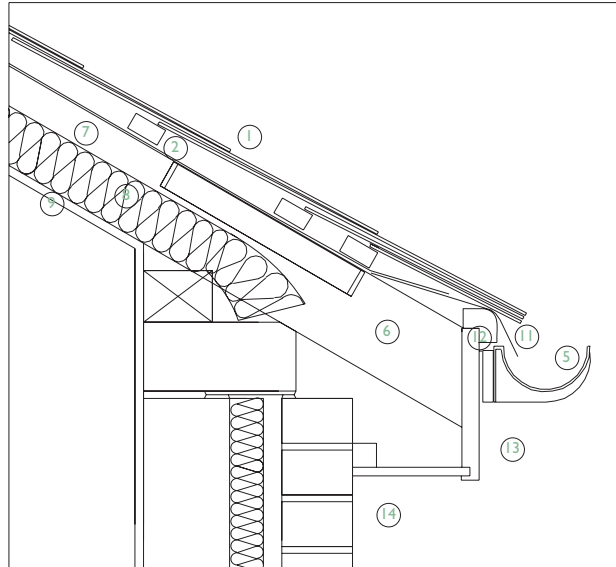
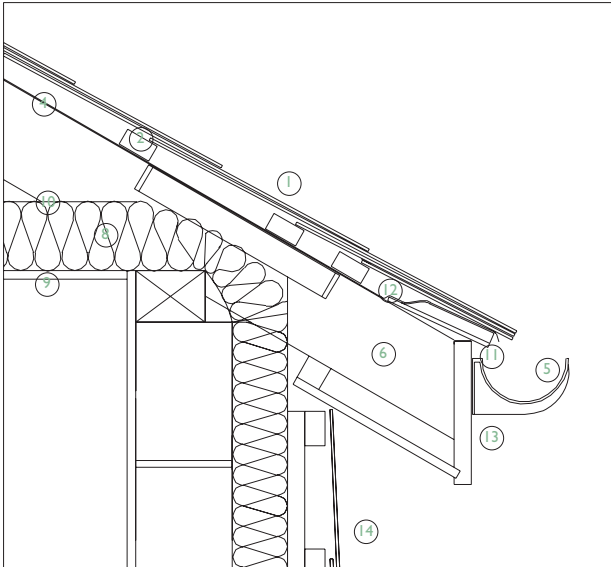
Sections 1:10. Ridges

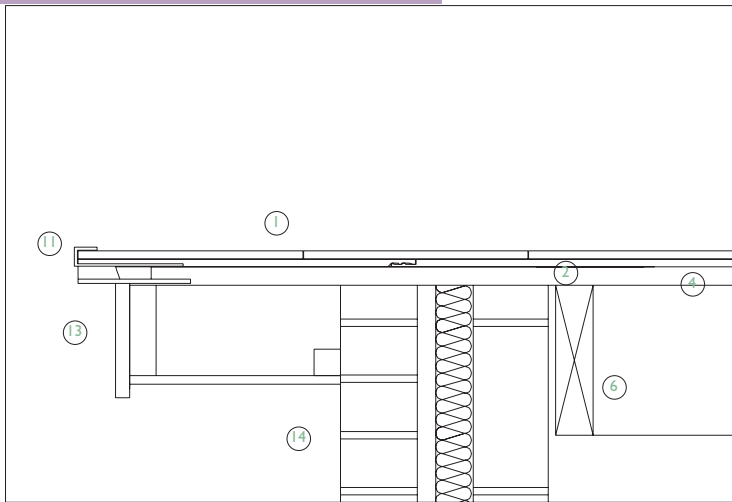


Sections 1:10. Hips

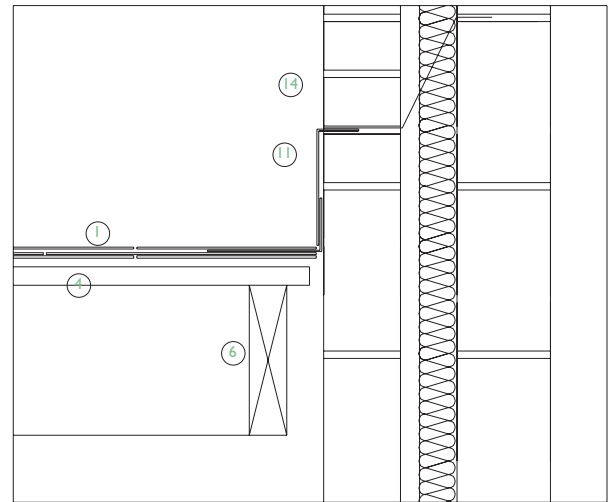


Sections 1:10. Eaves



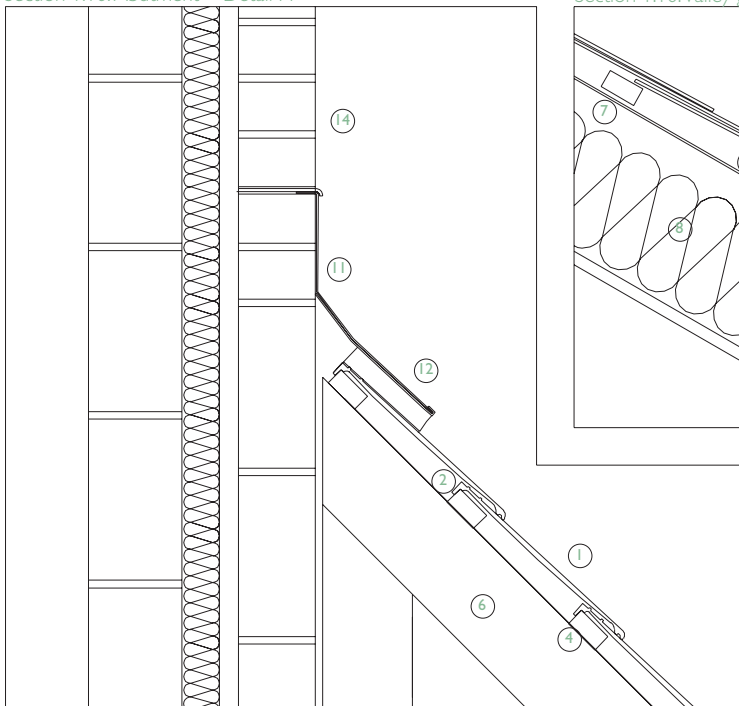


Section I:10.Verge

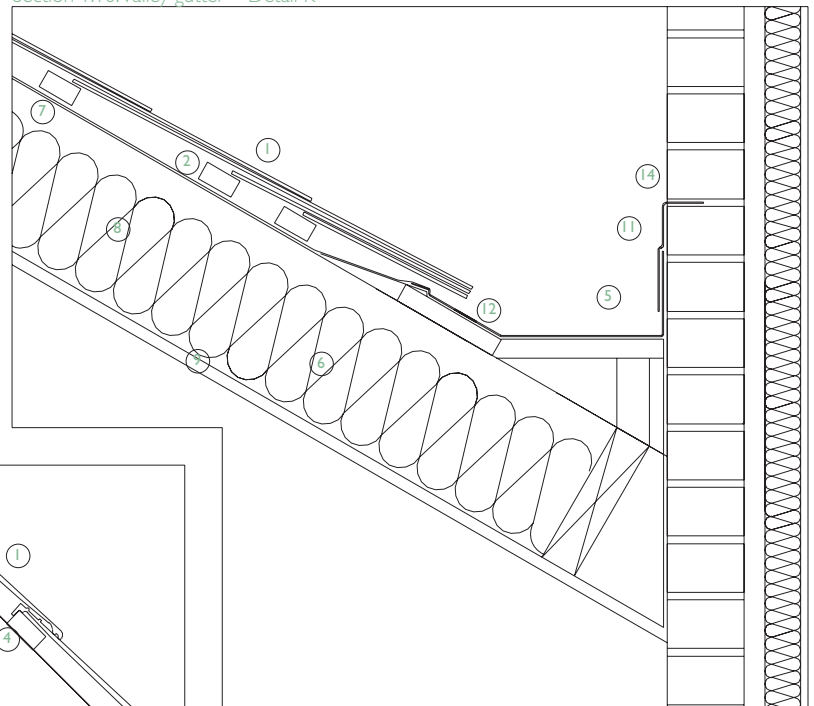


Section I:10.Abutment

Section I:10.Abutment Detail H



Section I:10.Valley gutter Detail K



Dormer windows

Slate cladding on the vertical faces, or cheeks, of a dormer window, are shown in (E). The supporting structure for the slates is typically timber framed, with insulation set between the timber studs (vertical framing members) in warm roof configuration. Horizontally-set softwood battens are fixed onto vertically-set battens which are fixed back to the underlay or breather membrane. The vertically-set battens, or counter battens, ensure that moisture is allowed to run freely down the membrane or underlay as well as encourage natural ventilation behind the slates. Slates are hung from the battens. The edge of the low pitched roof of the dormer window has its fascia board set forward of

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the slates, as in (E), to ensure that ventilation of the vertical cladding is maintained at the top of the cheek. Air is also allowed to enter the batten cavity at the base of the wall, as (F). At the corners of the vertically-hung slates, as (G), slates form internal and external corners by butting the slates together from each side to form a corner, and setting a metal flashing beneath to ensure the continuity of weather tightness at the corner.

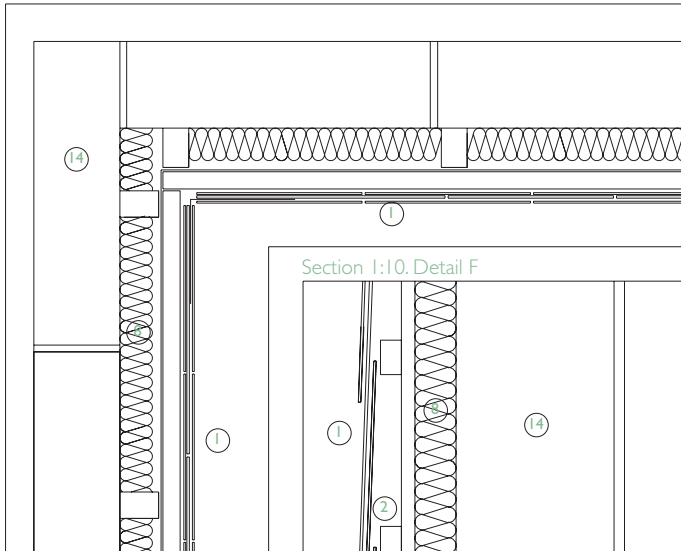
Abutments

Abutments at the side of a pitched roof, as (H), and at a monopitch ridge condition as (J), are formed by covering the joint between wall and roof with a metal flashing which is fixed over the top of the first slate

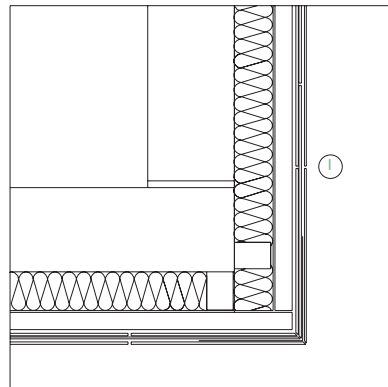
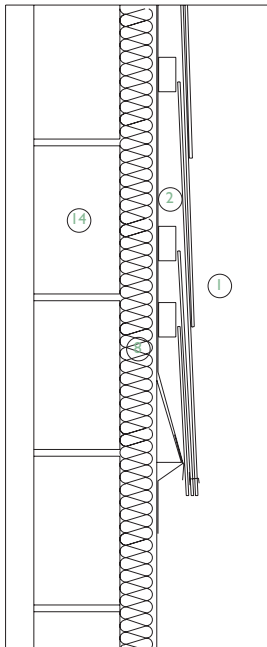
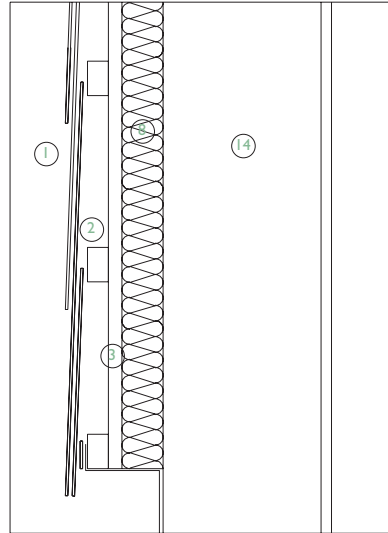
of the roof and is sealed against the vertical face of the wall. Where brick is used, as (H) and (J), the flashing is returned into a joint between brick courses.

Valley gutters are formed in the same way, with a metal tray folded up the underside of the slate, as described in the section on tiled roofs. The vertical face of the gutter where it meets the adjacent wall, as (K) is sealed with a flashing set over the top of the gutter to provide a complete weather tight seal.

Plan 1:10.Vertically hung slates at internal corner Detail G



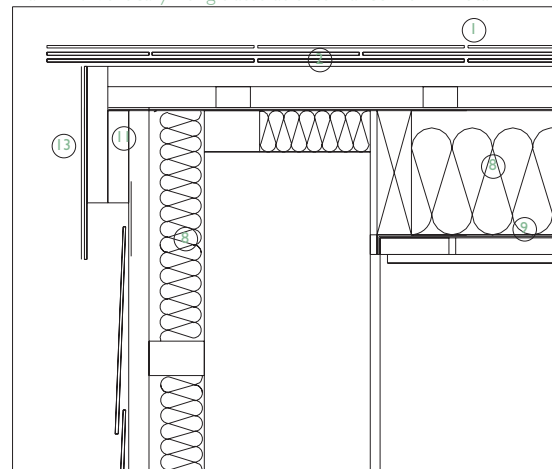
Section 1:10. Detail F



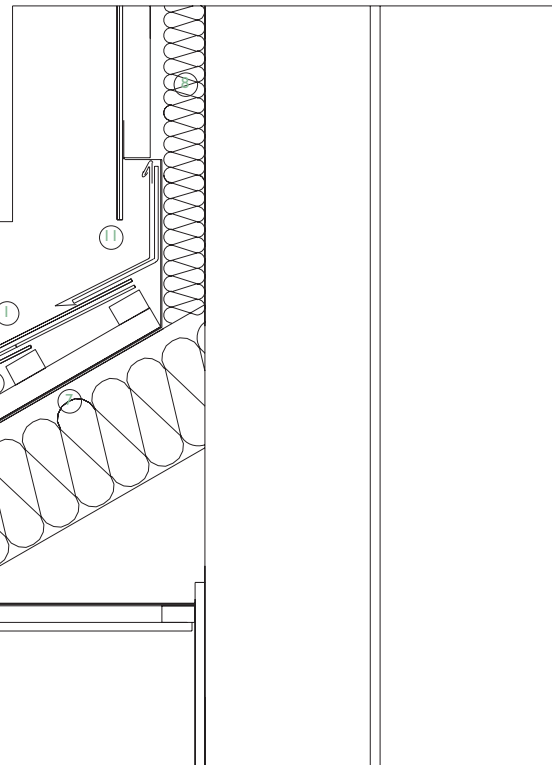
Tateyama Museum of Toyama, Japan. Architect: Arata Isozaki & Associates.



Plan 1:10.Vertically hung slates at external corner Detail E

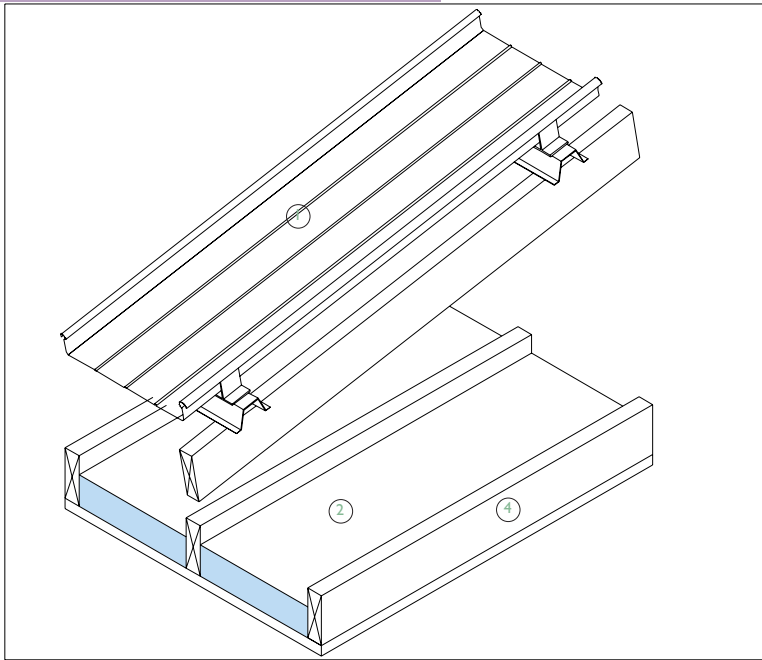


Section 1:10.Dormer window

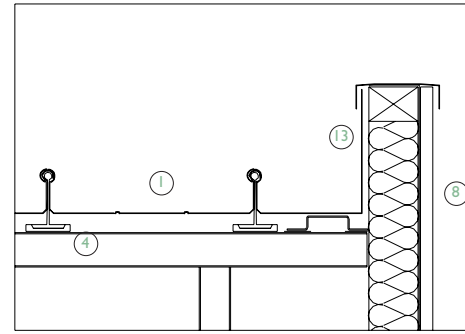


Details

1. Slate
2. Softwood battens
3. Softwood counter battens
4. Roofing felt
5. Gutter
6. Softwood rafter
7. Vapour permeable membrane
8. Thermal insulation
9. Vapour barrier
10. Softwood joist
11. Metal flashing
12. Ventilator
13. Fascia board
14. External wall
15. Ridge capping
16. Flexible pipe



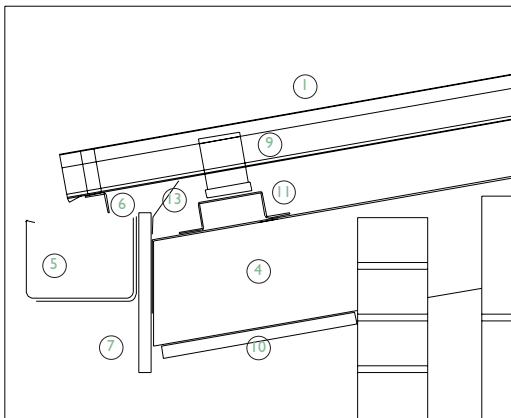
Isometric view of assembly



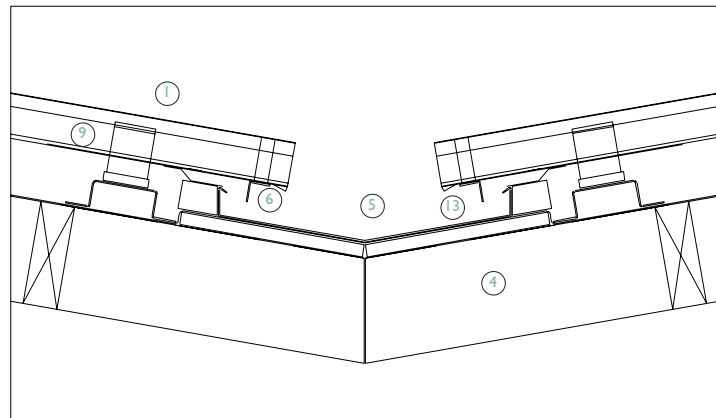
Section I:10. Parapet verge

Details : Standing seam roof

- | | |
|-----------------------------------|-------------------------------|
| 1. Standing seam sheet | 8. External wall |
| 2. Fibre quilt thermal insulation | 9. Metal sheet fixing bracket |
| 3. Vapour barrier | 10. Soffit board |
| 4. Timber beam/joist | 11. Metal supports |
| 5. Folded metal gutter | 12. Ridge piece |
| 6. Folded metal drip | 13. Metal flashing |
| 7. Fascia board | 14. Parapet flashing |



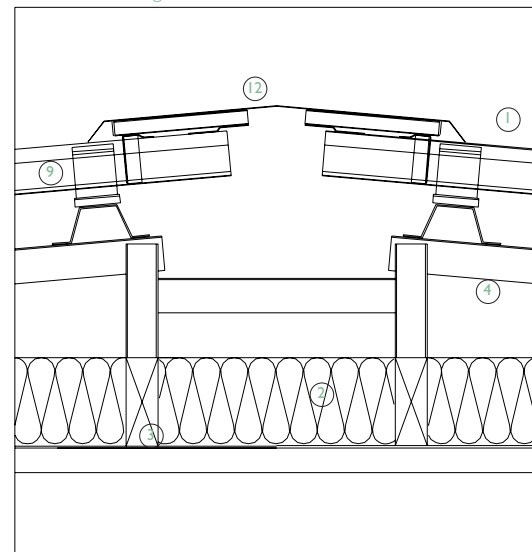
Section I:10. Eaves Detail A



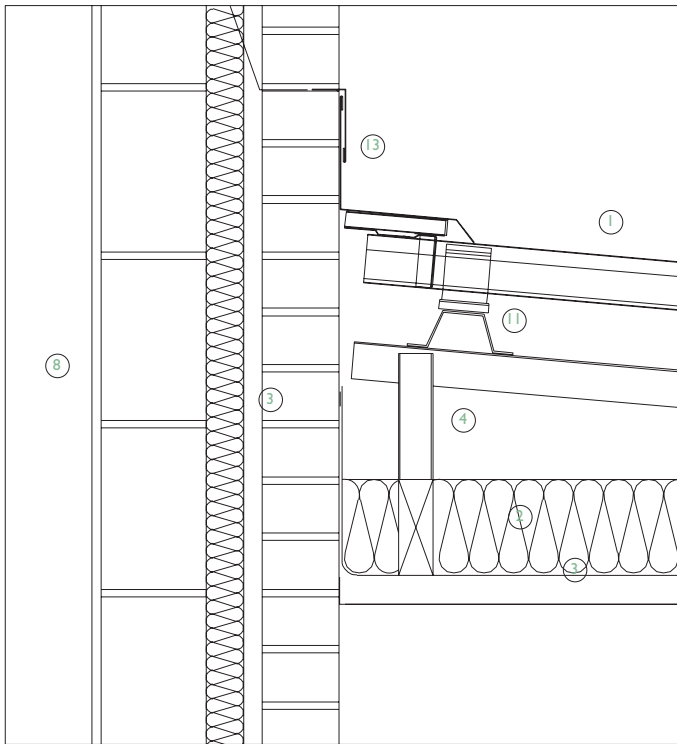
Section I:10. Valley gutter

House, Wye River, Australia. Architect: Bellemo & Cat.

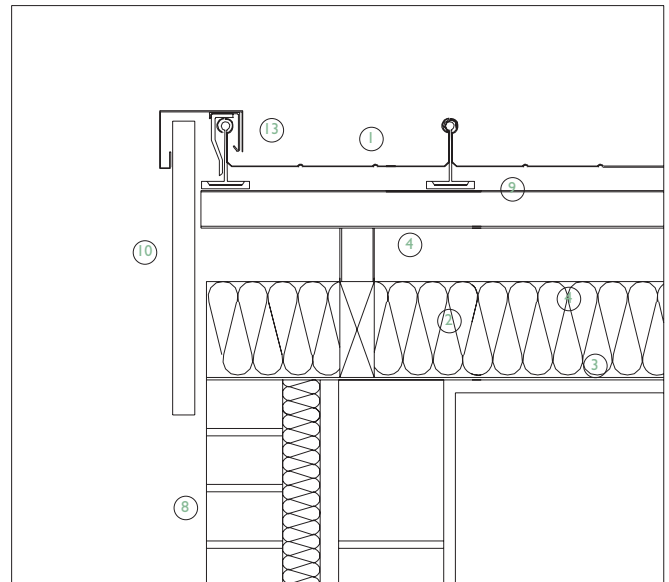
Section I:10. Ridge Detail B



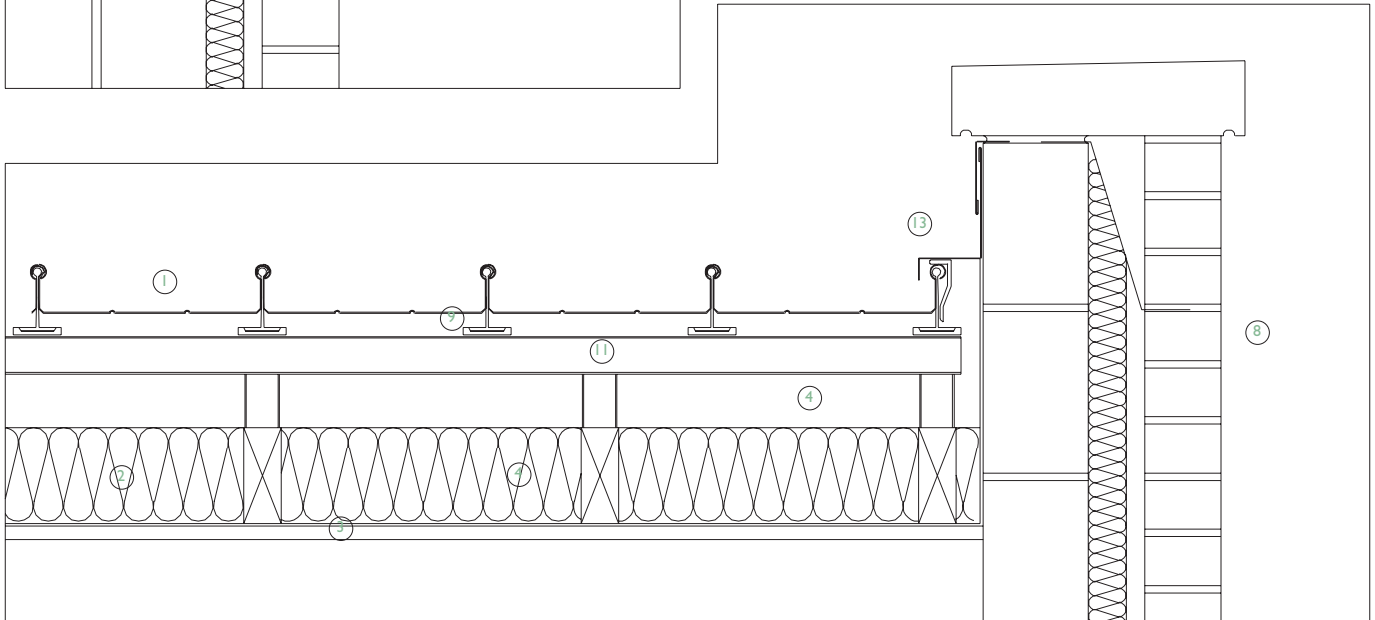
Section 1:10. Abutment



Section 1:10. Verge



Section 1:10. Parapet verge



Standing seam cold roofs

Standing seam roofs are discussed in the Metal chapter as sealed, insulated roof coverings in a warm roof configuration. When used in the cold roof configuration with a pitched timber roof, the standing seam roof is ventilated, with thermal insulation provided at ceiling level.

In this build-up a ventilated standing seam metal deck is set onto a timber roof of trusses and purlins. At ceiling level, thermal insulation quilt is set between the ceiling joists (horizontal members). A vapour barrier is set beneath the insulation, positioned on the top surface of a dry lined wall beneath. The roof void is ventilated at the lowest point (eaves or parapet gutter) and at the highest point

(ridge or abutment), with verges and parapets at the sides of the roof remaining sealed.

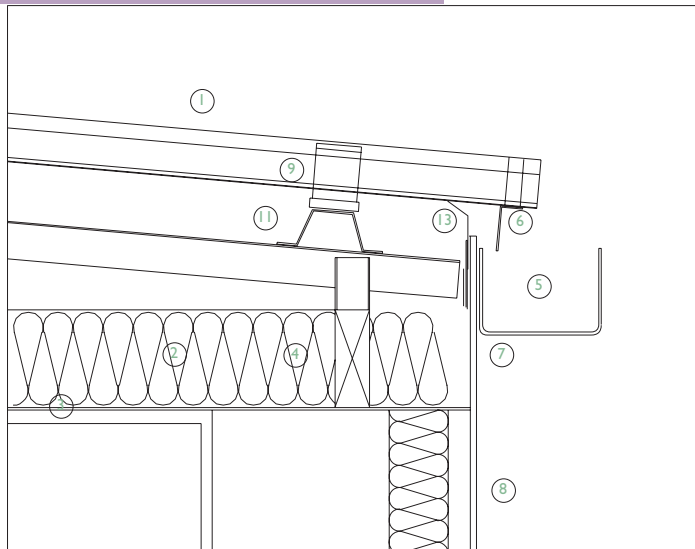
Eaves and valley gutters

Eaves are ventilated by leaving a gap between the top of the fascia board supporting the gutter and the underside of the standing seam roof sheet. A metal angle is fixed in front of the opening as (A) to avoid rainwater being blown through the opening into the roof void. Valley gutters are formed in a similar way, with a gap formed between the gutter tray and the metal sheet to provide ventilation to the roof void. The metal tray has an upstand at the edge which is lapped up to the underside of the metal

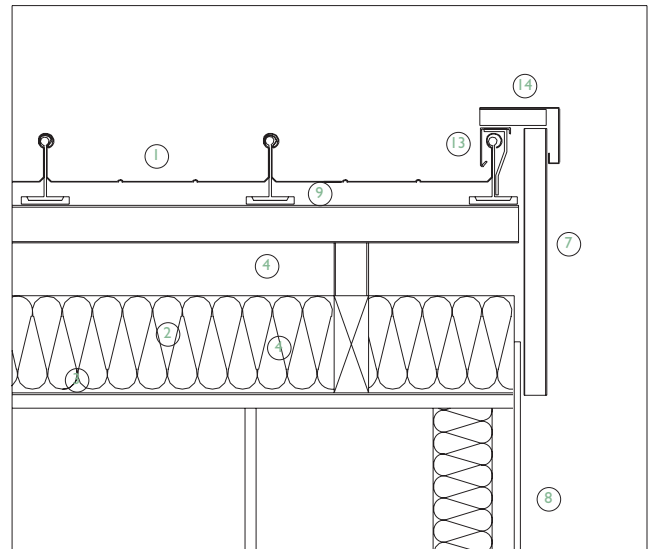
sheet and sealed against the sheet. This ensures that rainwater running down the gutter cannot enter the roof void, while air can still pass into the roof void.

Ridges and abutments

Ridges are formed by creating a gap, typically 100mm between the metal sheets, as (B). The gap at the ridge is covered with a folded metal ridge capping which is fixed to the sheets beneath. A narrow gap is maintained between the ridge sheet and the standing seam sheet in order to provide constant ventilation along the ridge. Alternatively, PVC-U ventilator blocks are added at centres along the ridge, and the joint between the ridge and the roof deck is

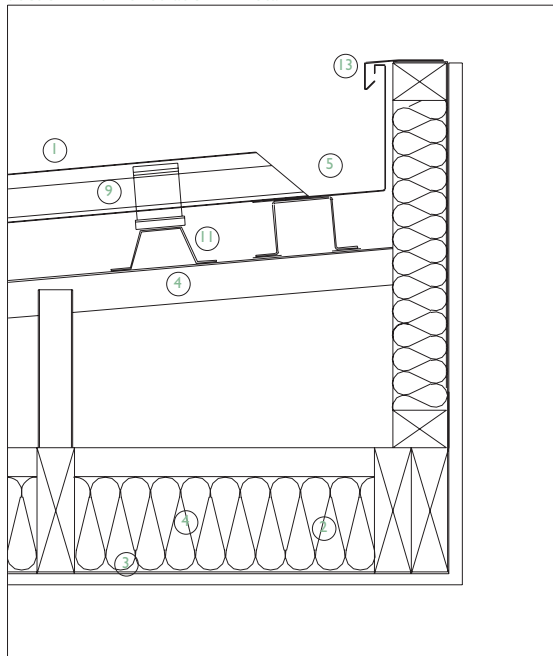


Section 1:10. Eaves

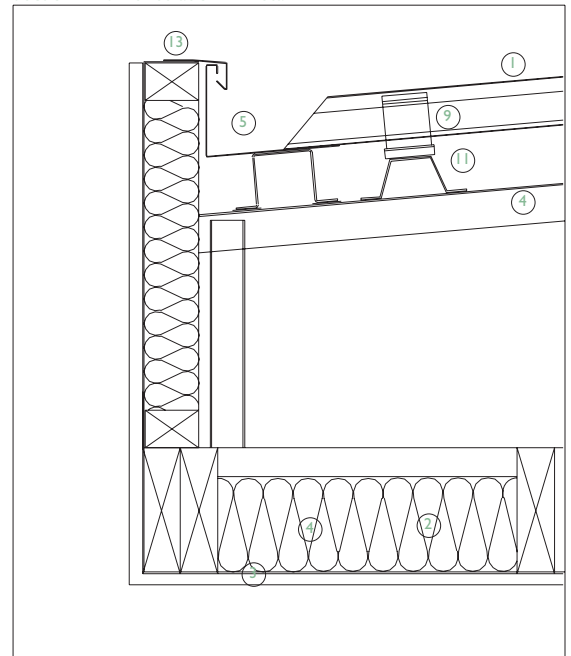


Section 1:10. Verge Detail C

Section 1:10. Penetration Detail D



Section 1:10. Penetration Detail E



Details : Standing seam roof

1. Standing seam sheet
2. Fibre quilt thermal insulation
3. Vapour barrier
4. Timber beam/joist
5. Folded metal gutter
6. Folded metal drip
7. Fascia board
8. External wall
9. Metal sheet fixing bracket
10. Soffit board
11. Metal supports
12. Ridge piece
13. Metal flashing
14. Parapet flashing

sealed. Abutments are formed in a similar way to ridges, with a folded metal sheet that is fixed to the roof sheet on one side and is sealed against the adjacent masonry/concrete wall or parapet, typically with an additional metal flashing which projects from within the depth of the wall. Verges are formed with a metal clip which provide a closer to the edge sheet as (C), with an additional metal coping set over this to provide a second line of defence against rainwater penetration.

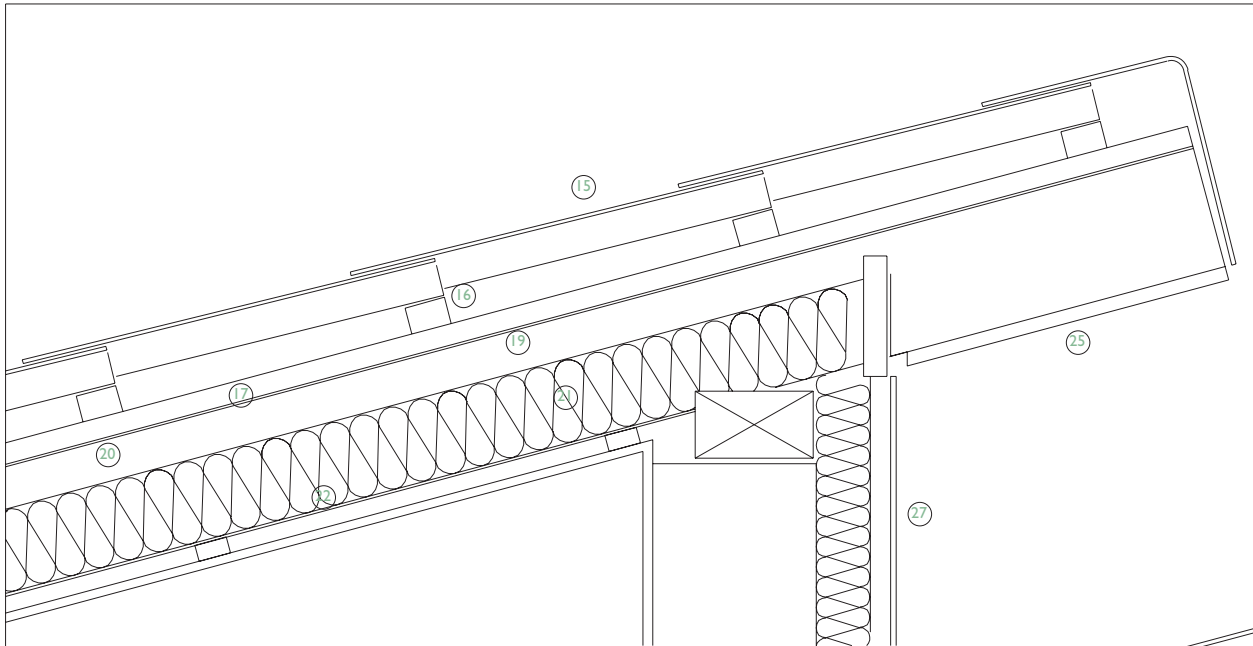
Penetrations

Penetrations are formed in a way which forms a gutter around the opening in the roof as (D) and (E). In (E) rainwater runs off the roof into the gutter, at the edge of the upstand, which is set at the level of the adjacent roof sheets. Water is directed around the sides of the upstand and back onto the roof sheeting below. Penetrations in roofs are positioned so that the standing seam joints between roofing sheets are clear of the sides of the opening in the roof to ensure that rainwater can run freely around the sides of the upstand to the roof opening.

Metal tiled roofs

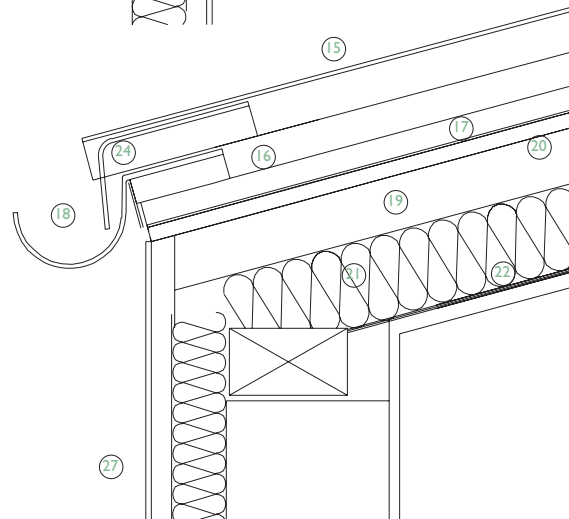
Metal tiles are increasingly being used for roofs due to the flexibility of the roof pitch and tile lap that can be formed economically for individual projects. Copper and zinc are commonly used, with their characteristic patina that is suitable for both walls and roofs. Metal tiles are fixed in the same manner as clay tiles and slates, with battens and counter battens set onto a bitumen- or polymer-based waterproof underlay. Eaves and parapet gutters are formed in the same way as standing seam roofs, with ventilation slots provided to ensure that air can pass through the roof void. Metal tiles are either flat like slates, or alternatively are made from profiled sheet, which imitates the appear-

Section 1:10. Monopitch ridge

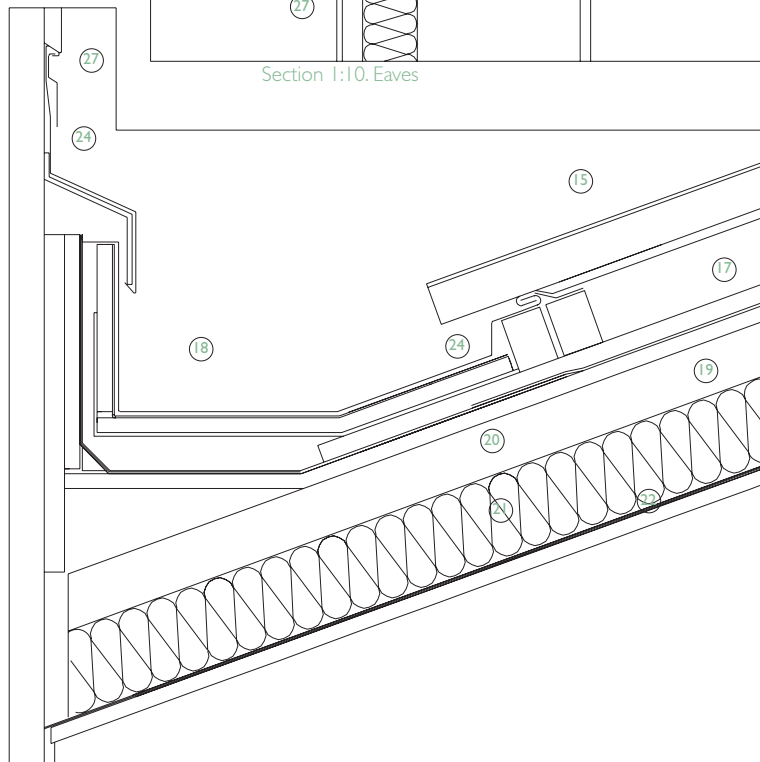


Details : Tiled roof

- | | |
|-------------------------------|--------------------|
| 15. Metal tiles | 23. Softwood joist |
| 16. Softwood battens | 24. Metal flashing |
| 17. Vapour permeable membrane | 25. Soffit board |
| 18. Gutter | 26. Fascia board |
| 19. Softwood rafter | 27. External wall |
| 20. Ventilation void | 28. Ridge piece |
| 21. Thermal insulation | 29. Ventilator |
| 22. Vapour barrier | |



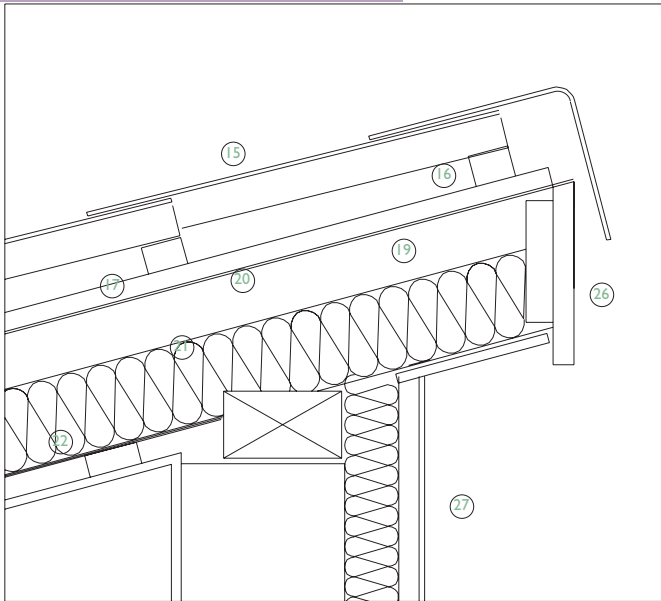
Section 1:10. Eaves



Section 1:10. Valley gutter

ance of traditional tiled roofs made from curved or profiled tiles. Their appearance is very different from profiled metal sheet, with its continuous long lengths of sheeting. The short metal tiles, lapped over one another, can easily take up complex geometries with a pattern of joints and laps that clearly show the form of the roof.

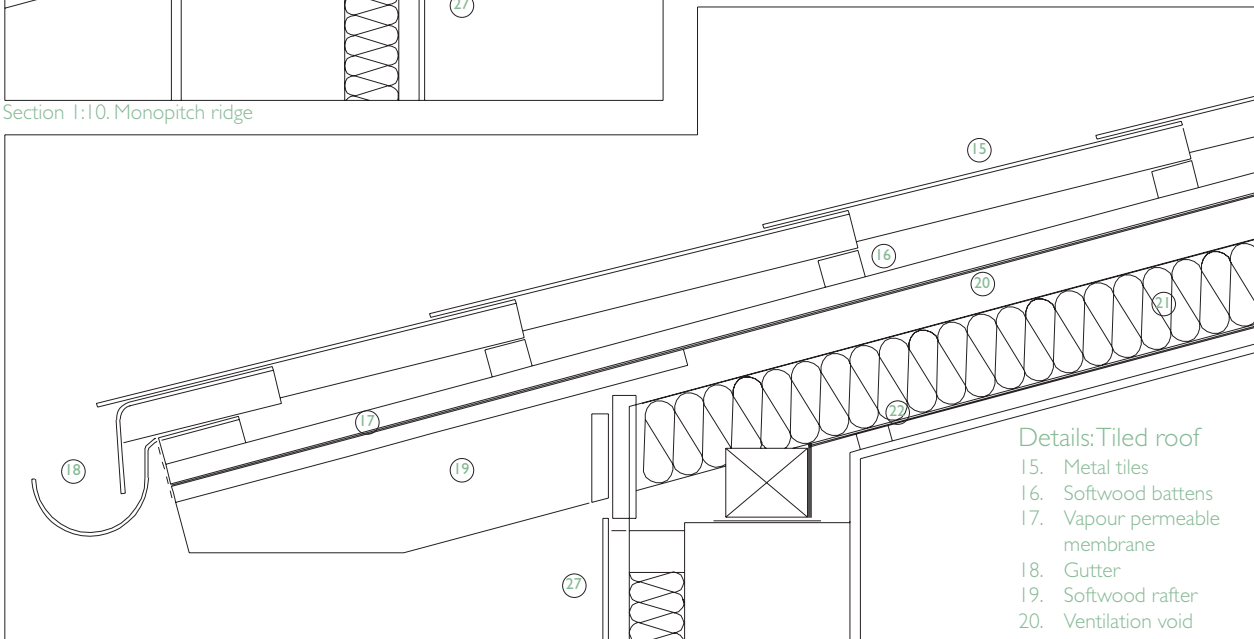
Ridges and verges are usually made from folded metal sheet and are individually designed and fabricated for a building project. An advantage of metal sheet tiles over clay tiles is that tiles and edging pieces can be individually designed for each project while remaining economic, since metal can be folded without the need for moulds which are required for clay tiles and slates.



Section 1:10. Monopitch ridge

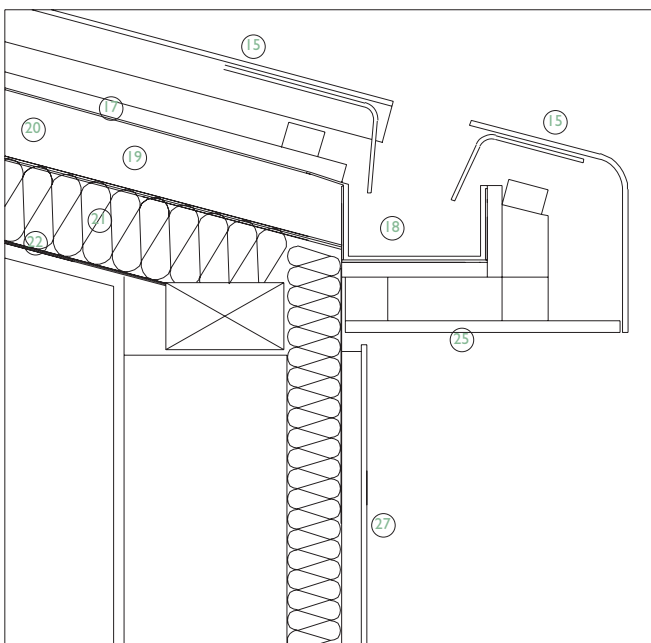


House, Wye River, Australia. Architect: Bellemo & Cat.

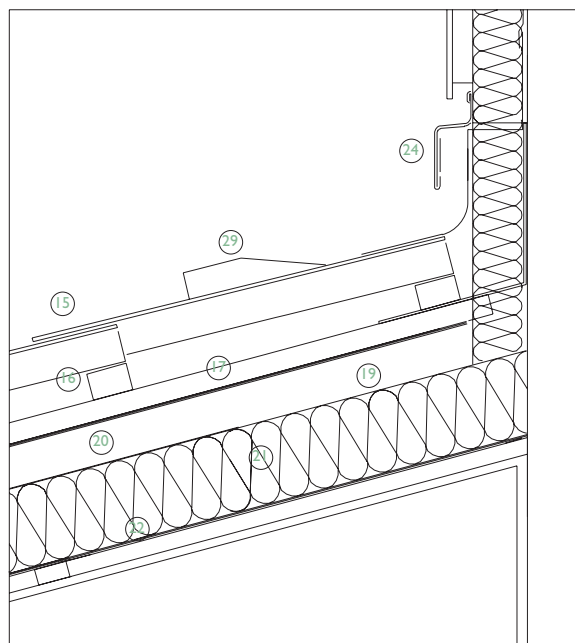


Section 1:10. Eaves

- Details: Tiled roof
- 15. Metal tiles
 - 16. Softwood battens
 - 17. Vapour permeable membrane
 - 18. Gutter
 - 19. Softwood rafter
 - 20. Ventilation void



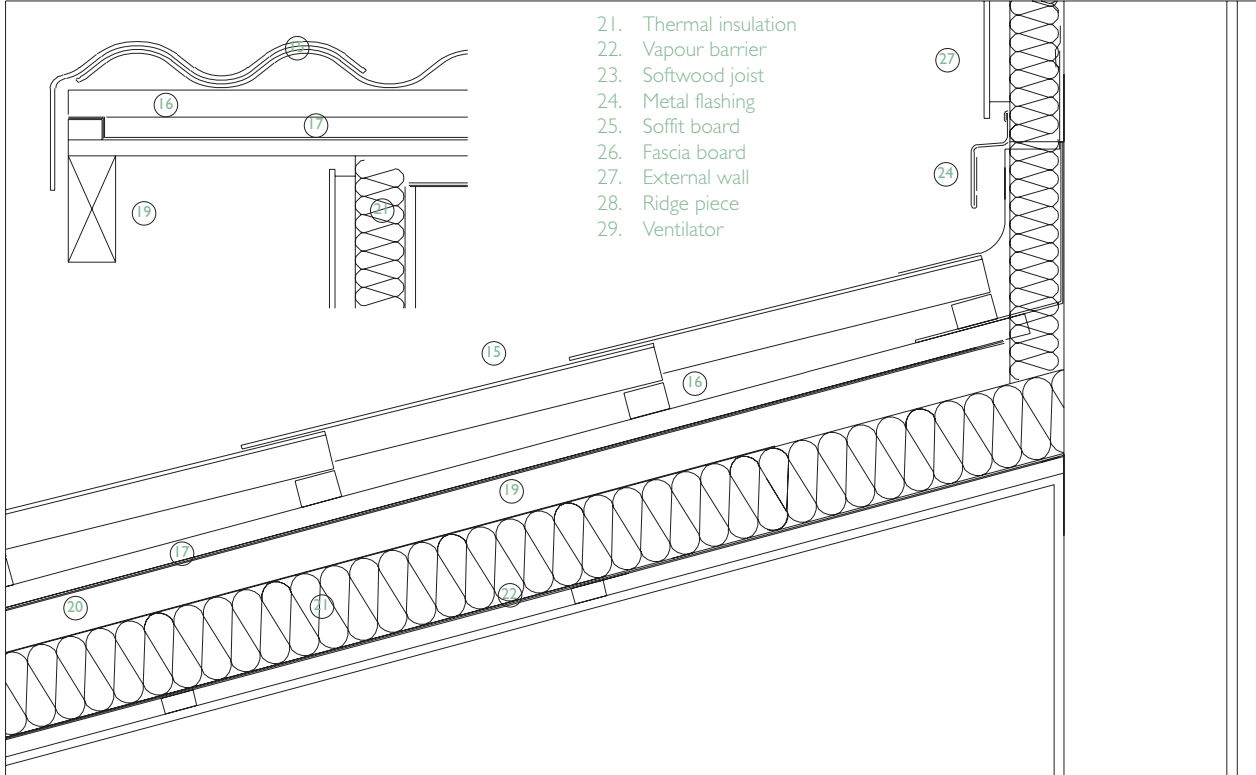
Section 1:10. Eaves



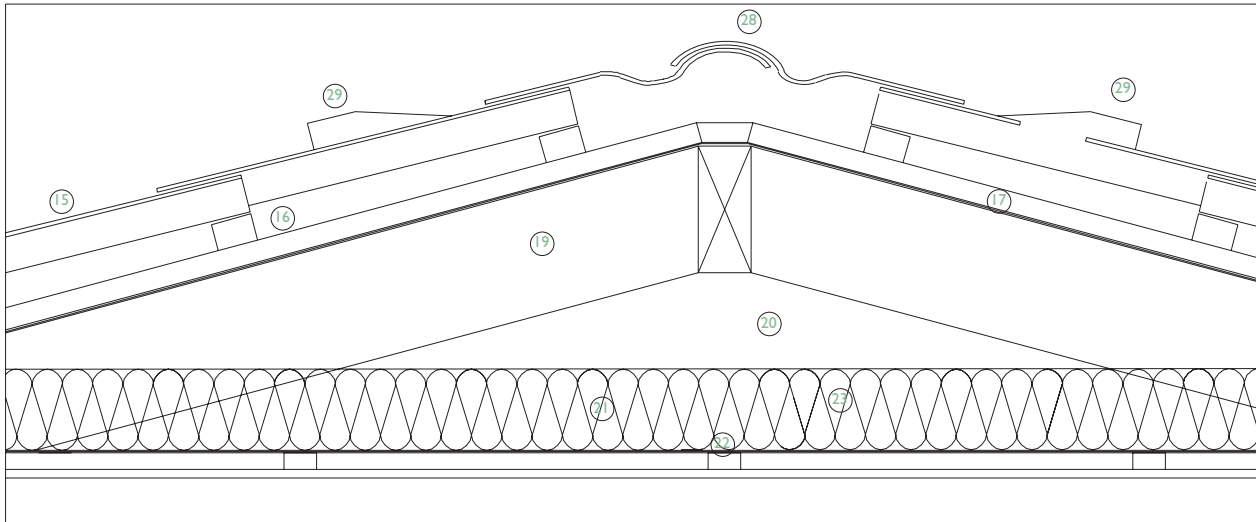
Section 1:10. Abutment

Section I:10.Verge

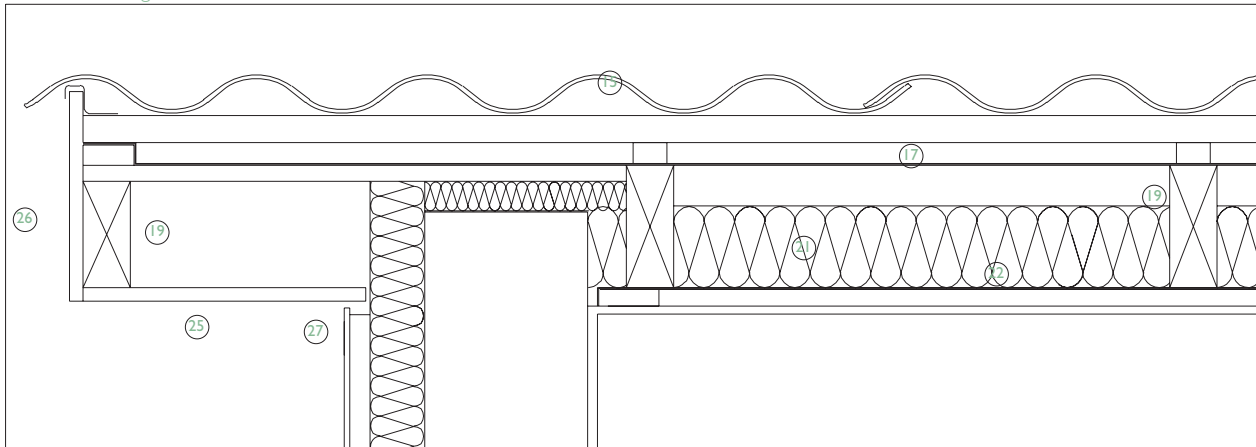
Section I:10.Abutment



Section I:10.Ridge



Section I:10.Verge



5

PLASTIC

(1) GRP rooflights

- Eaves and upstands

- Verges

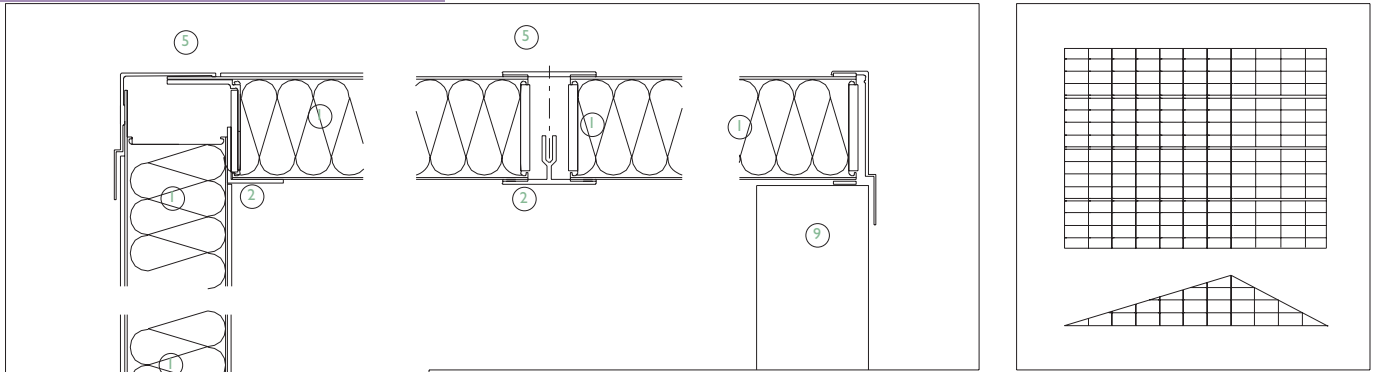
- Abutments

- Sliding roof panels

(2) GRP panels and shells

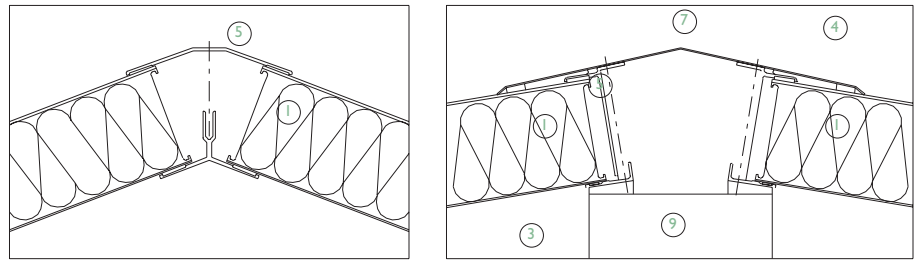
- Smaller panels and shells

- Larger panels and shells



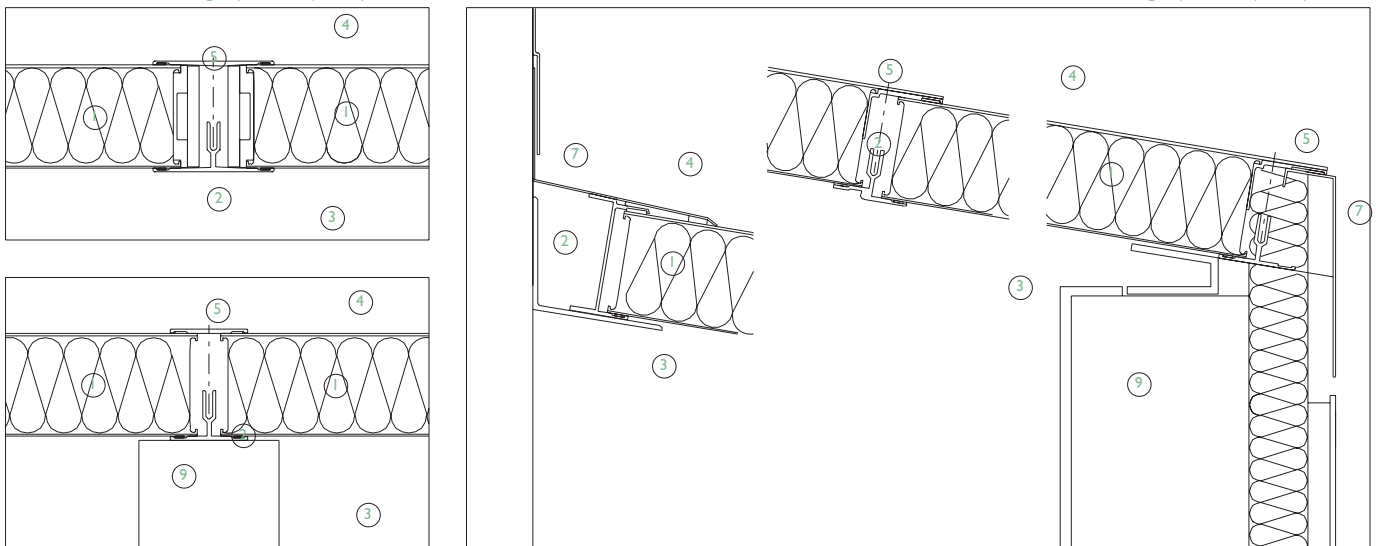
Section 1:5. Small rooflight verge

Sections 1:5. Small rooflight ridge and eaves



Sections 1:5. Small rooflight panel to panel junction

Sections 1:5. Small rooflight panel to panel junction



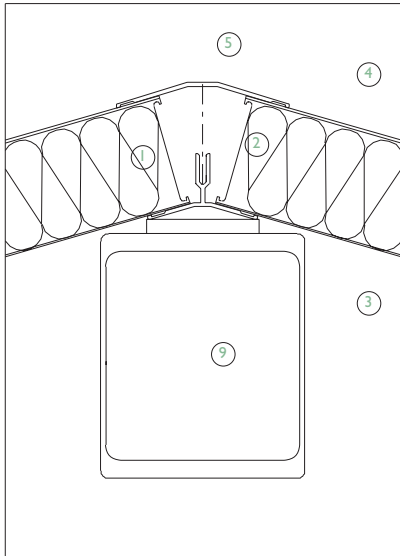
Glass reinforced polyester (GRP) is used in the form of thermally insulated panels to form translucent rooflights which are robust and economic when compared to an equivalent glazed rooflight with double glazed units. GRP rooflights use the principles of metal composite panels which are combined with greenhouse glazing framing to provide a lightweight, highly thermally insulated and economic rooflight. Where glazed rooflights sometimes need an additional layer of solar shading, or use solar performance glass to reduce the effects of the sun, GRP rooflights provide a more economic solution. The advantages of GRP over glass are its strength, lightness and flexibility, as well as the material's high resistance to impact dam-

age. GRP is a composite material formed by reinforcing flexible fibreglass mat (or fibres) with thermosetting polyester resins that provide high tensile and compressive strengths. The material is not combustible, making it a suitable material for rooflights as well as an opaque roof cladding material. While GRP rooflight systems do not usually achieve the high levels of resistance to wind blown rain of internally drained and ventilated curtain walling systems, they are robust and economic, making them ideal where translucency is required rather than the transparency provided by glass panels.

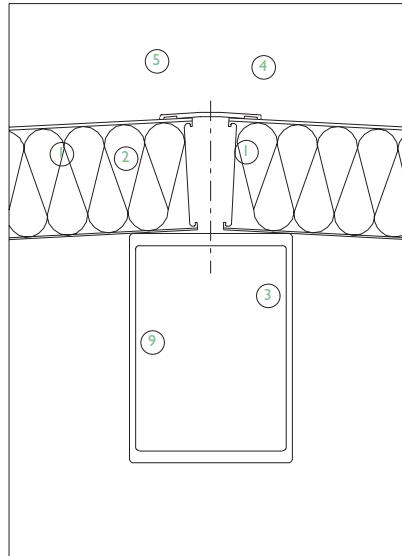
Rooflights are made from GRP sheet which is bonded to an aluminium carrier frame around its edges. Thermal insulation

set into the void is usually bonded to the outer GRP facing sheets to provide true composite action between the GRP skin and the insulated core. Like metal composite panels, GRP panels increasingly have a thermal break introduced into the framing to reduce the possibility of condensation forming on the underside of the panel in temperate climates as well as to improve the overall thermal insulation value of the rooflight. Thermal breaks are usually made from an extruded polymer that has a much lower thermal conductivity than aluminium, and are bonded to the extrusion in the manner of glazed curtain walling or are clipped to it and secured in place by self tapping screws that hold the pressure plate in position.

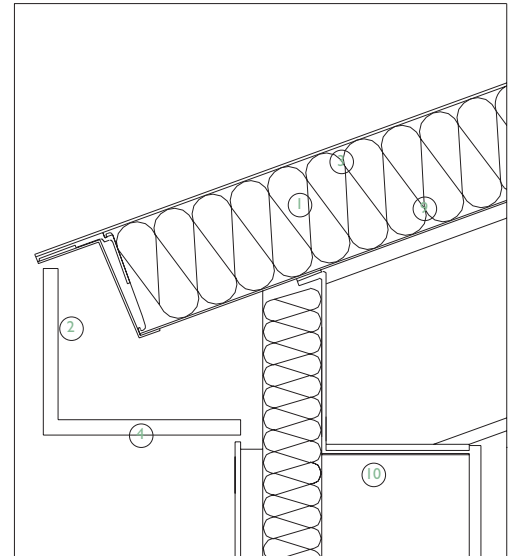
Section 1:5. Large rooflight ridges. Detail A



Section 1:5. Large rooflight ridges.



Section 1:5. Large rooflight eaves. Detail F



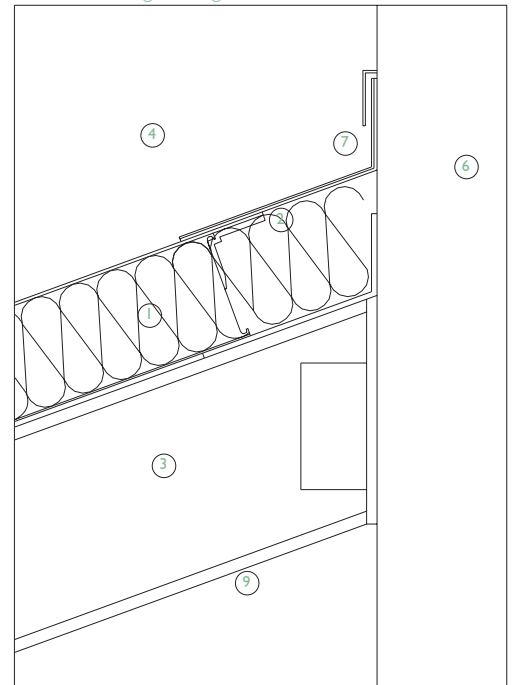
Details

- | | |
|---|-----------------------------------|
| 1. Translucent and insulated GRP roof panel | 6. Adjacent masonry/concrete wall |
| 2. Thermally broken aluminium framing | 7. Folded metal cover strip |
| 3. Inside | 8. EPDM strip |
| 4. Outside | 9. Supporting structure |
| 5. Pressure plate | 10. Concrete upstand |

Bus Station, Lugano, Switzerland. Architect: Mario Botta



Section 1:5. Large rooflight abutment. Detail K



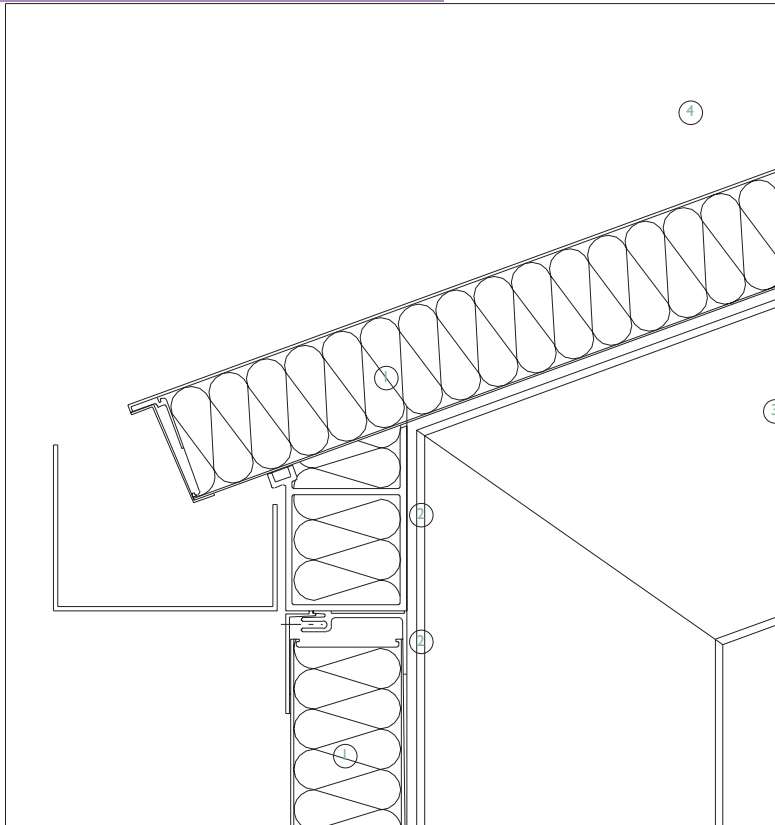
In small rooflights, up to around a 3000mm span, GRP composite panels require no additional support, while those of greater span use an additional aluminium or steel frame beneath to support the composite panels over the greater span. Panel sizes vary with the proprietary system and with the individual rooflight design. Typical panel sizes range from around 400mm x 800mm to 800mm x 3000mm. GRP rooflight panels use a lightweight framing system rather than a lapped junction or raised edges to providing a standing seam type joint used in metal composite panels. These make their appearance more refined, since the framing is very visible in translucent GRP panels, unlike their metal equivalent. An extruded aluminium T-

section forms the support to the panels on all four edges, with an extruded aluminium pressure plate being used to hold the panels in place on the outer face of the GRP panels. Most support frames are now internally drained and ventilated to provide a second line of defence against rainwater penetration. The outer seal is provided by an extruded EPDM gasket clipped into the aluminium extrusion. Proprietary tapes are also used, but are more dependent upon good workmanship on site than gaskets which are fixed to the pressure plate in factory conditions.

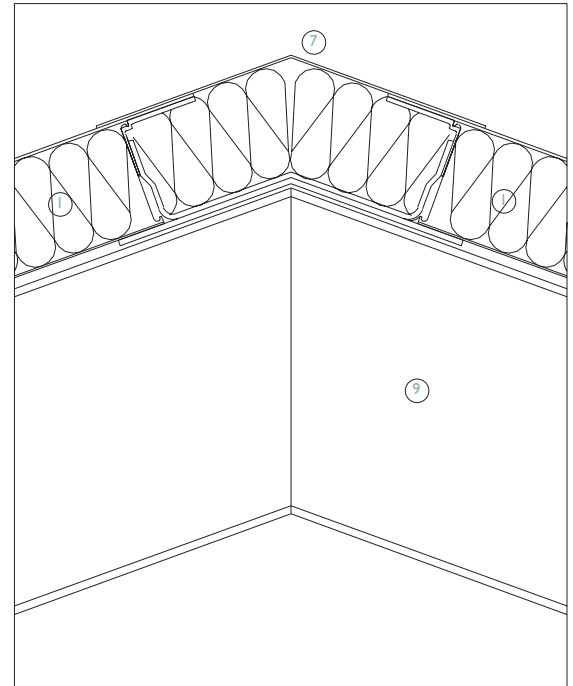
Pressure plates for panel joints running down the slope, as (A), are set over the joint between the panels in the manner of glazed curtain walling. Joints running across the

slope sometimes have pressure plates with lapped joints, as (B), in order to avoid water building up on the upper side of the joint and being unable to run over the joint. The lap is formed by setting an aluminium strip or extrusion, as (B), under the bottom edge of the panel which laps over the top of the panel below. This combination of glazed curtain walling (or greenhouse glazing) techniques and composite metal panel techniques provides a method of construction for translucent rooflights which is visually lightweight with slender joint lines.

In addition to these standard junctions which form part of proprietary systems, panels are jointed with folded metal sheet, as (C), where unusual junctions are to be

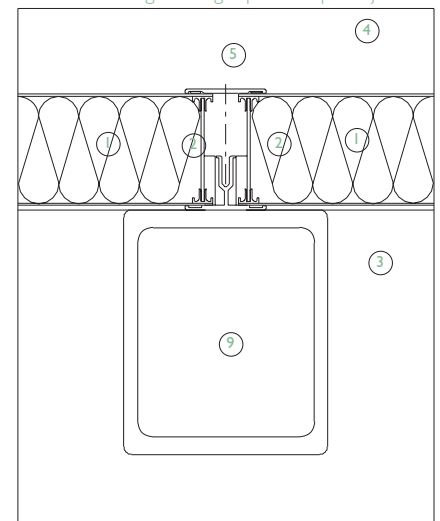


Section 1:5. Large rooflight eaves. Detail E



Section 1:5. Large rooflight ridge. Detail D

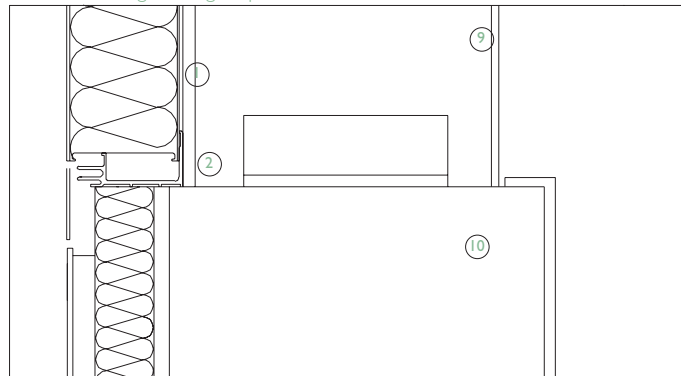
Section 1:5. Large rooflight panel to panel junction



Details

1. Translucent and insulated GRP roof panel
2. Thermally broken aluminium framing
3. Inside
4. Outside
5. Pressure plate
6. Adjacent masonry/ concrete wall
7. Folded metal cover strip
8. EPDM strip
9. Supporting structure
10. Concrete upstand

Section 1:5. Large rooflight upstand at base



formed. In (C) a folded metal sheet is fixed over the top of the upper panels, ensuring that rainwater runs down the panel, and forms a drip where it is fixed to the top of the vertical panel. An inner metal sheet is bonded to the junction of the panels to provide an inner seal and vapour barrier. An alternative detail is to fill the void with thermal insulation, as (D), in order to reduce the risk of condensation forming on the underside of the panel in temperate climates. This is typically used in a wider than typical joint where the provision of a thermal break is usually difficult to achieve. A second line of defence against rainwater penetration is provided by a membrane set immediately beneath the metal flashing rather than on the

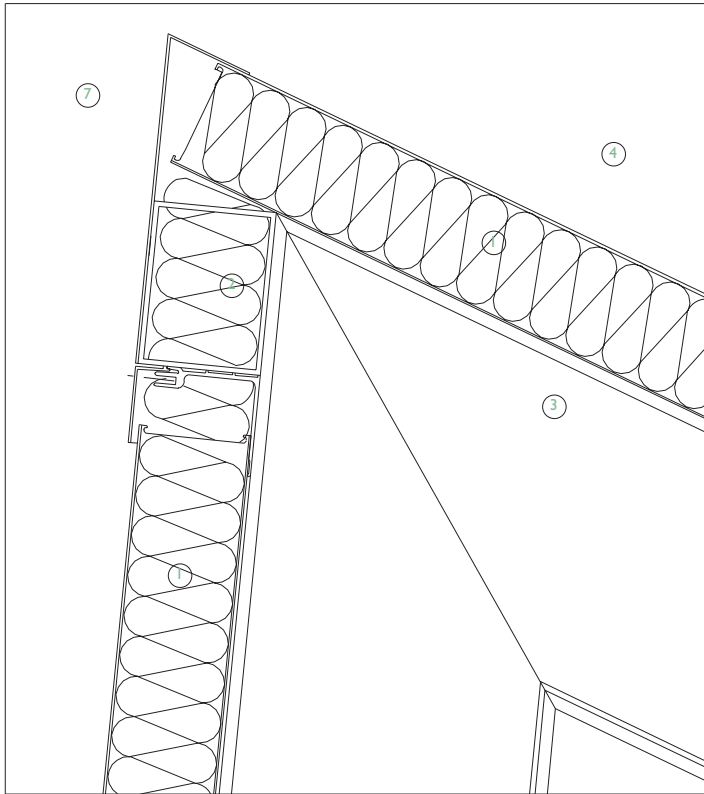
inner joint between panels, as is the case elsewhere, because the thermal insulation cannot be set within the drainage cavity where it would both impede the passage of the small amounts of water that would be drained in the internal cavity, as well as lose its thermal insulation properties due to the absorption of water.

In (D) a ridge flashing is formed in the same way, with a metal sheet fixed to the upper face of the GRP panel frame and a membrane waterproofing layer beneath. Any rainwater that penetrates the outer seal is drained either at the ends of the ridge or down the joint between the panels that run down the slope of the roof.

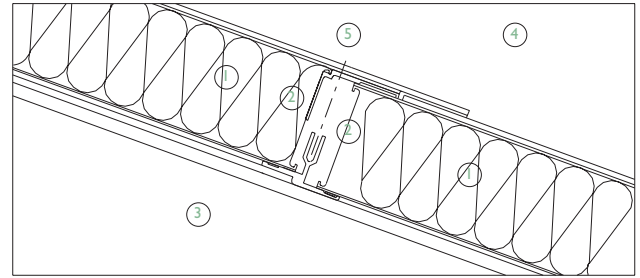
Eaves and upstands

When a rooflight terminates in an eaves, as (E), an intermediary aluminium extrusion or folded sheet is used to form the junction. An outer EPDM or extruded silicone seal is used as an outer line of defence against rainwater penetration at the junction with the GRP roof panel. Drainage slots formed in the bottom of the aluminium closer piece drain away any water that passes through the outer seal. These drainage slots also take away any water to the outside from the drainage channels within the joints between panels that run down the slope of the roof. The GRP panel beneath the closer piece that forms a vertical part of the rooflight is formed by setting the panel behind a vertical

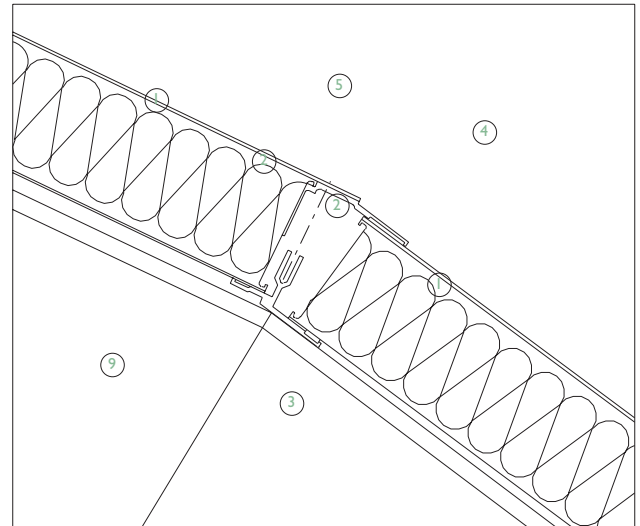
Section 1:5. Large rooflight monopitch ridge. Detail C



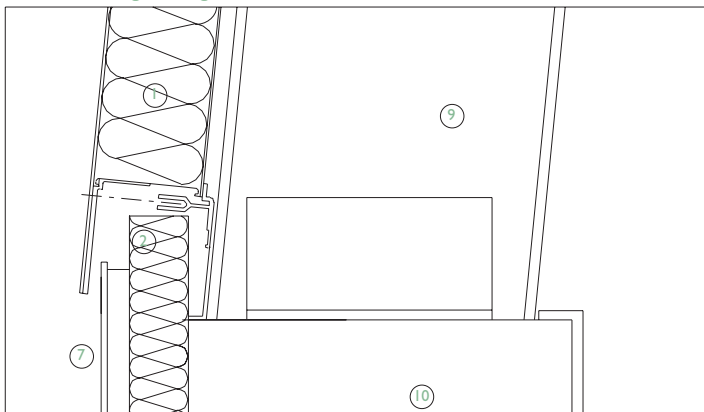
Section 1:5. Large rooflight internal fold. Detail B



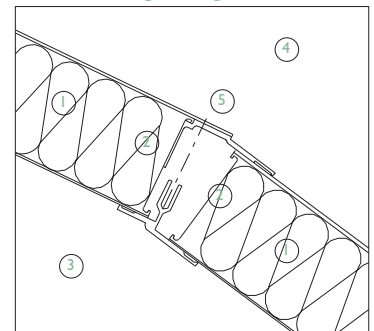
Section 1:5. Large rooflight external fold



Section 1:5. Large rooflight base. Detail G



Section 1:5. Large rooflight external fold

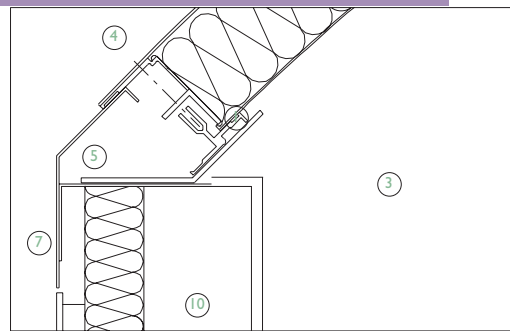


aluminium strip that forms a lapped joint over the top of the panel, avoiding the possibility of rainwater passing through the joint. The gap between the aluminium closer and the GRP panel is sealed with either an EPDM gasket, a proprietary tape, or a silicone sealant. A metal gutter is fixed to the metal closer if required, but this is usually exposed unless it forms part of a fascia, such as the curved eaves used in profiled metal roofing, for example. In smaller rooflights the rainwater typically runs off onto the surrounding area of flat roof.

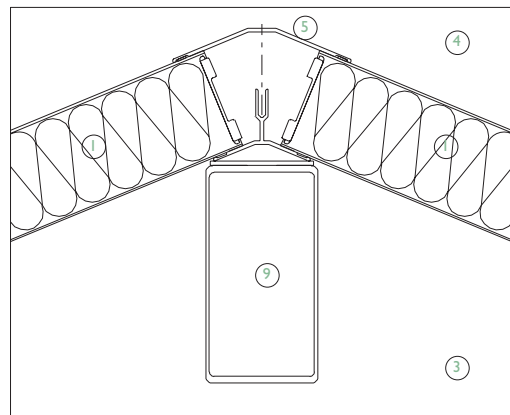
Upstands are formed either with an aluminium closer piece as used at eaves, or with a metal flashing, where the GRP panel is supported on an additional steel or aluminium

supporting frame. A metal closer piece is used to provide a continuous edge support to the GRP panel as well as a weathertight seal. A waterproof membrane is bonded to the outside of the closer piece and is secured to the upstand below, typically formed in reinforced concrete. The closer piece is thermally insulated and is sealed on its inner face with a thin folded aluminium strip that serves both to retain the thermal insulation in place and as a vapour barrier. The visible width of the inner closer strip usually matches that of the adjacent aluminium joints between the panels and is visible within the building, as (F). In (G) a GRP panel is fixed to a supporting frame. The gap between the bottom of the panel and the

upstand beneath is sealed with a metal flashing set forward of the vertical face of the upstand. This allows water to drain out of the ventilated channels in the joints that form the second line of defence against rainwater penetration. A waterproof membrane, typically EPDM, is bonded to the bottom edge of the metal frame surrounding the GRP panel and is sealed against the waterproofing layer of the upstand, providing a continuous seal from the surrounding area of flat roof up to the rooflight. A thermal break in the framing of the GRP composite panel ensures a continuity in the thermal insulation from upstand to GRP rooflight.



Section 1:5. Small rooflight upstand at base

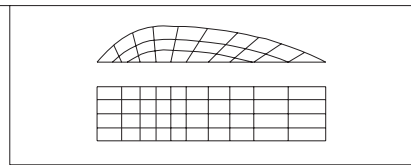


Section 1:5. Small rooflight ridge

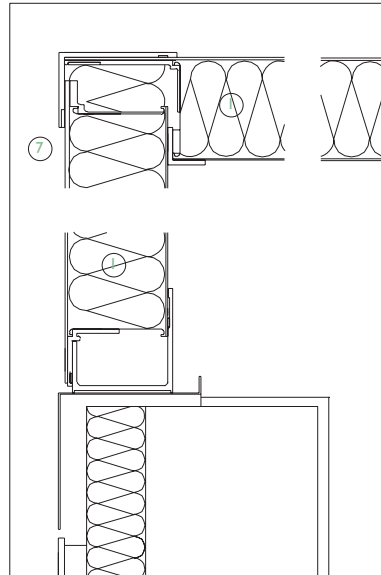
Bus Station, Lugano, Switzerland. Architect: Mario Botta



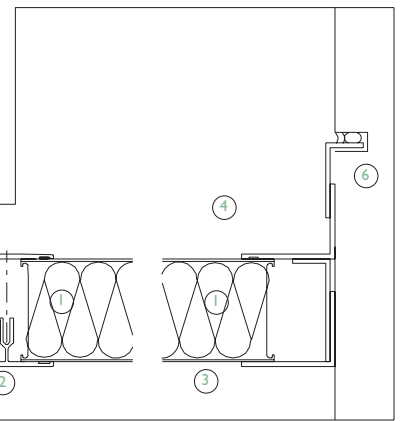
Key plan. Small curved roof layout



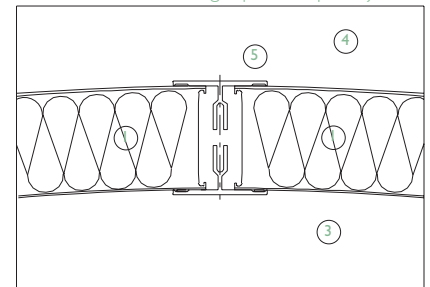
Section 1:5. Verge. Detail J



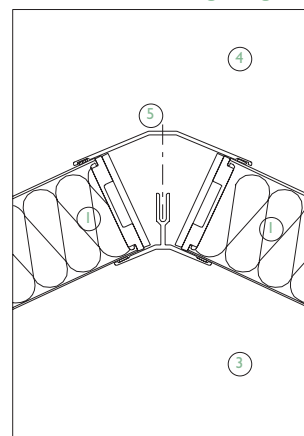
Section 1:5. Abutment. Detail L



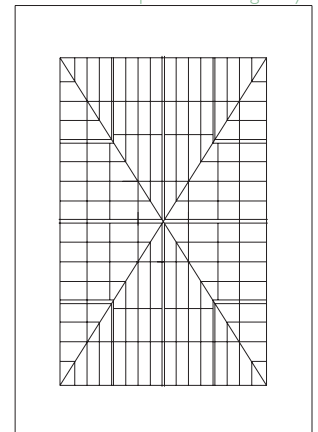
Section 1:5. Small rooflight panel to panel junction



Section 1:5. Small rooflight ridge



Key plan.
Small faceted pitched rooflight layout



Verges

The gable ends of sloping GRP rooflights are formed with an aluminium flashing that is bonded, or mechanically fixed and sealed, to the metal edge frame to the side of the GRP panel forming the sloping panel, and to the top of the triangular-shaped vertical end panel. In (H) the sloping panel extends slightly forward of the vertical panels to give a thin edge to the roof, while in (J) the roof terminates in a sharp edge, with a folded aluminium sheet or angle closing the gap between the panels. As with other panel to panel junctions, a waterproof membrane is set on the underside of the outer metal flashing as a second line of defence against rainwater penetration. The void between the panels is filled

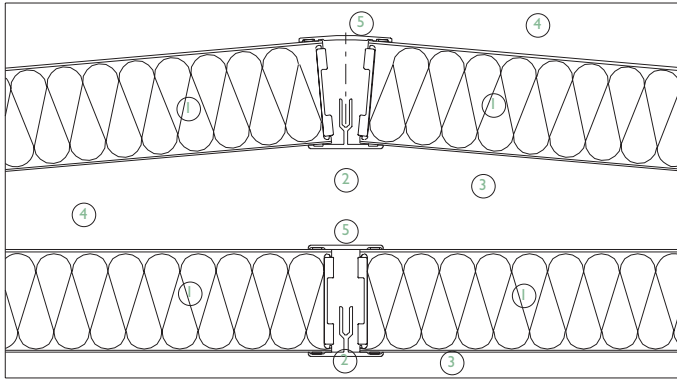
with mineral fibre quilt type thermal insulation, which has the flexibility required to fill the irregular-shaped voids between GRP panels. An additional aluminium angle is used at the junction of the inner face of the panels to provide an additional seal and vapour barrier.

Abutments

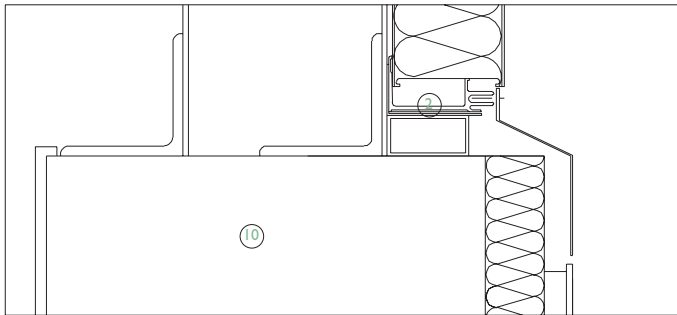
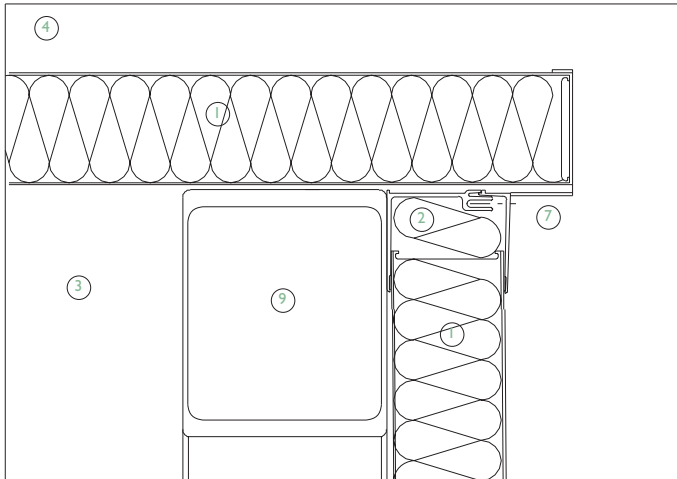
Where a GRP rooflight is set against a vertical wall in another material, such as reinforced concrete or concrete block, a metal flashing is used as in (K) and (L). Beneath the metal flashing, a waterproof membrane is bonded to the edge of the GRP panel and is folded up the abutting wall to which it is bonded. Where wall and rooflight are not

connected structurally, as (L), the membrane usually has an extra curve of material between the panel and the wall to allow for structural movement between wall and roof. The outer line of defence formed by the metal flashing is set onto the membrane and is folded up the vertical face of the wall. An additional metal flashing is used to cover the top edge of the metal flashing where significant structural movement is expected, as in (K), the outer metal flashing being fixed into a continuous groove or horizontal joint line in the concrete or masonry wall to provide a weathertight seal to the top of the flashing.

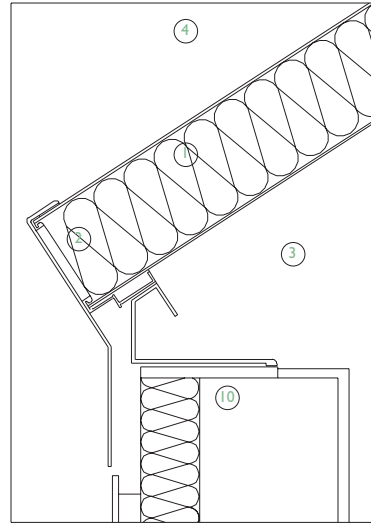
Section 1:5. Small rooflight panel to panel junction



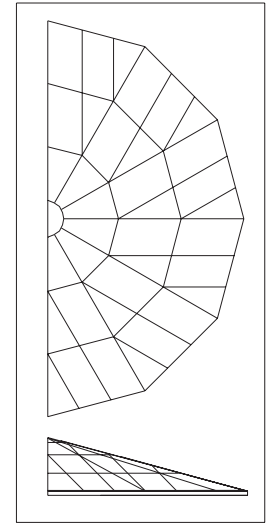
Section 1:5. Verge. Detail H



Section 1:5. Eaves



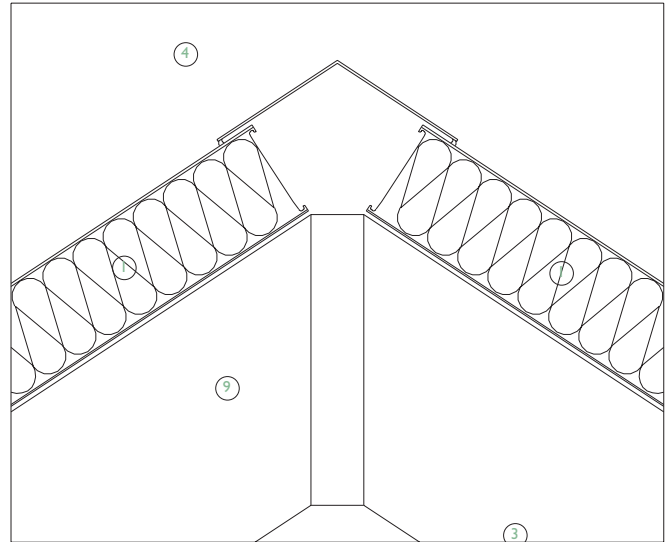
Small curved rooflight layout



Details

- | | |
|---|-----------------------------------|
| 1. Translucent and insulated GRP roof panel | 4. Outside |
| 2. Thermally broken aluminium framing | 5. Pressure plate |
| 3. Inside | 6. Adjacent masonry/concrete wall |
| | 7. Folded metal cover strip |
| | 8. EPDM strip |
| | 9. Supporting structure |
| | 10. Concrete upstand |

Section 1:5. Ridge



Sliding roof panels

The lightweight nature of GRP rooflight panels is being used increasingly in sliding panels that allow a rooflight to be opened at different times of the year. Typically up to around 40% of panels in a rooflight are opened by sliding them over adjacent fixed panels, in relatively modest electrically operated systems. Where larger-scale glass rooflight panels are difficult and expensive to become openable due to the weight of the glass and the complexity of their seals, GRP rooflight panels are easier to slide, with seals being provided by lapped joints with EPDM or extruded silicone seals in the manner of sliding doors. Opening panels are sealed to the levels of air infiltration associated with

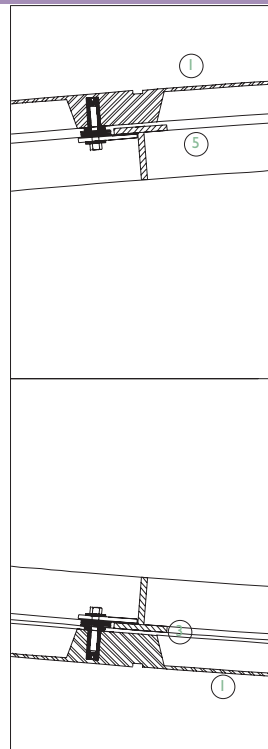
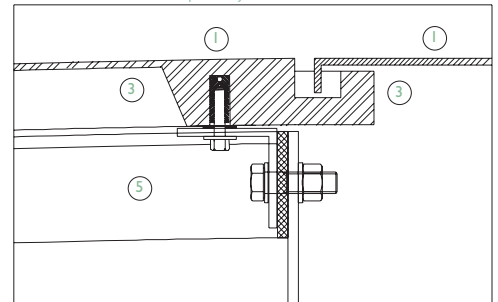
opening windows, which are usually higher than those of fixed glazed rooflights.

Panels can move either side to side in the manner of sliding doors, or vertically in the manner of sash windows. The same principles of fixing and waterproofing joints are used regardless of the direction of movement of the panels. In (M), one side of the horizontally sliding panel has an upstand, while the other three sides are set into a slot. In the slot connection, the outer (upper) seal comprises EPDM or silicone-based gaskets, usually in a 'flipper' section that allows the aluminium framing to slide in and out of the housing on one side, and to slide on the other two sides. Any rainwater that penetrates the outer seal is drained away in a

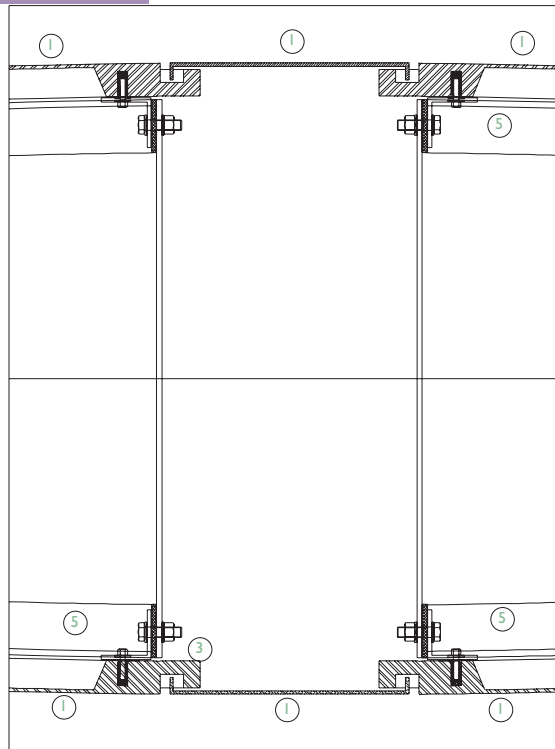
cavity within the rooflight frame, draining out through holes in the bottom of the aluminium profile onto the roof below. An inner air seal, either polymer foam based or similar to the outer gasket seals, is provided on the underside of the GRP panel. These general principles of sliding panels will no doubt be developed to suit more complex geometries of openable panels over the next 10 years. The pop-out type sliding doors that move outward before sliding, together with hinged panels, will make this rooflight system more generally applicable to large-scale applications of all building types.



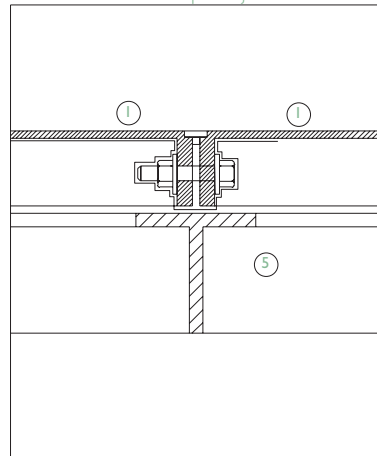
Section 1:5. Panel to panel junction



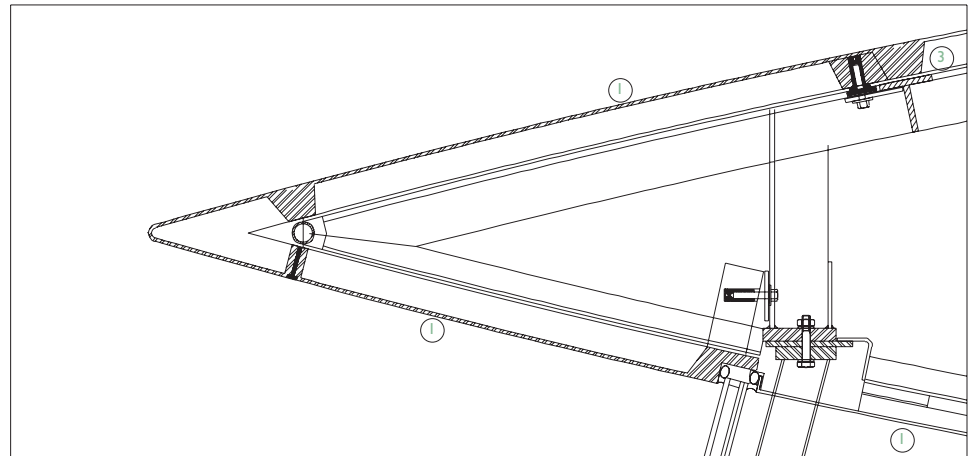
Section 1:10. Panel to panel junction Detail E



Sections 1:5. Panel to panel junction Detail C



Section 1:10. Perimeter



Where glass reinforced polyester (GRP) rooflights, discussed in the previous section on rooflights, are made as panels which are joined to form translucent rooflights, opaque GRP panels can be made as monolithic, self-supporting shells, usually made from panel segments which are brought to site and bolted together. The segment sizes of GRP shells are made in sizes which are suitable for transportation by road, usually set upright on a trailer. The shells can then be lifted by crane into place as a completed assembly, which makes them quite different from roof structures in other materials.

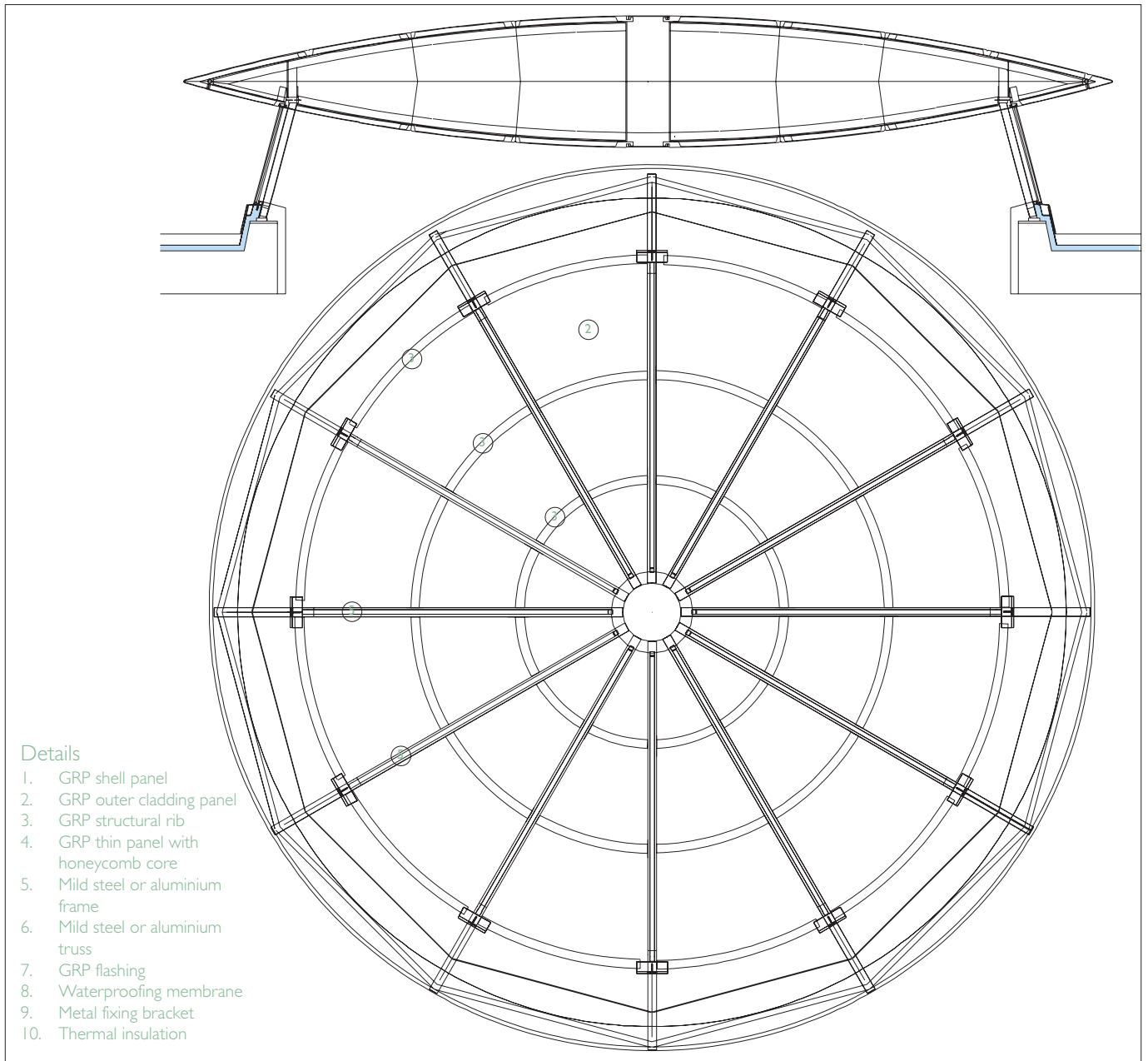
Smaller panels and shells

Smaller shells, as shown in generic examples (A1) and (A2), consist of a set of segmented panels which are bolted together to form a roof shell of approximately 7.0 metres diameter. Type (A1) is supported by an additional frame, while (A2) is a self-supporting GRP shell.

In (A1), GRP panels are supported by a light metal frame beneath. The frame comprises steel or aluminium T-sections which are welded together to form a structure that supports the complete outer skin. The frame has curved members that radiate from the centre at the top to the edge and from the centre at the lowest point of the structure, back to the perimeter. The radiating 'spokes'

of the wheel are held in place by T-sections that, in plan, form concentric circles. This 'bicycle wheel' form is supported near its perimeter by a metal ring beam that is set immediately above the glazing beneath the GRP roof. The ring beam is supported by posts that are fixed to the roof deck beneath.

The metal frame is clad in prefabricated GRP panels which are bolted to the support frame on their internal face in order to avoid visible fixings. Panels are made with an outer skin of GRP around 5mm thick, with an overall panel depth of around 45mm for the panels sizes shown of 3500mm long and 1800mm wide. The GRP panels are stiffened by concentric ribs, around 120mm wide, as

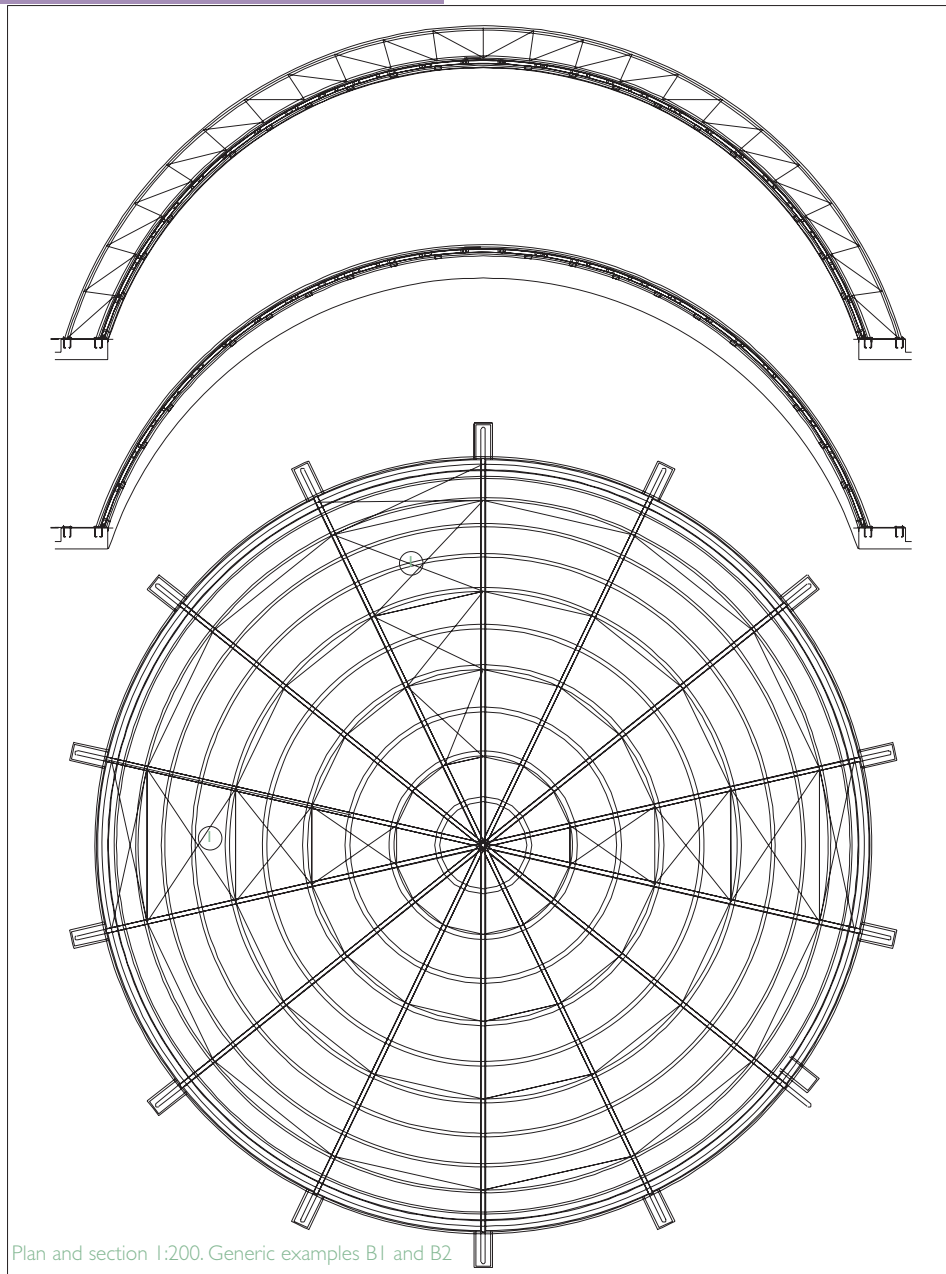


shown in (B). The long edges of panels do not require thick ribs, and these are around 10mm thick as shown in (C). Panels are secured with bolts which are fixed through the metal support frame into reinforcing ribs at the edges of the GRP panels. Joints between GRP panels are formed by butting panels up to one another and sealing the gap between the panels. The seal is formed in a continuous step profile on the long edges of each panel that creates a continuous groove at the joint between panels. The groove is filled with a lamination of glass fibre and resin to fill the groove to the level of the top of the panels. The external face of the GRP is then ground smooth, usually by a hand-held grinder, to achieve a uniform, smooth surface

that conceals the joint lines. Finally, a paint finish is applied, usually as a spray, to give a smooth and reflective finish. Where pigments are applied to the top coat, or 'gel' coat, in the factory, a more limited range of colours is available. Thermal insulation is set on the underside of the shell, being bonded to the inner face of the GRP panels in order to achieve continuity of insulation.

Generic example (A2) uses glass fibre ribs that form part of the shell to provide integral structural stability to the shell. Panels are around 200mm deep, as (D), and are bolted together to form a self-supporting GRP shell. Ribs are made in solid GRP in order to allow them to be bolted together easily. Panels are joined and sealed on their

external face in the same way as example (A1). A different method for forming the top of example (A2) is shown in (E). Where panel segments converge at the top of the shell, a separate centre panel is used to create a smooth external finish. A central external panel avoids the difficulty of bringing up to 16 panels together at a single point which would make it difficult to achieve a smooth transition from one side of the shell to the other. In the example shown, a shadow groove is set around the joint between the central panel and the segments in order to avoid any misalignment between segmented panels from being visible. The perimeter joint of the panel can be filled and sealed using the method described earlier, with additional



Details

1. GRP shell panel
2. GRP outer cladding panel
3. GRP structural rib
4. GRP thin panel with honeycomb core
5. Mild steel or aluminium frame
6. Mild steel or aluminium truss
7. GRP flashing
8. Waterproofing membrane
9. Metal fixing bracket
10. Thermal insulation

Plan and section 1:200. Generic examples B1 and B2

grinding required on site to ensure a smooth finish.

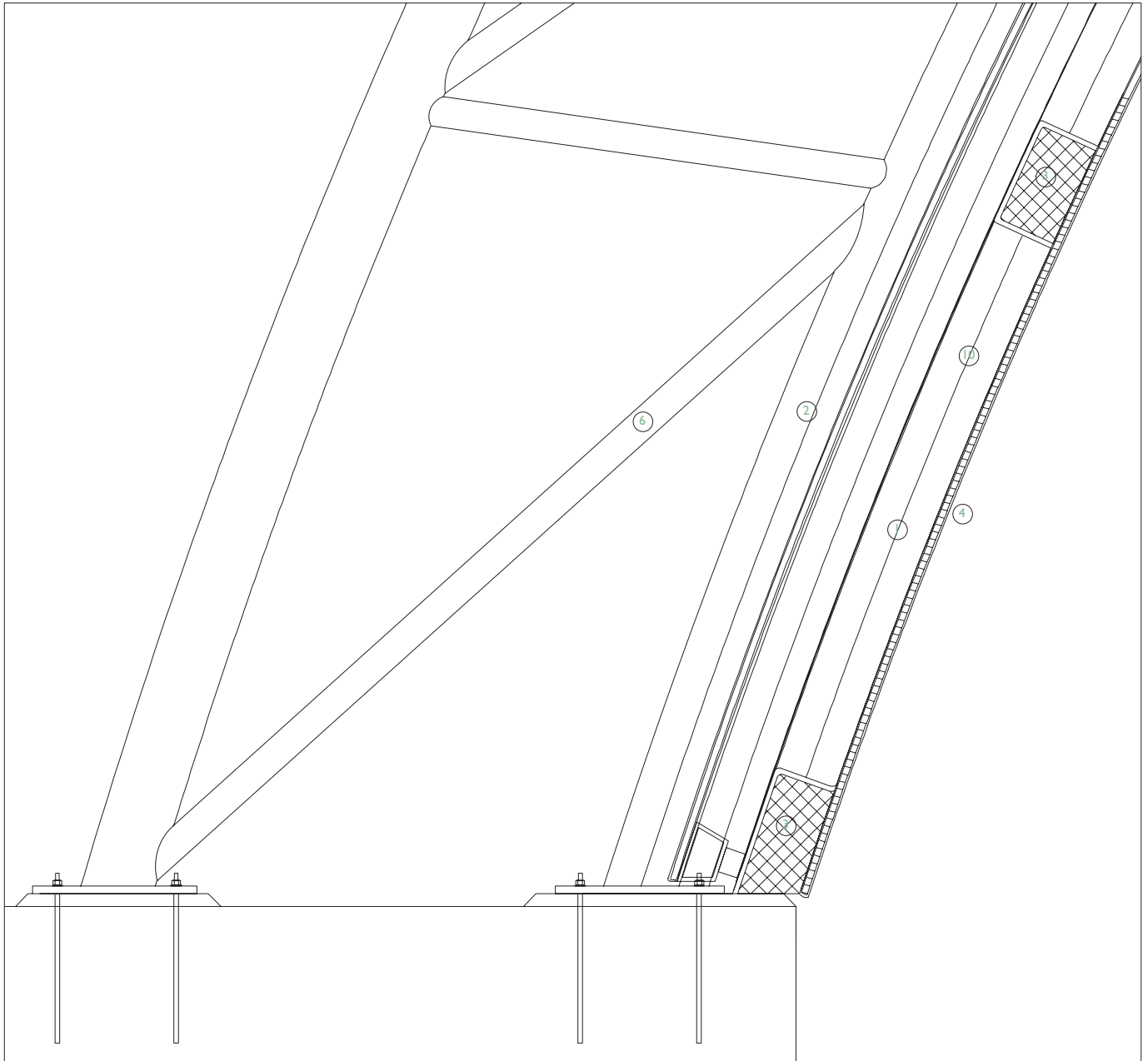
The underside of the shell is mostly set internally behind curved glazed units set near the perimeter of the roof. The internal part of the shell on its underside, has the same panels with the same finish, but without any thermal insulation, which is typically set around the outer edge of the shell in order to keep temperatures within the void close to those within the building. Close to the edge of the shell, on the underside, the joint between the top panel which curves around the edges, and the adjacent panel underneath, has a groove formed along the joint to serve as a drip. Windblown rain will still be pushed along the underside of the soffit

panel, but the drip reduces the amount of water that runs down to the glazing below.

The curved glazed units beneath the roof shell are set into a recessed slot at the panel joint. The recess avoids the possibility of a weakness in the seal that could result in using a butt joint between shell and glazing. The edge of the double glazed unit is sealed completely around the junction with the shell, typically with silicone.

Both the cladding panels of (A1) and the self-supporting shell of (A2) are made using the same manufacturing process. Panels are made in a mould, usually from a single segmented panel type to form a complete rooflight. Moulds are usually made from plywood to create the shape and are then fin-

ished in GRP to create the negative shape of the panel being formed. GRP panels are fabricated by first applying a release agent to the mould to allow the finished panel to be removed easily, then thermosetting polyester resins are applied to the face of the mould, with flexible fibreglass mat being laid into the resin, usually with rollers. The process of fabricating GRP panels is very labour intensive, but requires no expensive equipment, making panel production a craft-based technique rather than an industrial process. When the panels are released from the mould they are trimmed along their edges and ground smooth where necessary. An alternative method is to apply a mixture of resin and glass fibre particles as a spray directly into



the mould. The mixture is applied to a thickness of 3mm to 5mm depending on the panel size required.

Larger panels and shells

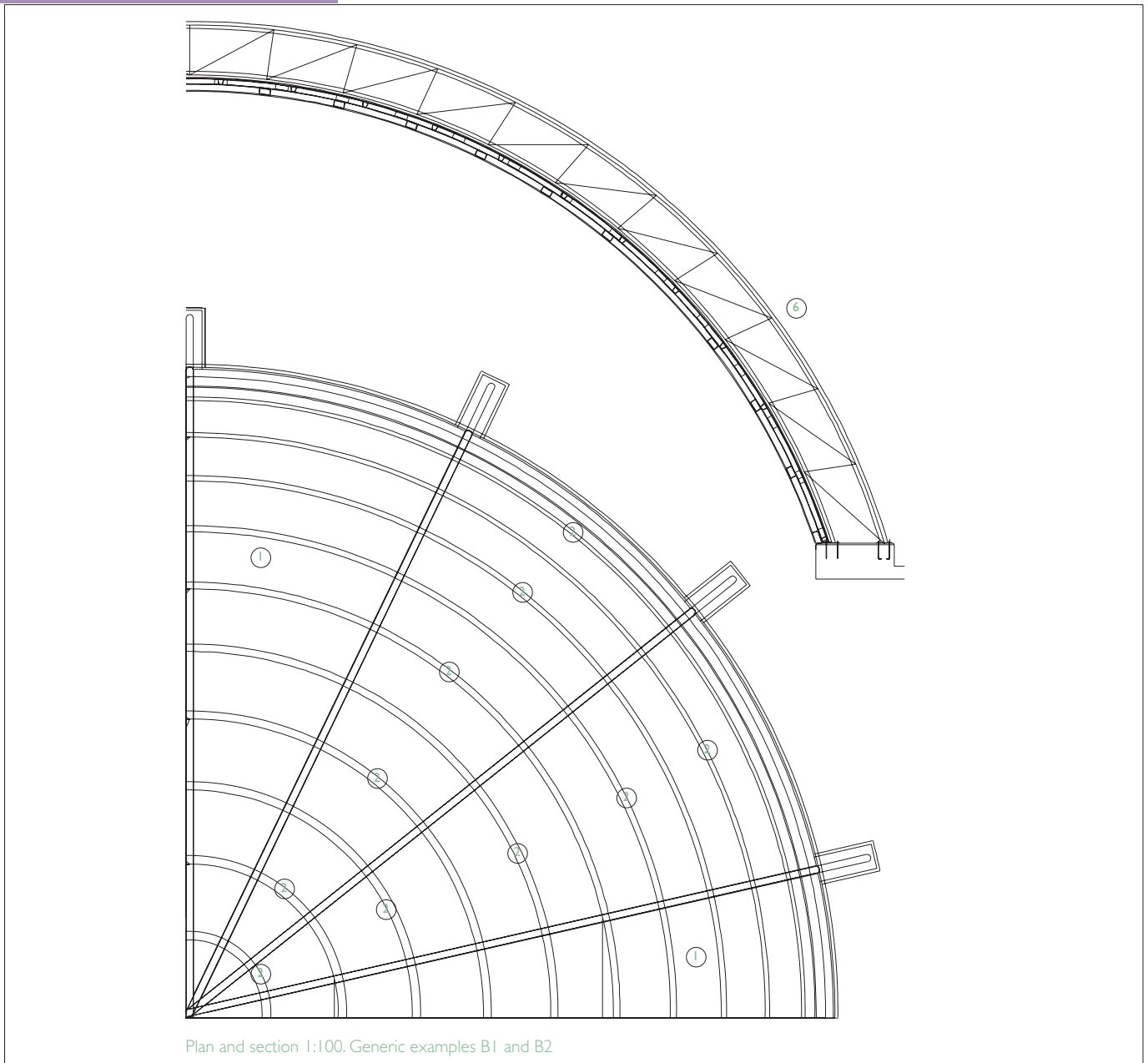
In generic example (B1) and (B2) a hemispherical dome of 20 metre diameter is constructed as a self-supporting shell. In (B1) a shell is made from GRP only, while in (B2) the dome has structural stability provided by an external steel or aluminium truss. The truss might be used to support a decorative outer screen or a lighting system to illuminate translucent panels, for example.

In example (B1) a loadbearing inner shell, with integral GRP structural ribs, is clad with GRP panels that form a weathertight

outer screen. The inner shell serves as the loadbearing structure, it being easier to install panels with a pre-finished internal surface since no further access is required for finishes work on its internal face. Consequently, no scaffolding or access platforms are required inside the building to install and finish the rooflight. The outer skin of GRP cladding panels is fixed using a lightweight crane that lifts the outer segmented panels into position. The construction method can, of course, be reversed so that an outer shell with a factory-applied finish can be installed as a pre-assembled item that requires no further work externally. GRP cladding panels can then be applied to the internal face of the shell from inside the building, but this the

more difficult construction method.

The structural shell is usually assembled by bringing the panel segments to site individually, due to their size. The panels are then bolted together on site, on the ground. The joints are then formed on the finished face, either internal or external. Finally, the shell is lifted by crane into position on the roof as a complete item. The flexibility and lightweight nature of GRP makes this possible, which avoids the need for scaffolding and access equipment at roof level. An alternative method, where no space is available on site for assembly, is to create a platform beneath the shell inside the building, where the roof can be assembled in place. However, the sanding and grinding operations required to



Plan and section 1:100. Generic examples B1 and B2

make the inner face of the shell smooth and continuous, and ready for painting, usually requires the in-situ constructed solution to be in an enclosed space to avoid GRP dust particles from spreading around the building.

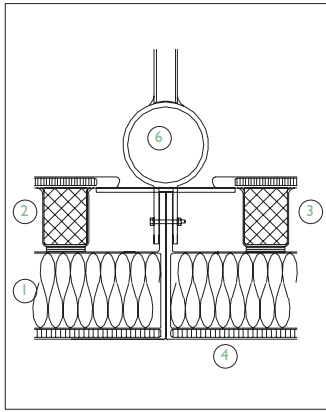
The inner shell in example (B1) is made with an inner wall around 15mm thick made as a thin composite panel. The panel is formed with two outer skins of GRP, 2-3mm thick, with an inner core made from polypropylene-based honeycomb sheet. The honeycomb core provides a rigid reinforcing layer to the outer skins of GRP that give them a flat, smooth appearance. This inner skin is reinforced by structural ribs that form an integral part of the panel, and are set horizontally at approximately 1000mm centres.

They are also made from GRP, filled with mineral fibre insulation or injected foam to provide thermal insulation, with overall section sizes of around 200mm wide x 300mm deep, as shown in detail (F). The horizontally-set ribs span a maximum of around 450mm at the base of the shell, decreasing in size until they reach the top of the shell, as shown in (G). GRP ribs are also set vertically on the edges of the panels, filled with thermal insulation but made as solid GRP where panels are fixed together with bolted connections, as (H).

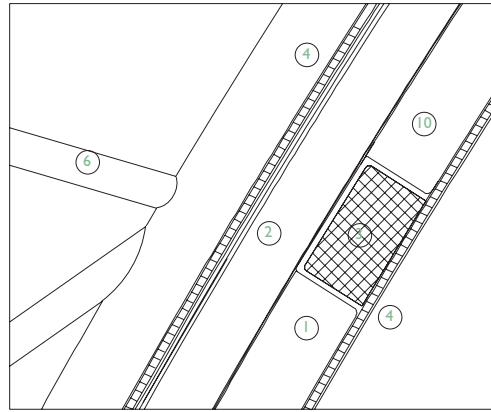
The shell is thermally insulated with mineral fibre or foam-based insulation set in the voids between the ribs. The outer face of the shell is covered with a GRP skin that pro-

vides an outer seal against rainwater penetration. The layer is given a further protection and visual screen provided by outer cladding panels. Like the inner shell, the outer cladding is made from 15mm thick composite panels, stiffened by GRP ribs around 100mm deep x 200mm wide. These outer segmented panels are bonded to the inner shell with resins or with silicone, and sealed with silicone at their joints to form a continuous outer skin. Small amounts of rainwater that might penetrate the outer line of defence are drained away down the outer GRP skin of the inner shell. While it is easier to provide a continuous smooth finish in a smaller shell, in larger examples it is more difficult to avoid visible surface irregularities

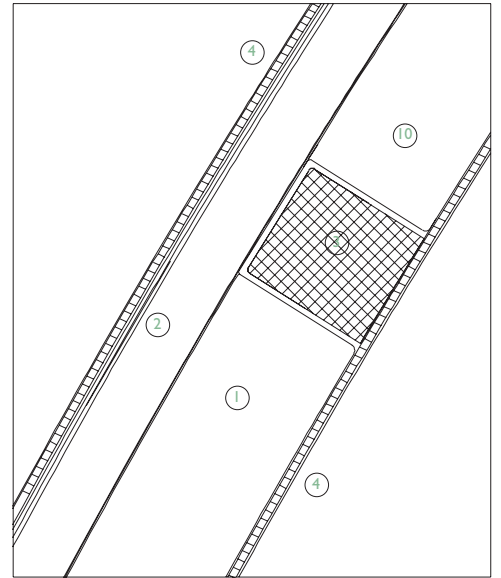
Plan 1:10. Panel to panel junction, example B2 Detail J



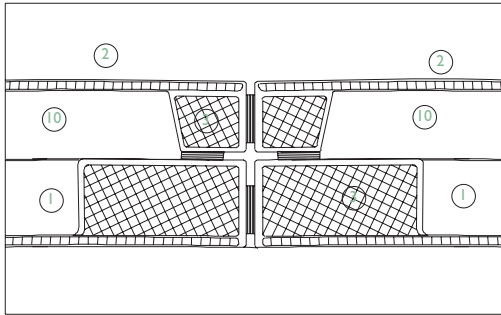
Section 1:10. Panel to panel junction, example B2



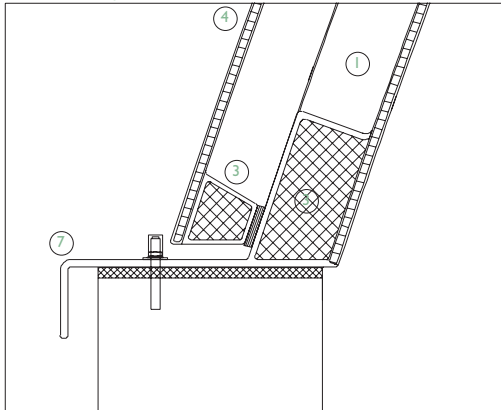
Section 1:10. Panel to panel junction, example B1 Detail F



Plan 1:10. Panel to panel junction, example B1 Detail H



Section 1:10. Junction at base Detail K



Bus Station, Hoofddorp, The Netherlands. Architect: NIO architecten



on larger shells. For this reason, visible joints are usually preferred in larger-scale GRP shells.

In generic example (B2), an additional metal truss in either mild steel or aluminium is fixed at the panel joints to provide structural stability. The GRP ribs within the panels forming the inner shell are reduced to 20mm thick ribs, as (J). A metal plate is set between the adjacent panels, with the joint being sealed with silicone. Like example (B1), an outer skin of GRP cladding panels provides an outer line of defence against rain-water penetration. Panels are mechanically fixed to a continuous metal plate forming part of the truss, the panel being sealed against the plate with silicone seal, as (J).

In both examples (B1) and (B2), the junction at the base of the shell is treated as an upstand. This allows the shell to be set a minimum 150mm above the adjacent roof level without the need for complex junctions between roof slab and shell. The base of the shell has a continuous GRP flashing bonded which also serves as a fixing plate onto the concrete upstand, as (K). The base plate is set on levelling shims to take up the construction tolerances in the height of the concrete upstand. The waterproofing membrane of the adjacent roof is taken up to the top of the upstand and is lapped under the GRP flashing, as (K). An additional waterproofing membrane may extend to the inside of the inner shell and up the internal face of the

shell where it is protected by another GRP cover strip, concealed from view by internal finishes.

Details

1. GRP shell panel
2. GRP outer cladding panel
3. GRP structural rib
4. GRP thin panel with honeycomb core
5. Mild steel or aluminium frame
6. Mild steel or aluminium truss
7. GRP flashing
8. Waterproofing membrane
9. Metal fixing bracket
10. Thermal insulation

6

FABRIC

(1) ETFE cushions

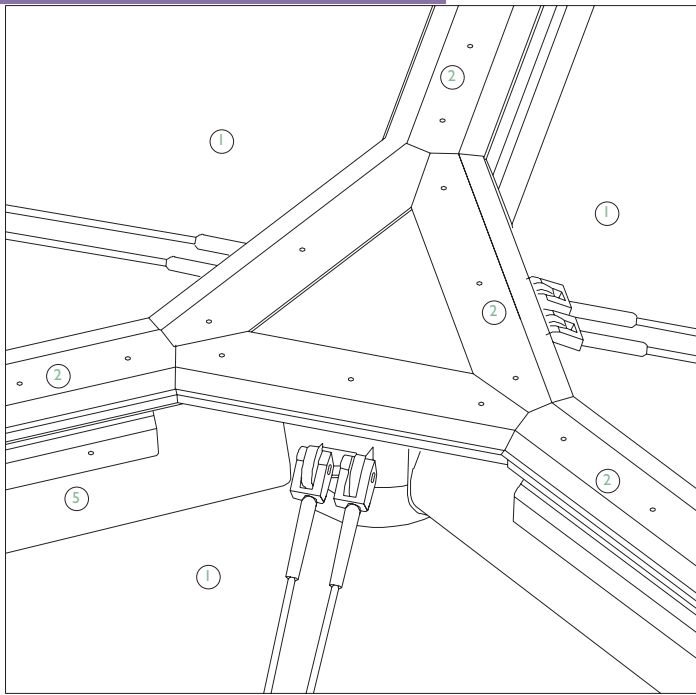
- Cushions
- Air supply
- The material
- Fabrication
- Durability
- Performance in fire

(2) Single membrane : Cone-shaped roof

- Fabric roof principles
- Fabric types
- Comparison of types
- Thermal insulation
- Acoustics
- Durability
- Performance in fire
- Condensation

(3) Single membrane : Barrel-shaped roof

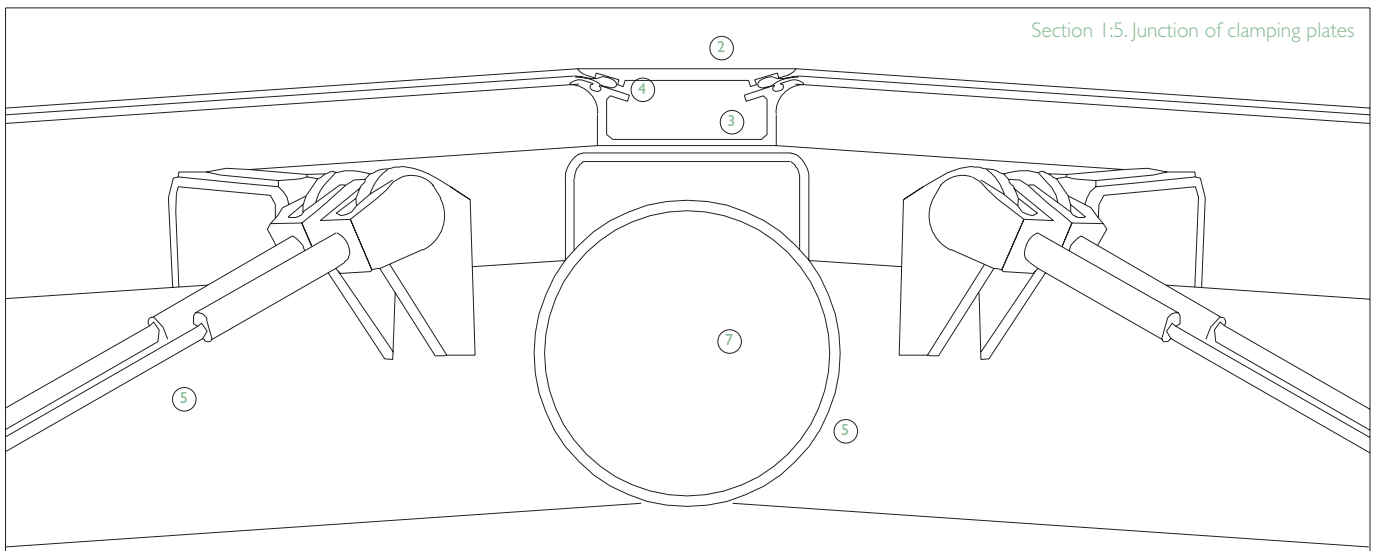
- Membrane roof fabrication
- Membrane roof edges
- Suspension points
- Membrane folds



Isometric view of junction of clamping plates



Artepilage, Neuchâtel, Switzerland. Architect: Groupe Multipac.



Section 1:5, Junction of clamping plates

Fabrics used as roof membranes have the advantage of being light in weight, strong in tension and durable, and have the ability to be cut to different shapes and joined together economically, which is difficult to achieve so easily with metal and is very expensive to achieve with curved glass. Roof membrane fabrics are used in tension structures, either by stretching the material, or 'prestressing' the membrane, between structural supports or, alternatively, by supporting the material pneumatically in inflated structures. The use of fabric membranes in prestressed roofs is discussed in the next two sections on single layer fabric membranes. This section considers ETFE cushions, also called 'pillows' or 'foils', which are the most common applica-

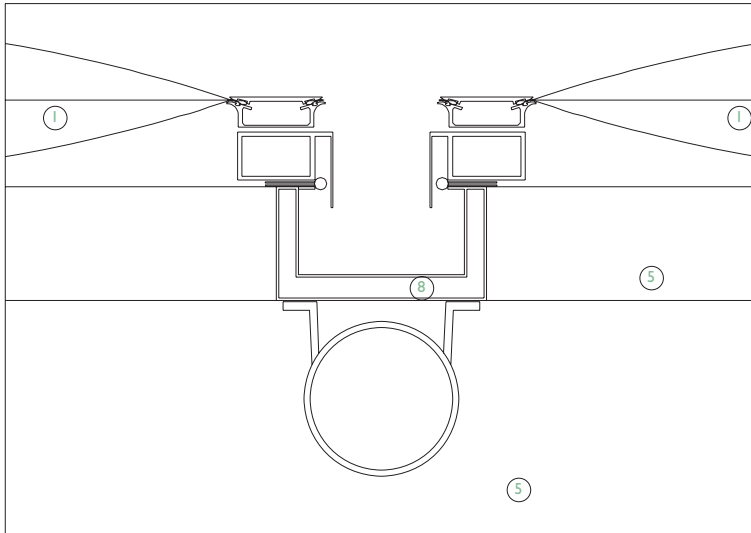
tion of inflatable fabric roofs.

Although large scale self-supporting inflatable roof structures are in use, particularly for covering sports stadiums, they remain structurally stable only while air is being supplied to the structure. If the air supply is interrupted, the complete roof structure deflates. In smaller scale applications, air-filled cushions remain in place when the air supply fails or is switched off when used as non-loadbearing panels. This type, where ETFE sheet is used to make panels formed as air-filled 'cushions', provides highly transparent, lightweight and resilient roofs that have thermal insulation values similar to those of double glazed units.

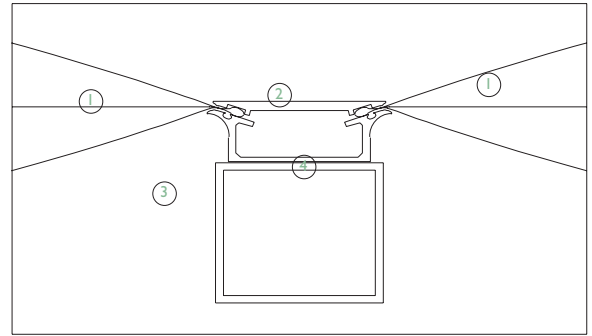
Cushions

ETFE cushions usually consist of a minimum of two layers of ETFE sheet which are set back to back to form a flat panel and are sealed at the edges. The void within the cushion-shaped panel is inflated with air to a pressure of between 200 Pascals and 700 Pascals, depending on the cushion size and the manufacturer's proprietary system, to provide structural stability to the panel. The increased air pressure stretches, or 'prestresses', the outer membranes, giving ETFE cushions their characteristic curved shape. The cushions are held in place by clamps that form a frame around the cushions in the manner of glazed rooflights. The clamping frames are then supported by a mild steel

Section 1:10. Opening smoke vents with insulated gutter Detail F

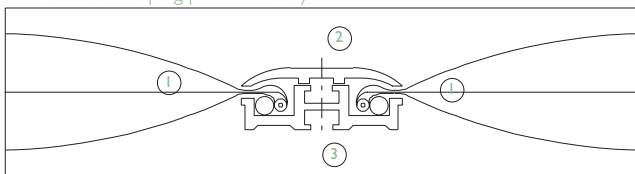


Section 1:5. Clamping plate assembly

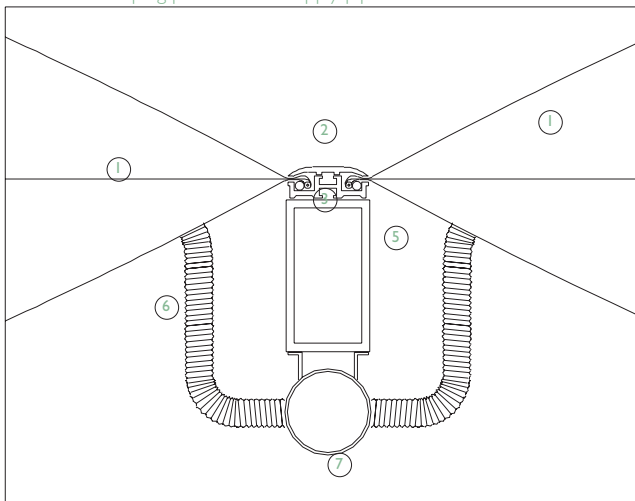


- Details
- | | |
|---|--|
| 1. ETFE cushion | 5. Supporting structure |
| 2. Extruded aluminium clamping plate | 6. Plastic air supply tube |
| 3. Extruded aluminium retaining profile | 7. Main air supply tube |
| 4. Plastic edge bead to fabric membrane | 8. Insulated metal lined gutter |
| | 9. Metal flashing |
| | 10. ETFE cushion with contours shown for clarity |

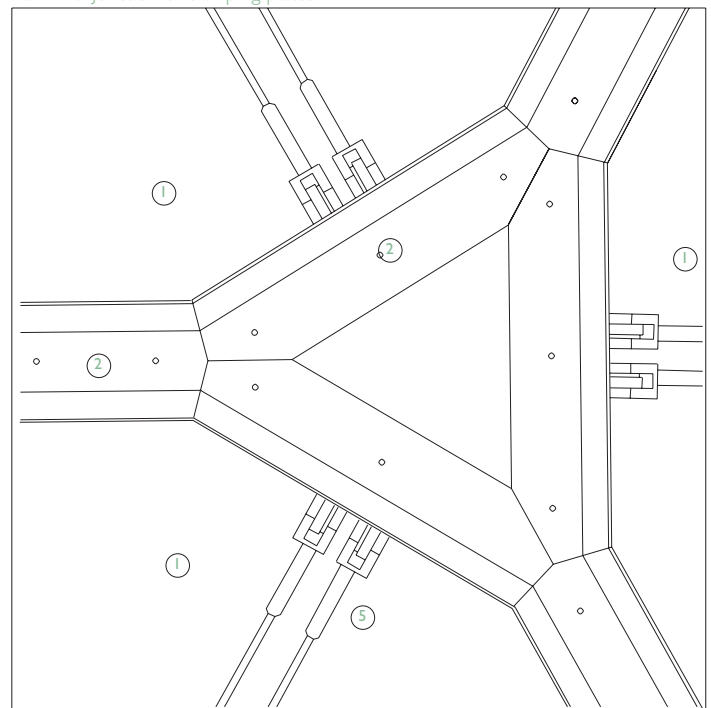
Section 1:5. Clamping plate assembly



Plan 1:10. Clamping plate with air supply pipes Detail C



Plan 1:10. Junction of clamping plates



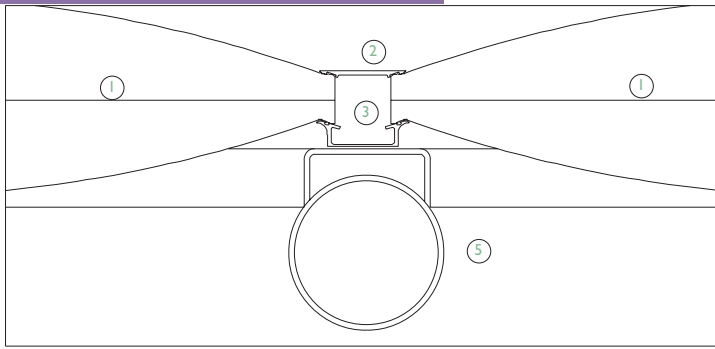
structure formed typically as box sections or tubes. Cushions typically have three layers that form two chambers, as (A). The two chambers are linked by a hole formed in the middle (flat) membrane in order to allow air to pass to both chambers from a single air supply, and to ensure that the air pressure in both chambers remains equal. This three layer cushion provides a U-value of around $2.0 \text{ W/m}^2\text{K}$, which is similar to a double glazed unit used in glass roofs. Cushions made from two layers of ETFE sheet are also used but the thermal insulation performance is reduced considerably. Thermal insulation performance is reduced at the perimeter of the cushion where its thickness is reduced to a thin edge. Some cushions have thermal

breaks at the panel perimeter to partially overcome this loss of thermal insulation. The overall U-value can be reduced by forming a wide gap between the two outer membranes, as (B), to provide a consistently wide air space within the cushion. Thermal insulation performance can also be improved by increasing the number of air chambers within the cushion by adding further layers of ETFE membrane.

Air supply

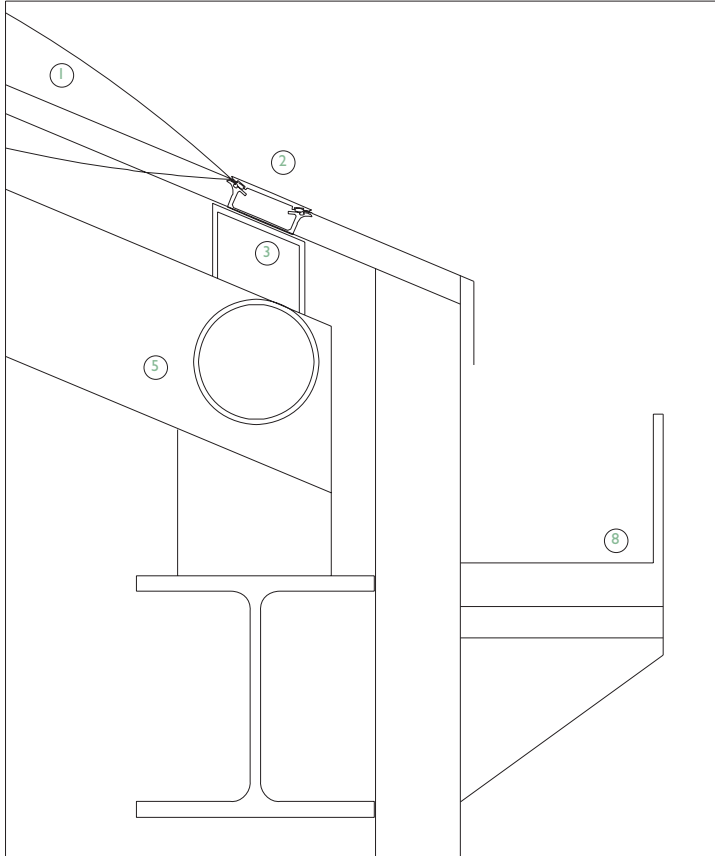
Air is supplied to cushions from rubber pipes or flexible plastic pipes that are connected to the underside of the cushion near the clamping assembly, as shown in (C). Pipes are usually of around 25mm diameter, and

are connected to a larger pipe that supplies the air to all the cushions either side of a single structural support. This main pipe is also usually made from plastic and can be concealed within the supporting structure, being only up to a diameter of around 60mm. The air supply, which maintains the air pressure within the cushions at a constant level, is supplied by electrically powered fans with air filters (to avoid the passage of dust), as used in mechanical ventilation systems within buildings. The humidity level of the air is usually controlled to avoid the possibility of condensation forming within the cushions. Once the ETFE cushions have been inflated, air is supplied to the cushions for only around 5-10 minutes per hour to compensate for loss

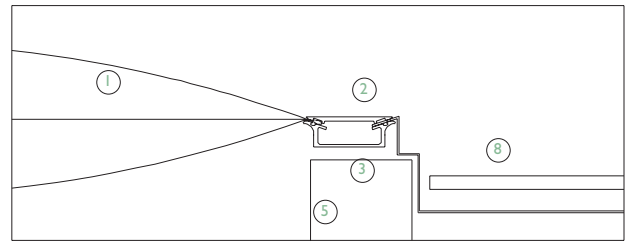


Section I:10. Junction of clamping plates Detail B

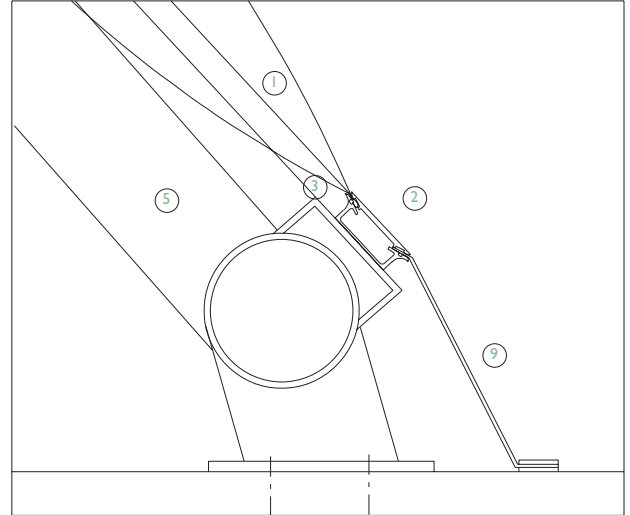
Section I:5. Junction with gutter



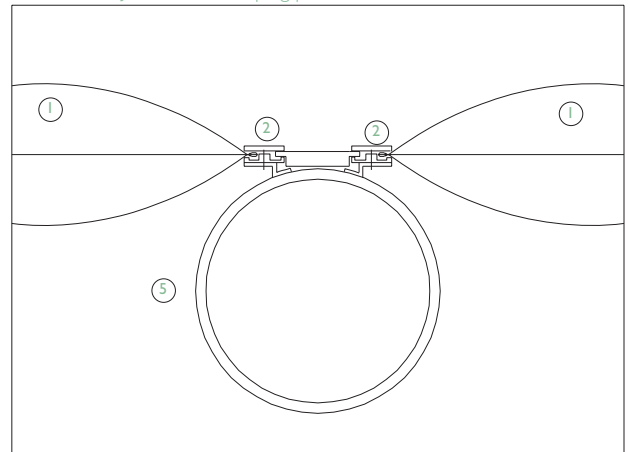
Section I:10. Junction with adjacent roof



Section I:10. Junction at base



Section I:10. Junction of clamping plates Detail A



of air pressure from leaks from cushions or from air supply pipes.

If air pressure within the cushion is lost as a result of damage to one of the outer membranes or from loss of air pressure in the supply pipe, the cushion deflates to its flattened shape. As wind pressures are applied to the external face of the cushion, the outer skin will deflect either inwards or outwards as a result of the positive or negative pressures. This does not usually cause damage to the cushions before the air supply is restored. Some manufacturers' systems have one-way valves to prevent loss of air pressure from the cushions back to the supply pipes.

Condensation on the underside, or internal face, of ETFE cushions is avoided by

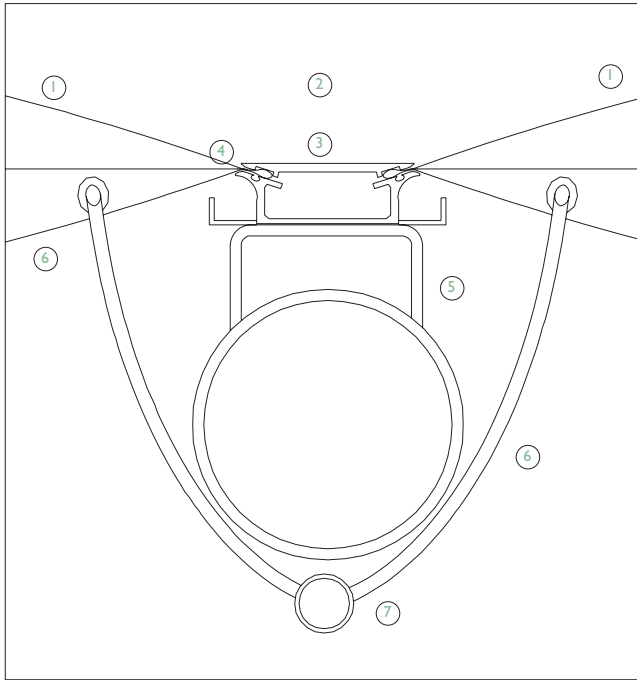
ensuring that ventilation levels within the building are sufficiently high to avoid this occurring, and that levels of relative humidity are suitably controlled. Where condensation is still a risk, condensation channels are fixed to the underside of the cushion clamping assembly as shown in (D), similar to that used for glazed rooflights. In most cases the temperature of the air supplied to the cushions is similar to that of the internal space immediately below the roof, so condensation does not usually occur on the underside of the cushion.

The material

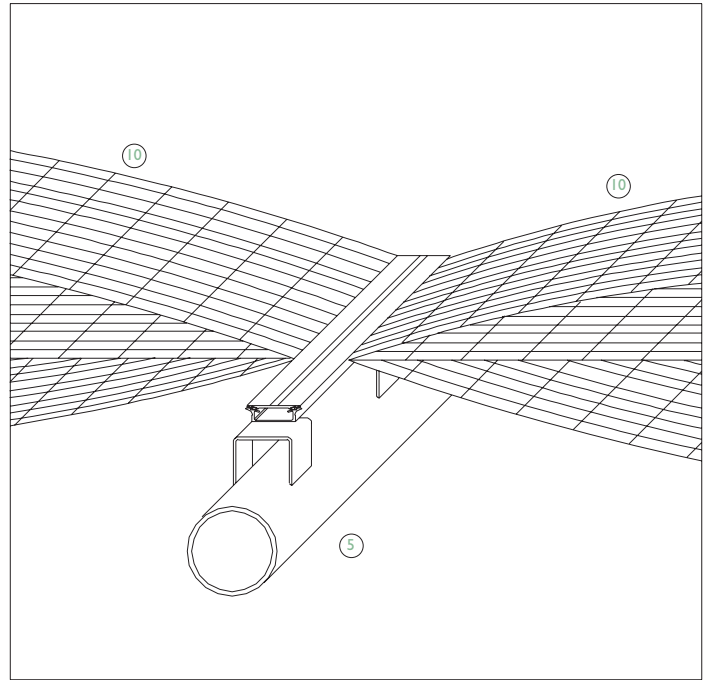
ETFE (ethylene-tetra-flouro-ethylene) is a polymer similar to PTFE (marketed as

Teflon) which is made by extrusion as a sheet material. Thicknesses vary but 0.2mm is a common thickness of material for ETFE cushions, allowing them to be very light in weight at around 350g/m² for this thickness of sheet. Heavier gauge sheet at 0.5mm thickness weighs around 1000g/m². Inner layers of ETFE sheet that provide separate chambers within the cushion are often made from 0.1mm thick sheet. The material is also used for its high level of transparency, with 95% light transmission, and its durability when compared to other fabric materials, with a life expectancy of 25-35 years, based on visual criteria. In order to provide translucent areas of roof (or façade) using the same material, a white coloured translucent

Section 1:5. Junction of clamping plates Detail D



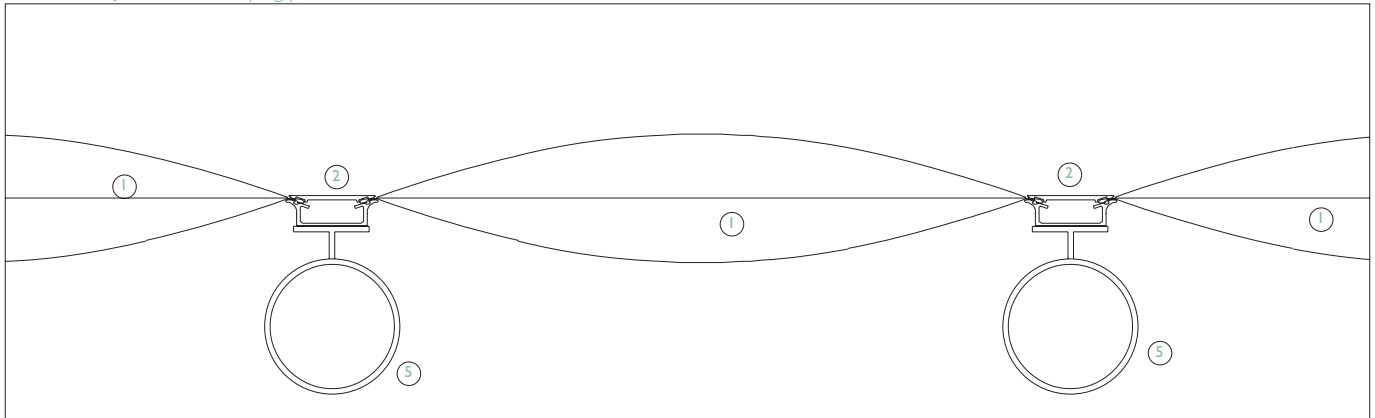
Isometric view of junction of clamping plates



Details

- 1. ETFE cushion
- 2. Extruded aluminium clamping plate
- 3. Extruded aluminium retaining profile
- 4. Plastic edge bead to fabric membrane
- 5. Supporting structure
- 6. Plastic air supply tube
- 7. Main air supply tube
- 8. Insulated metal lined gutter
- 9. Metal flashing
- 10. ETFE cushion with contours shown for clarity

Section 1:10. Junction of clamping plates



sheet is manufactured which provides around 40% light transmission. ETFE does not provide a barrier to the passage of UV light, making it ideal for use in buildings where extensive planting is displayed, though the translucent white sheet has greatly reduced UV light transmission. Solar shading can be provided by a pattern of dots printed onto the surface of the ETFE cushion, with a reflective silver colour being a popular choice, though other colours and patterns can be developed for individual projects. The printed dots on clear ETFE sheet reduce the light transmission to around 50-60%, but this can be increased further by printing dots on two faces of the air-filled cushion in areas of the roof where more shading is required.

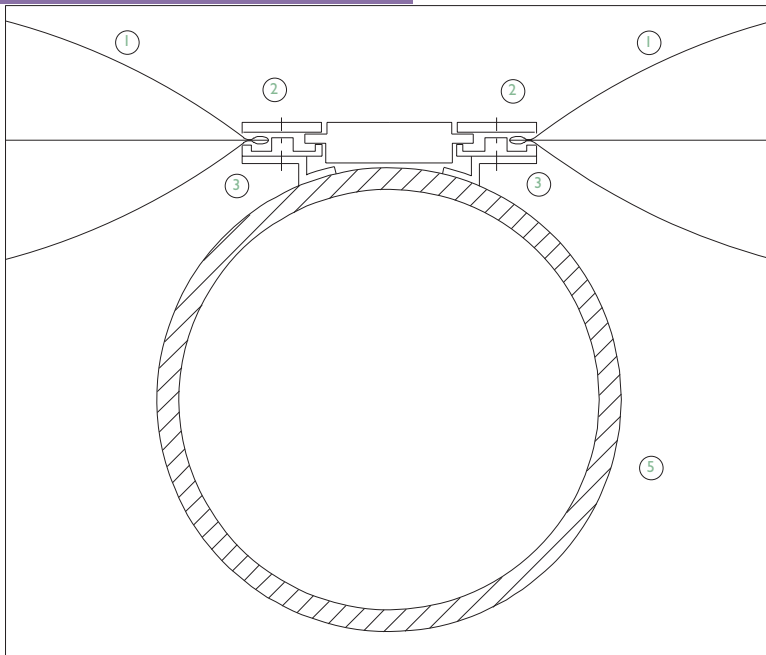
The amount of solar shading provided can be varied by allowing the middle layer to move as a result of changing the air pressure within the cushion. The middle layer moves either outwards or inwards to increase the overlap of the printed screen of dots that has the effect of varying the amount of solar shading provided.

The sound absorption of ETFE cushions is low, so that sound travels easily through the material. While this can be an advantage in noisy internal environments, it can be an inappropriate material if external noise is able to travel through the roof to internal spaces where a quiet environment is required. Cushions can also produce a drumming effect during rain resulting from

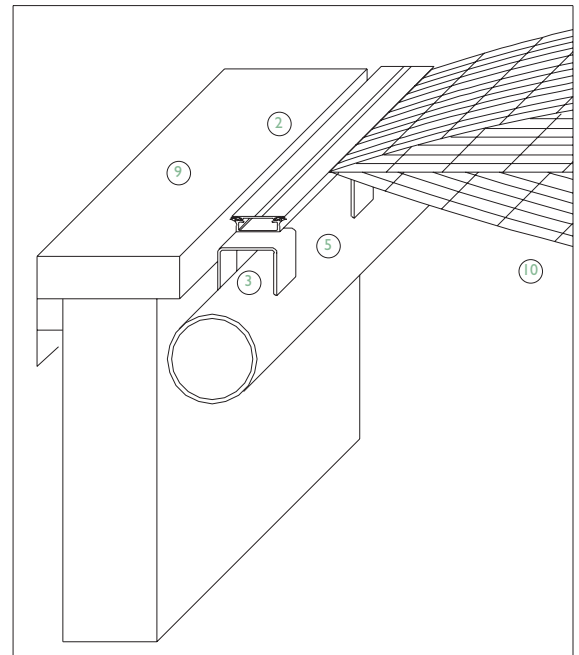
the use of a thin, stretched, membrane material.

Fabrication

ETFE cushions are usually fabricated in the workshop but can be assembled on site to suit project conditions. The material is manufactured in rolls of considerable length but of a width of around 1.5 metres. For this reason, ETFE cushions are often made with spans in widths of around 3.0 metres to 4.0 metres between clamped frames, in lengths up to between 15 - 30 metres, but lengths up to 60 metres have been used. Larger cushions are made by welding sheet together in the workshop to form wider sheets to form cushions that vary from the rectangular



Section 1:5. Junction of clamping plates - Detail E

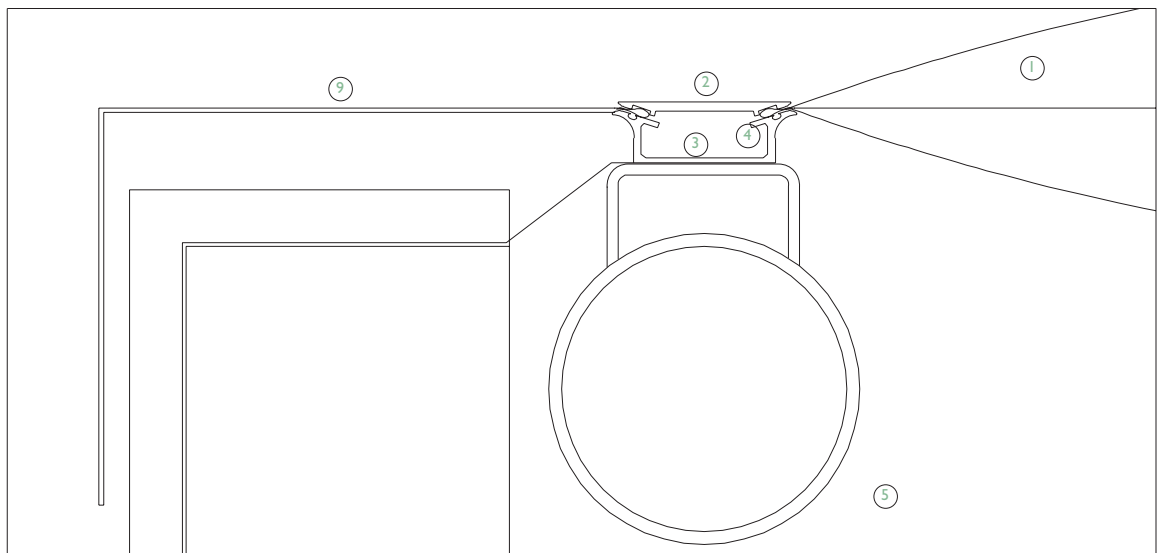


Isometric view of junction of clamping plates

Details

1. ETFE cushion
2. Extruded aluminium clamping plate
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Supporting structure
6. Plastic air supply tube
7. Main air supply tube
8. Insulated metal lined gutter
9. Metal flashing
10. ETFE cushion with contours shown for clarity

Section 1:5. Junction with adjacent roof



form created from a standard width of ETFE sheet. Cushions up to around 7.0 x 7.0 metres have been made in a variety of shapes from circles to hexagons using a hot welded process undertaken in the workshop. The welded seams are visible but are not visually striking when viewed from around the building. The width, or span, of the cushion has an effect on its depth, where the depth is typically around 1/5 the span of the cushion. Larger cushions sometimes use a net of connected cables to provide additional restraint.

The cushions have an edge bead, typically in plastic, which is used to retain the panel in its supporting frame. The cushion is set into a clamping frame, usually made from extruded

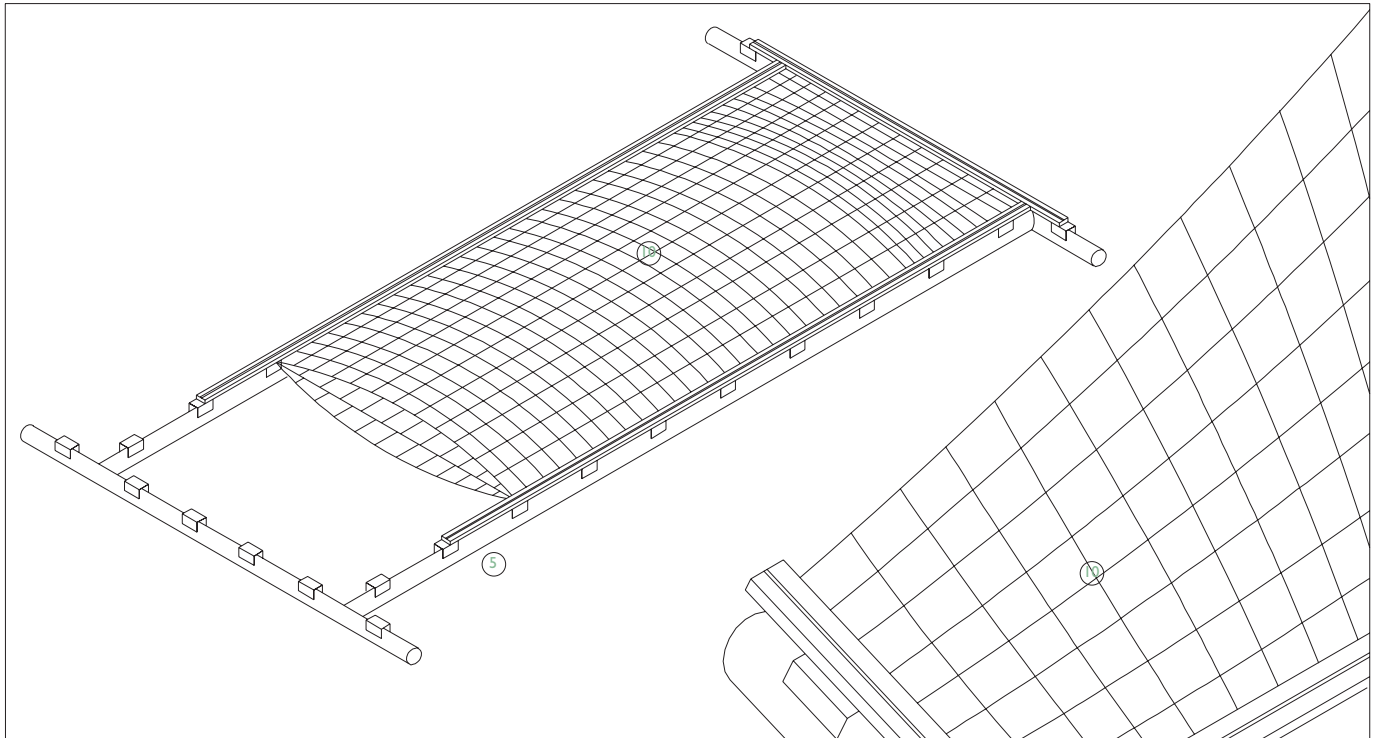
aluminium, that holds the panel in place by clipping it into an aluminium profile, then holding it in place with an aluminium pressure plate that clamps the edges. The complete assembly usually performs in a similar way to the framing used for glazed roofs, with a drained and ventilated inner chamber that serves as a second line of defence against rainwater penetration. Any rainwater that passes through the outer clamping plate is drained away in grooves formed adjacent to the edges of the ETFE cushions, the water being drained back to the outside of the roof. The clamping assembly is typically around 100mm wide, which is wider than that used for glazed roofs, but less framing is required than that used on glazed roofs.

The complete ETFE cushion assembly is supported by a structural frame beneath, with mild steel, aluminium and laminated timber all being used to suit the design. In (E), the clamped framing assembly is fixed to mild steel tubes by fixing the framing onto T-sections which are welded in short lengths to the mild steel tube. The aluminium framing spans between the T-section supports to provide a visual separation between the ETFE cushions and the supporting steelwork.

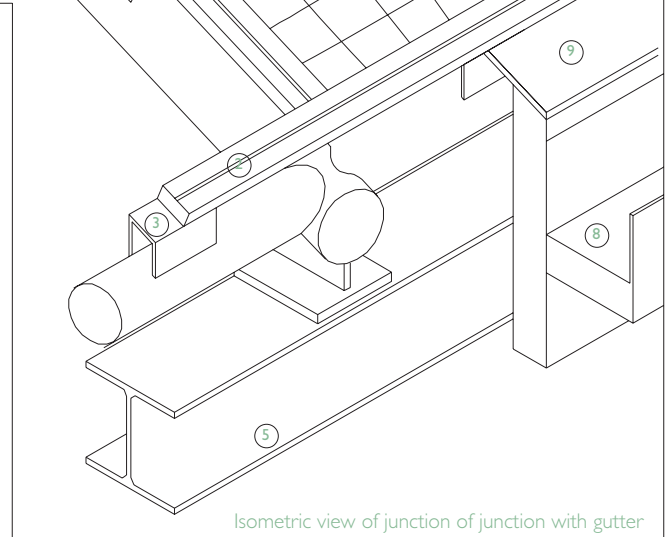
Durability

The toughness of ETFE sheet is combined with a high resistance to tear. Damage by sharp objects puncturing an outer membrane does not spread easily into a larger

Isometric view of junction of ETFE cushion assembly



Arteplage, Neuchatel, Switzerland. Architect: Groupe Multipac.



Isometric view of junction of junction with gutter

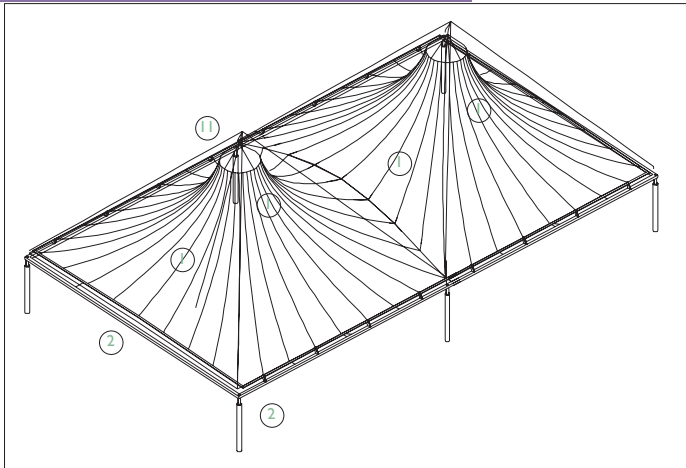
tear easily. Birds can puncture the outer membrane, but they have great difficulty in coming to rest on the roof itself, except on the clamping plates, where wire is sometimes fitted to avoid providing any spaces for birds to stand. The material has fairly high resistance to surface fading from UV light where there is a gradual loss of surface reflectivity. ETFE sheet is also highly resistant to attack from chemicals and from airborne pollution in urban areas. Its low level of surface friction ensures that cushions do not hold dirt and dust easily, making cushion roofs relatively easy to maintain. ETFE roofs are usually cleaned as a result of rain in temperate climates, though access for maintenance is required, usually provided by walk-

ing along the external clamping plates with cable assistance or from external structure. Roofs are designed so as to ensure rainwater drains easily from the roof. Gutters are introduced on long span roofs between sets of clamping plates, as shown in (F). Cushions are repaired by the use of ETFE tape, which is visible, or by complete replacement of the panel, depending largely on the visual requirements of the roof design.

Performance in fire

A major concern in the use of polymer materials for single layer and multiple layer fabric roofs is their performance in fire. ETFE sheet is not easily inflammable and will self-extinguish quickly under direct flame. Few

burning fragments will fall below during a fire, since the material melts rather than burns, with most of the burnt material being carried away in the rising hot air of a fire. ETFE sheet melts at around 275°C, forming holes in the fabric which allows the heat and smoke of a fire to escape. However, some roofs still require smoke vents, since this may not always occur during a fire if the smoke and heat is being generated in an area away from the roof, where the ETFE cushions are not affected by the fire. The small amounts of material used in ETFE cushions, with an average wall thickness of 0.2mm, result in little material being deposited during a fire.



Isometric view of cone-shaped fabric roof

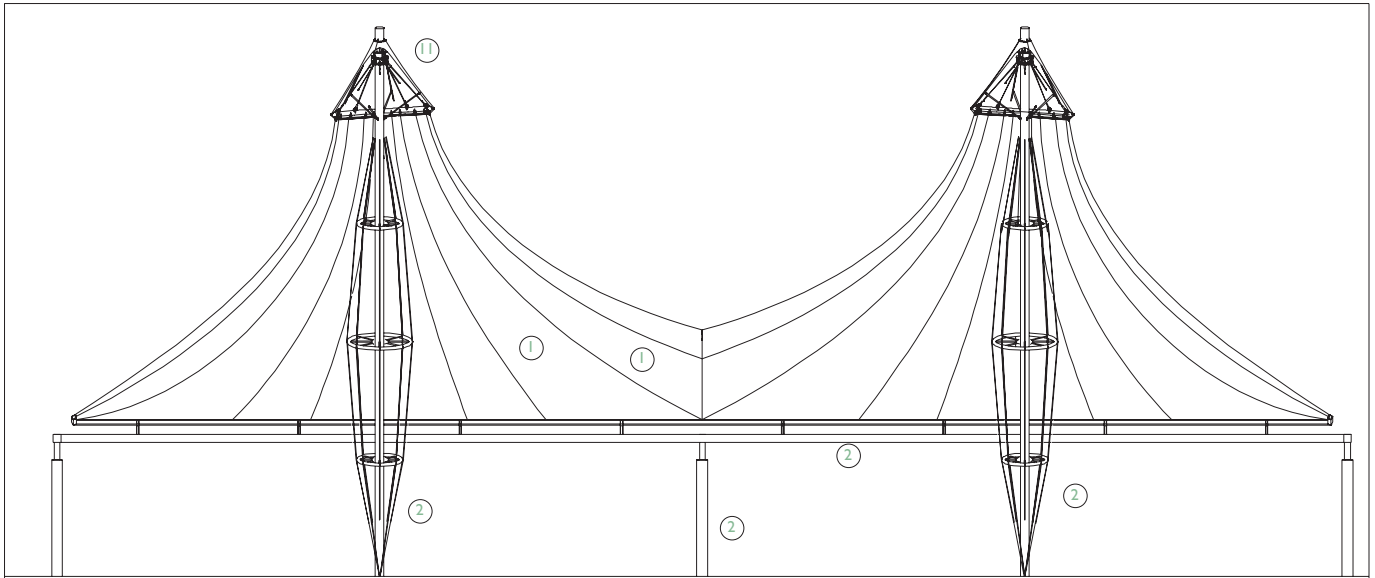


Plaza de toros, Madrid, Spain.
Architect: Schlaich Bergermann und Partner / Ayuntamiento de Madrid

Details

- | | | |
|---|---|------------------------------------|
| 1. Fabric membrane panel | 4. Plastic edge bead to fabric membrane | 7. Stainless steel connector |
| 2. Supporting mild steel structure | 5. Extruded aluminium clamp assembly | 8. Membrane skirt |
| 3. Extruded aluminium retaining profile | 6. Stainless steel cable | 9. Gutter formed by membrane skirt |
| | | 10. Mild steel ring support |
| | | 11. Fabric cover to close ring |

Section 1:400. Cone-shaped fabric roof



The following two sections discuss the two most common shapes used for single layer roofs: the 'cone-shaped' roof and the 'barrel-shaped' roof. A third type, based on the shape of a hyperbolic paraboloid, uses the same principles as those for these two types and is constructed using the same principles and same construction details. For that reason its specific geometry is not discussed here, but the construction principles described here can be applied equally to hyperbolic paraboloid forms.

The advantages of single membrane fabric roofs are their smooth curves, typically with different in opposite directions, and thin, sharp edges that provide translucent roofs that allow diffused daylight to pass through

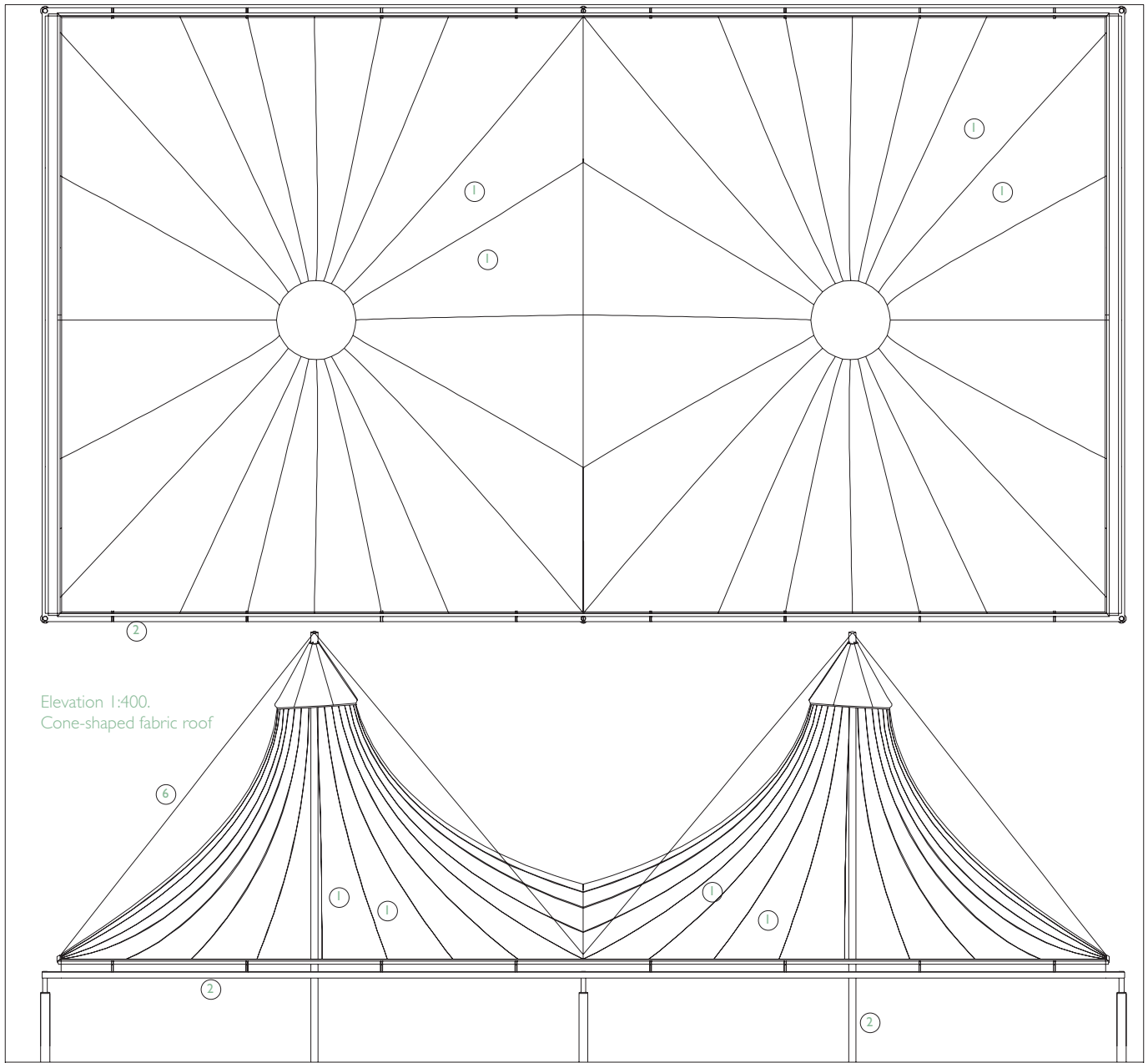
them. They use their curvature as a method of tensioning the membrane against a supporting structure, which is typically a mixture of mild steel tubes and stainless steel cables.

Fabric roof principles

Early examples of fabric roof structures of 30 years ago were based, in part, on observations of how forces act in soap bubbles, where the soap film wall of the bubble takes up a minimum of surface area as a result of the surface tension of the wall of the bubble being evenly distributed. In a fabric roof the membrane is structurally modelled so that the resultant form developed between architect and structural engineer distributes the tensile forces within the

membrane without over-tensioning some parts and under-tensioning other parts of the membrane, with the resulting design resisting all load combinations in their different directions. This work is usually developed in the form of a computer model, either by specialist structural consultants or by manufacturers as part of the design development process. The minimal surface form must also be suitable for draining away rainwater, which forms another aspect of design development, together with the treatment of interfaces with adjacent areas roof and external wall. The resulting form is designed to keep all parts of the fabric membrane in tension, not just from the supporting structure but from imposed loads, mainly wind

Plan 1:400. Cone-shaped fabric roof



loads. Wind pressures are resisted by re-distributing the forces within the fabric membrane. Any areas of the fabric roof that go into compression as a result of slackness in the membrane reveal themselves as creases in the material.

Both the cone-shaped example in this section and the barrel-shaped example of the following section make use of an internal steel structure that supports part of the membrane, to tension it in some areas, with roof edges where the material is held and tensioned, either at points or with continuous clamped fixings similar to those described in the previous section on ETFE cushions. Generally speaking, the high points of the supporting structure take up the

downloads from the membrane and imposed loads (mainly wind loads) and the lower points at the edges take up the effect of wind uplift. In shallow sloped roof membranes, more of the structural loads are taken by the edges or points at the base, often resulting in large columns or posts being required at these points. The distribution of loads within the fabric roof design is revealed in the supporting structure, which can be as visually lightweight and elegant as the fabric membrane itself, or can become visually heavy, which can detract from the intended lightweight effect of the membrane. Where roofs transfer forces to an adjoining structure, rather than contain the loads within their own supporting frame, the

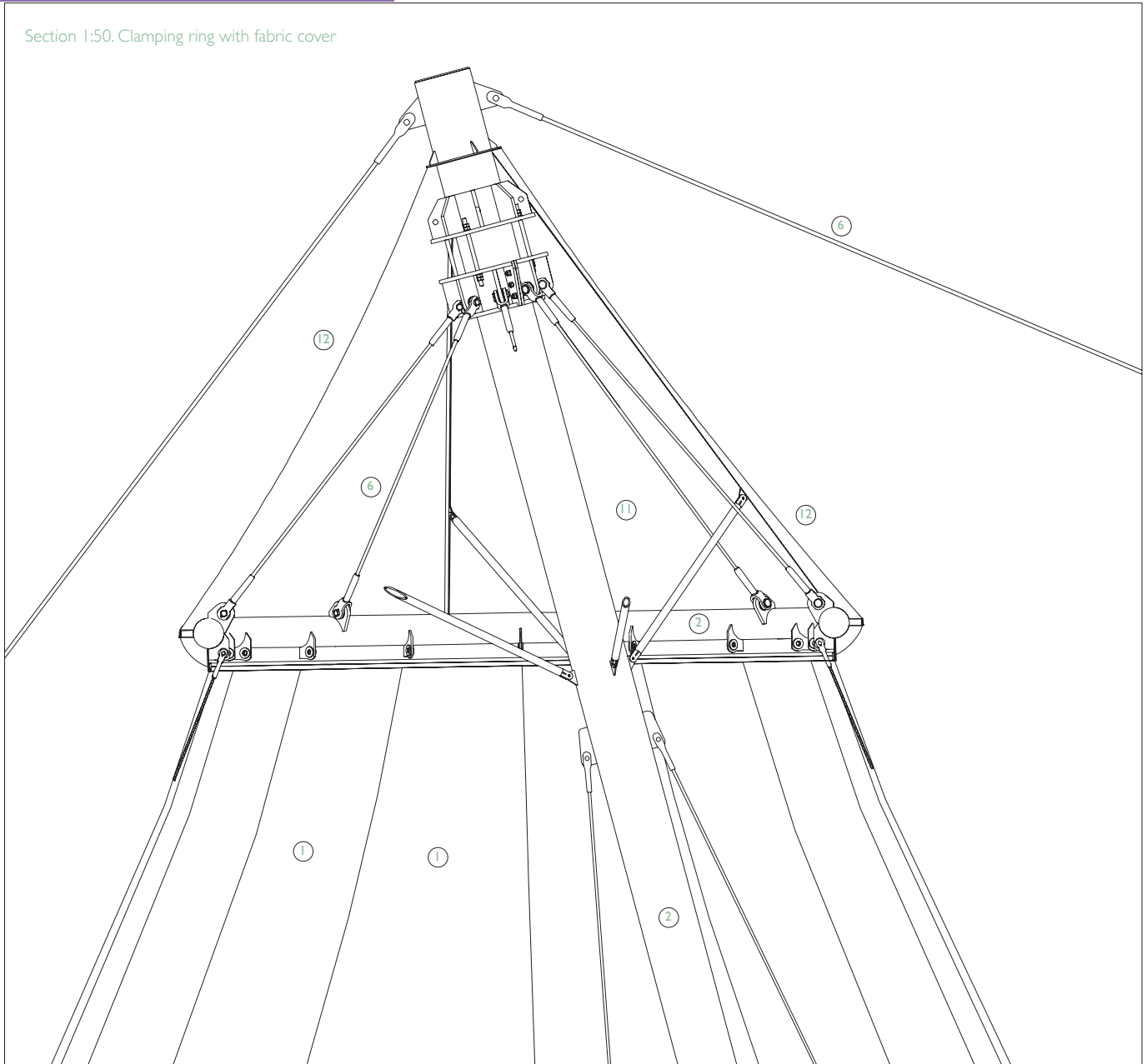
visual effect on the adjoining structure is balanced with the requirements of the membrane roof and its own frame.

Where imposed loads such as snow or sand can cause permanent stretching of the fabric membrane, the form of the roof and its associated slopes are made sufficiently steep to avoid creating areas or pockets on the fabric roof where they can collect.

Fabric types

The two most common fabrics used are PVC-coated polyester fabric and PTFE-coated glass fibre fabric. Both are woven cloth materials which are protected by coatings, usually applied on both sides. Other open-weave materials are used as solar shading

Section 1:50. Clamping ring with fabric cover



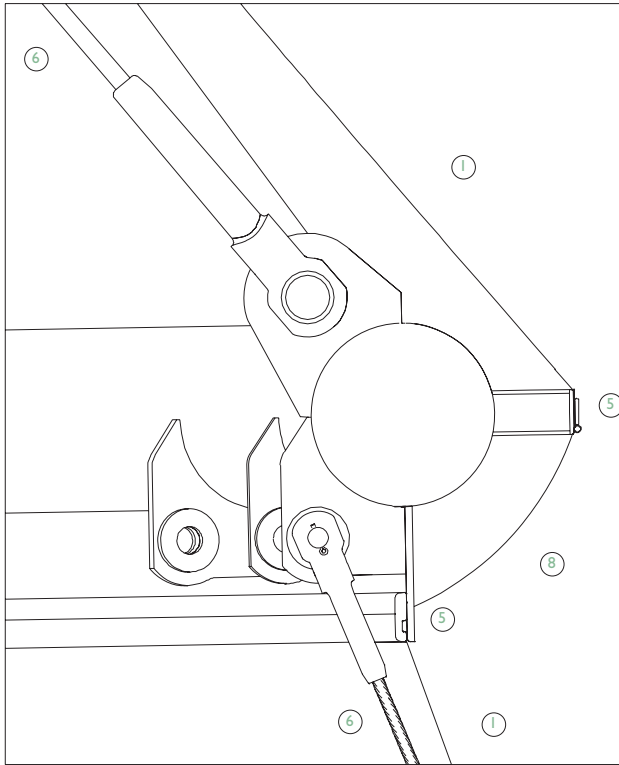
only, and are manufactured without protective coatings. These are made from polymer threads, sometimes with a protective coating applied to the manufactured thread itself, to increase the life expectancy of the material. In all these woven materials the strength of the fabric can be different in the two directions in which the 'cloth' is woven. When selecting a material, the strength of the 'warp' threads running the length of the material is compared to the 'weft' threads running the width. In most commonly used roof membranes, the tensile strength of the warp and weft directions are similar, but these need to be checked when the material type is chosen.

Most fabric roof materials imitate the appearance of natural canvas, but this material is used only where its appearance and individual texture is considered to be the most important consideration. Natural canvas is less stable than synthetic fabrics when used in tension structures, and is difficult to clean. A modified acrylic canvas material, with a similar texture to natural canvas, is sometimes used for its greater dimensional stability. Neither material is suitable for long span fabric roofs.

PVC/polyester fabrics are made from polyester cloth which is coated on both sides with a layer of PVC. The coating protects the fabric against the effects of rain and of UV light. The PVC coating is a mixture of

PVC powder, softeners and plasticisers, UV stabilisers, pigments and fire retardants. An additional outer coat of lacquer slows down the effect in the PVC coating of becoming increasingly brittle with age, which results from the softeners within the material gradually moving to the surface of the PVC coating. The lacquer coating also slows down the fading effects of the colour pigments. A PVDF lacquer (a fluorinated polymer) is typically used, which also ensures that the surface has low surface friction so that it will attract little dust and dirt, and allowing the membrane to be cleaned easily. Acrylic lacquers are also used. The typical weight of roof using this material is 500-800g/m². A PVC/polyester membrane roof will last

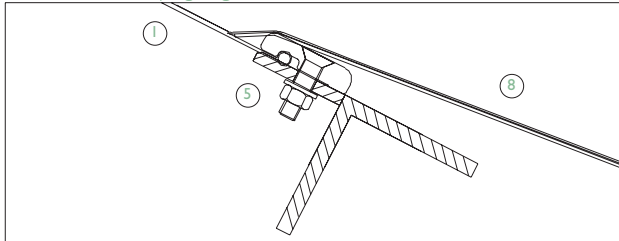
Section 1:5. Base of roof with membrane skirt



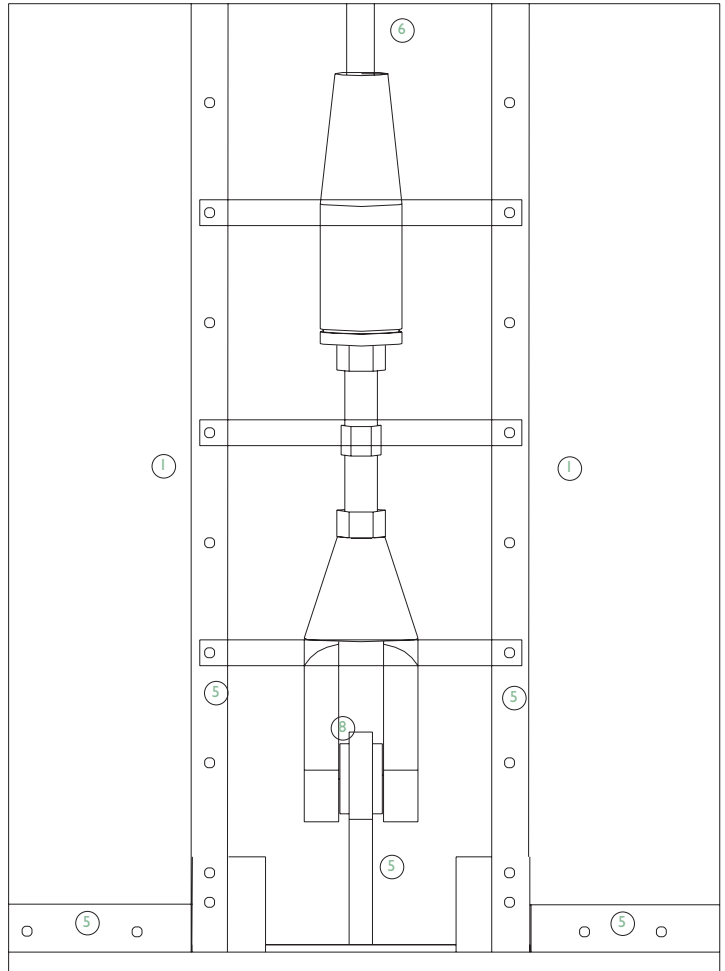
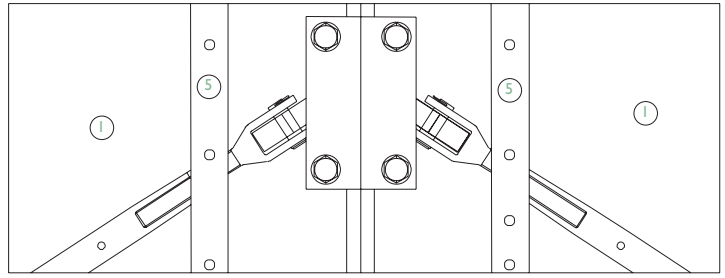
Details

- | | |
|---|------------------------------------|
| 1. Fabric membrane panel | 6. Stainless steel cable |
| 2. Supporting mild steel structure | 7. Stainless steel connector |
| 3. Extruded aluminium retaining profile | 8. Membrane skirt |
| 4. Plastic edge bead to fabric membrane | 9. Gutter formed by membrane skirt |
| 5. Extruded aluminium clamp | 10. Mild steel ring support |
| | 11. Fabric cover to close ring |

Section 1:10. Clamping ring



Plan 1:10. Junction of adjacent fabric membranes



around 15-25 years.

PTFE/glass fibre membranes are made from a glass fibre mat which is coated with a PTFE layer such as Teflon. As with PVC/polyester membranes, the coating protects the fabric from the effects of both the weather and UV light as well as forming a low friction surface to reduce the collection of dirt and dust. Most dirt is washed away by rain, but some cleaning is needed using the same methods as for PVC/polyester roofs. Typically it weighs 800-1500g/m². The life expectancy of a PTFE/glass fibre membrane roof is longer than PVC/polyester membranes at around 30-40 years.

Comparison of types

Both PVC/polyester and PTFE/glass fibre have high tensile strength and high flexibility, making them very suitable for curved and double curved roof membranes. They both have a light transmission of 5-20% depending on the thickness of membrane used, reflecting 75-80% of light. Neither will catch fire easily, and both resist the deteriorating effects of UV light, though PVC/polyester becomes increasingly brittle with age. Both have almost no acoustic performance and have poor thermal insulation performance when used as a single membrane roof. PVC/polyester has a greater range of colours readily available, while PTFE/glass fibre is usually white, the colour to which it bleaches

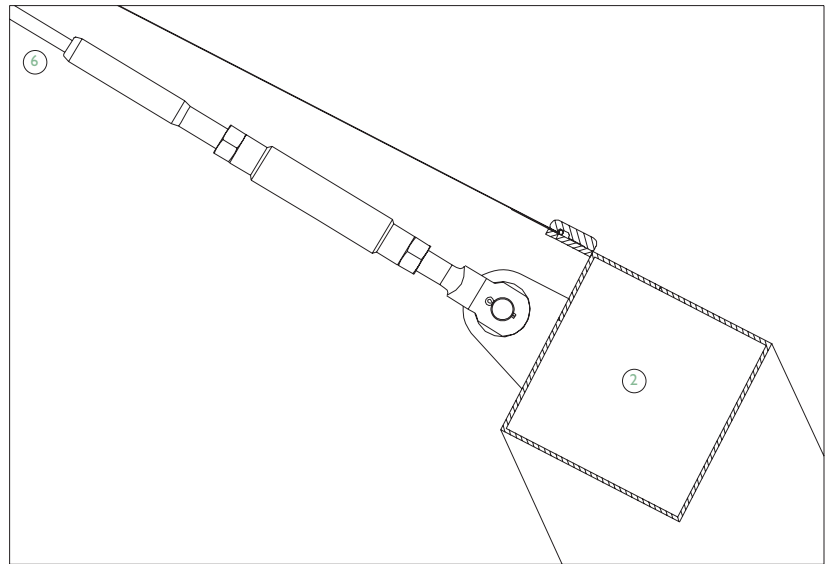
naturally from its manufactured beige colour after a few months of being exposed to sunlight. Weld marks that occur during fabrication also disappear as a result of bleaching in sunlight. PTFE/glass fibre has lower surface friction than PVC/polyester; allowing the former to remain cleaner; while PVC/polyester requires cleaning more frequently. PTFE/glass fibre requires greater care in transportation to site and erection than PVC/polyester; the latter being capable of being folded without damage to the membrane.

Thermal insulation

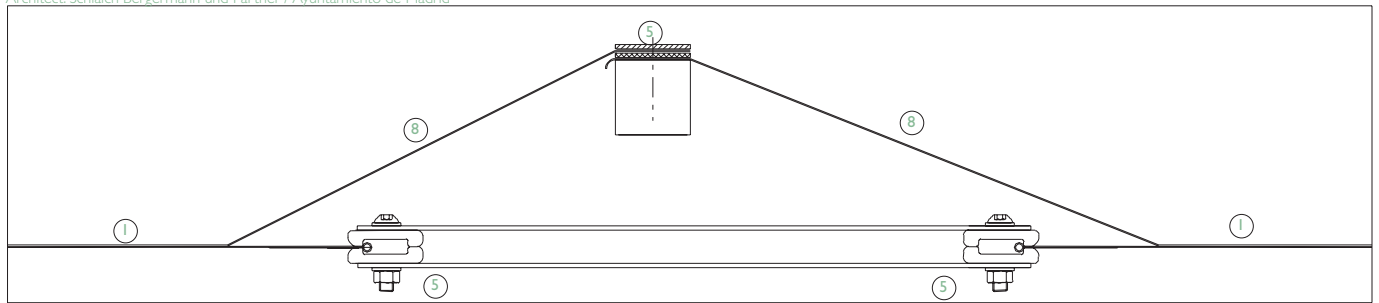
A single layer membrane fabric roof in either PVC/polyester or PTFE/glass fibre typically has a U-value of around 6.0W/m²K.



Plaza de toros, Madrid, Spain.
Architect: Schlaich Bergermann und Partner / Ayuntamiento de Madrid

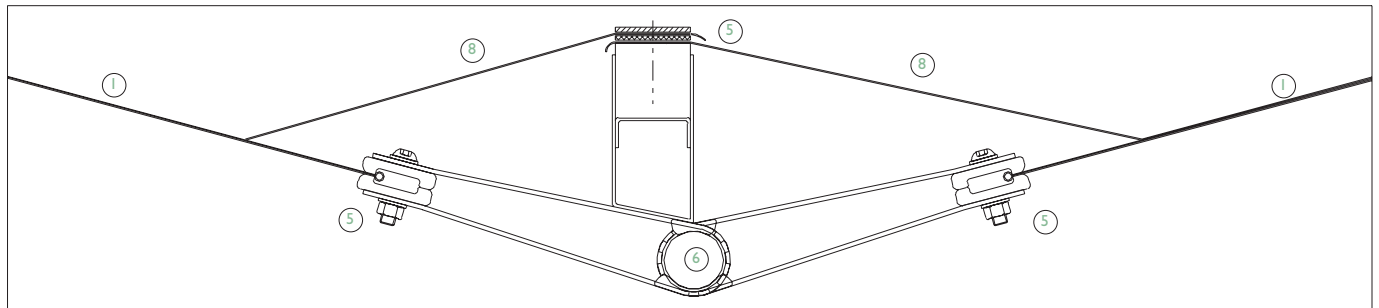


Section 1:10. Base of fabric roof Detail G



Section 1:10. Junction of adjacent fabric membranes meeting at same angle Detail F

Section 1:10. Junction of adjacent fabric membranes meeting at different angles Detail E



Where two layered membranes are used, with a minimum air gap of 200mm between the membranes, the U-value can be reduced to around $3.0 \text{ W/m}^2\text{K}$. Double layer membranes are less commonly used as they have a severely reduced light transmission, the translucency of the material being one of the main advantages of the material. Thermal insulation can be added to a double layer membrane by using a translucent fibre-based insulation, as used in fibre glass cladding panels discussed in the previous chapter. The insulation can be fixed to the inner face of either membrane, depending on how the roof void is ventilated. With the increasing importance of the role of thermal insulation in the reduction of energy use in buildings,

the use of double layer fabric membranes is set to develop considerably over the next 10 years.

Acoustics

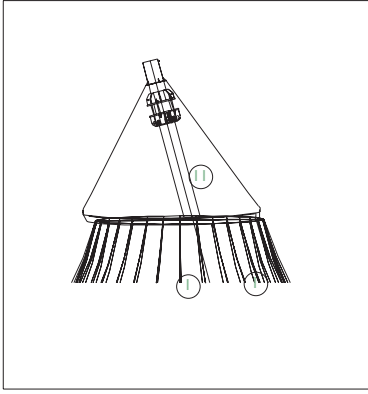
Like ETFE cushions discussed in the previous section, single layer membranes provide no significant reduction of noise through the roof. A double layer roof with an acoustic lining will provide some acoustic performance but will have the effect of losing most of the light transmission through the membranes. In addition, low frequency sound is difficult to absorb due to the low mass of the cladding material. In common with ETFE cushion roofs, the roofs are almost transparent to sound emitted from

within the building.

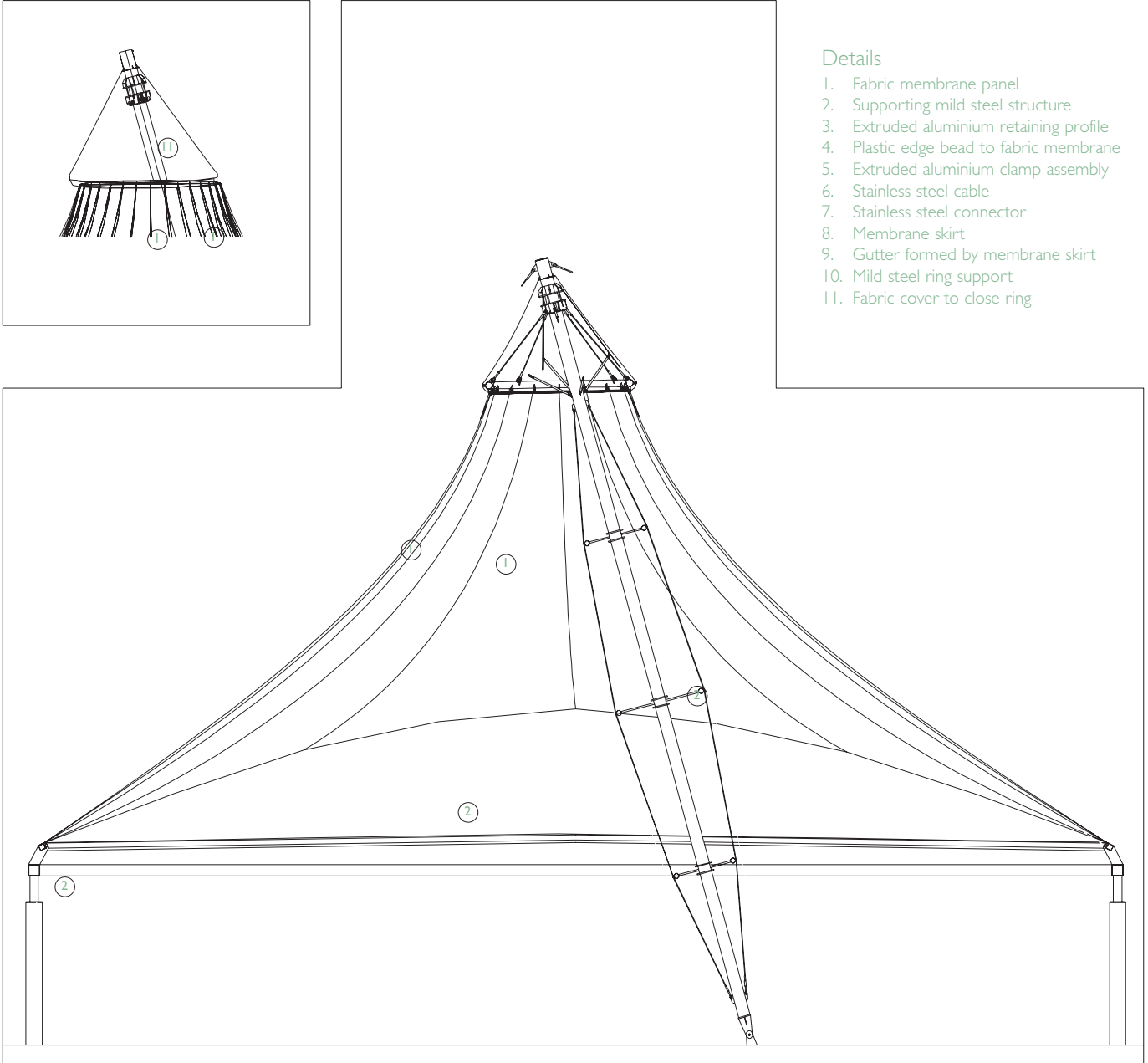
Durability

Fabric roofs are highly susceptible to damage from sharp objects. Small cuts in the membrane can be repaired with patches made from the same material which are glued into position. Larger tears are repaired with hot air welders, usually undertaken by the specialist contractor that installed the fabric roof. Large repairs are visible, and panels are replaced where visibility is the most important consideration. Since large tears can affect the overall structural performance of the membrane, the complete membrane is sometimes removed for another panel to be stitched or welded, and re-coated in the

Elevation 1:200. Membrane cover



Section 1:200. Cone-shaped fabric roof



Details

- 1. Fabric membrane panel
- 2. Supporting mild steel structure
- 3. Extruded aluminium retaining profile
- 4. Plastic edge bead to fabric membrane
- 5. Extruded aluminium clamp assembly
- 6. Stainless steel cable
- 7. Stainless steel connector
- 8. Membrane skirt
- 9. Gutter formed by membrane skirt
- 10. Mild steel ring support
- 11. Fabric cover to close ring

factory.

The outer surface of fabric roofs are cleaned with soft brushes that wash the membrane surface, the work being done typically from either a mobile platform or by rope access cleaners (abseilers) who are attached in harnesses and suspended from cables attached to a steel bracket anchor point on the top of the membrane roof. The anchor point forms part of the steel or timber supporting structure to the membrane roof. Cleaning is also an important consideration in areas of high humidity where there is a higher risk of mould forming on the surface of the fabric which can cause permanent staining. Regular cleaning prevents mould growth. PVC/polyester is more sus-

ceptible to mould growth than PTFE/glass fibre fabrics, essentially because the latter has lower surface friction.

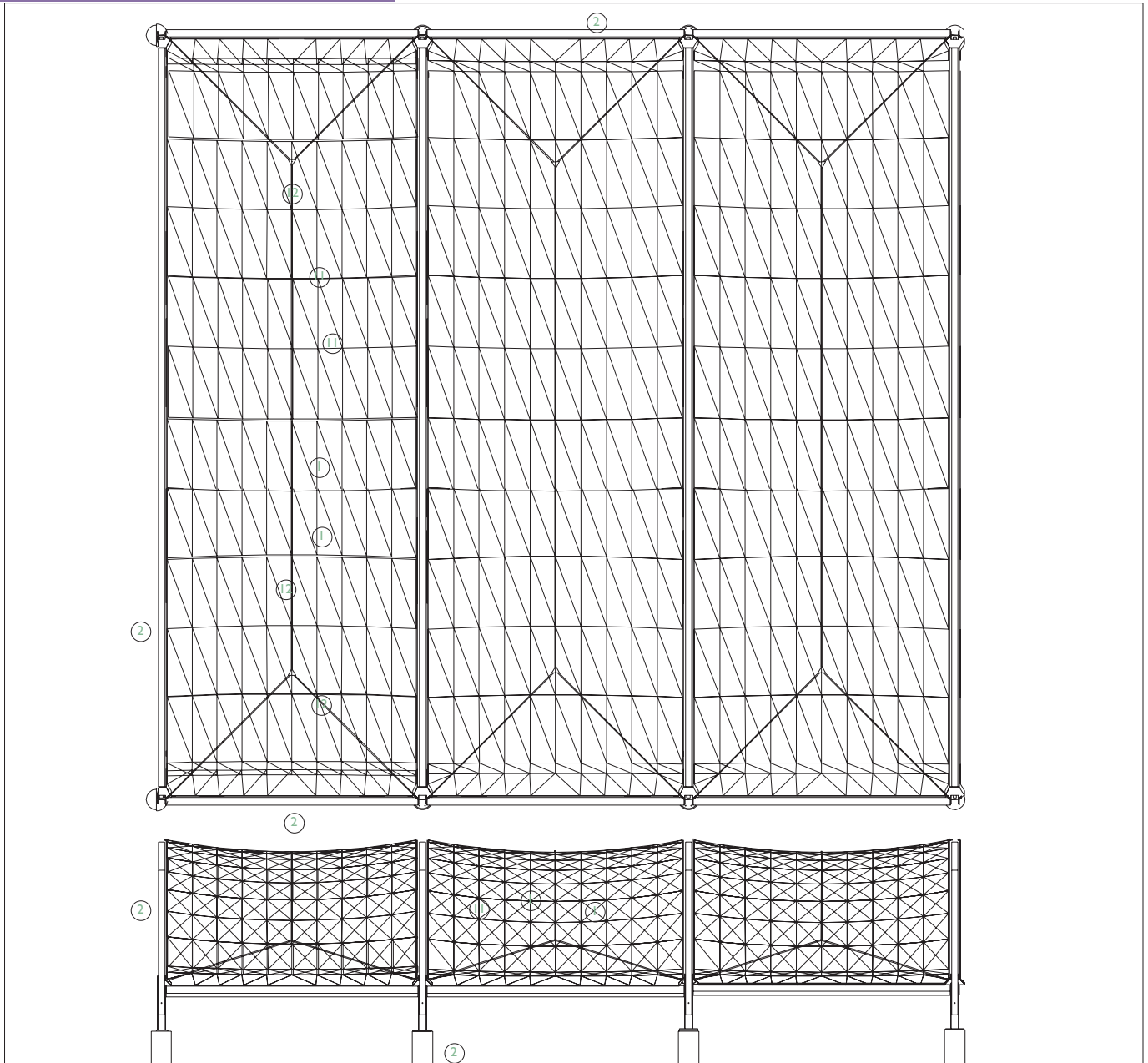
Performance in fire

The performance of a membrane during a fire depends on both the fabric used and the stitching at the seams, where this joining method is used. Membranes lose their tension under high temperatures, with PVC/polyester stretching above 70-80°C, and PVC/polyester seams starting to peel at around 100°C. At 250°C the PVC melts, leaving holes in the membrane. PVC has fire retardants in the coating so that it self-extinguishes when the flame source is removed which results in few, if any, burning fragments

to drop down from the roof. PTFE/glass fibre fabrics fail at a around 1000°C, but seams will fail at a much lower temperature of around 270°C. With both materials, the failure of the membrane forms holes in the roof which allow heat and smoke to escape.

Condensation

Where condensation is likely to occur on the underside of the membrane in an internal space within the building, then either a second membrane is added or, more commonly, increased ventilation is provided within the space below the roof.



Membrane roof fabrication

Roof membranes are made from individual panels of fabric which are cut from sheet material, the curved forms of membranes being formed from flat sheet material. The conical-shaped example shown in the previous section is made from panels with edges that curve inward, while the barrel-shaped roof shown in this section is made from panels with edges that curve outward. PVC coated polyester fabric is made in widths from 2000-3000mm, in thicknesses up to 1.2mm, while PTFE coated glass fibre fabric is made in widths up to around 5000mm in thicknesses up to 1.0mm. Large panels are usually cut by CNC cutting machines, with small pieces cut by hand, but even small pieces are now

being made increasingly by a cutting machine. Fabric panels are usually made slightly undersized to allow for the stretching of the material when it is under tension as a roof membrane.

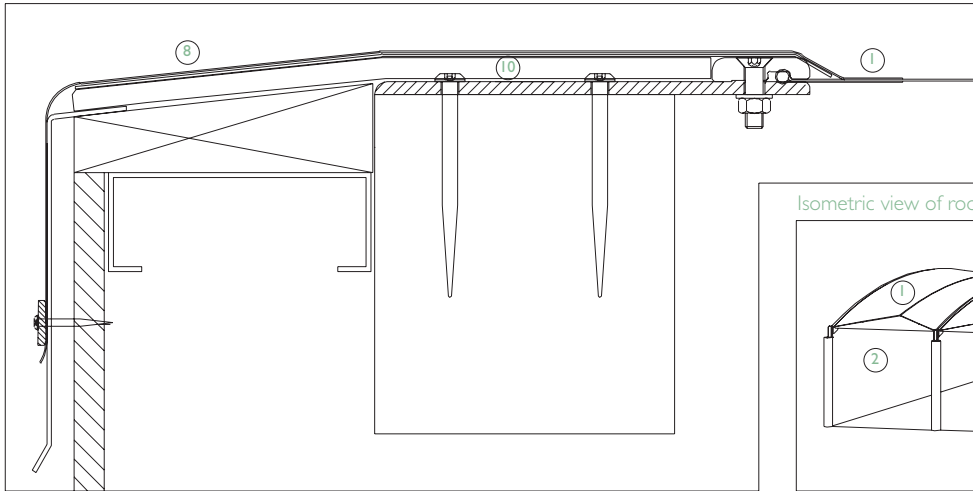
Fabric panels are joined together with lapped seams which are either sewn, welded, bonded or joined in a combination of stitching and welding, with all processes being carried out in the workshop. The width of the lap, which is visible from below the roof as well as from outside the building, is determined by the structural forces on the membrane, with higher loads requiring wider seams.

In stitched panel joints, wider seams have more rows of stitching visible, with the mate-

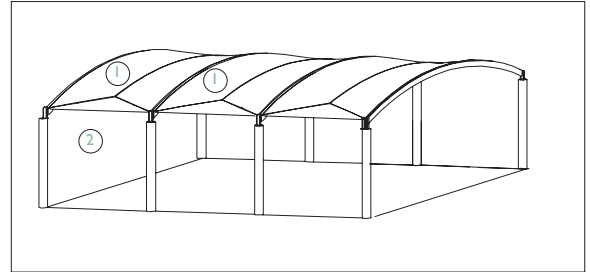
rial folded over itself to strengthen the joint. Joint widths vary from around 25mm to 100mm depending on the size of the membrane and its associated loads. Additional strips of fabric are usually bonded onto the outer (upper) face of the stitched seam to avoid rainwater penetration through the sewn thread. PVC/polyester panels can be stitched in conjunction with most lacquer types.

Welded seams are made by forming a lap between panels, then heating the lapped areas and pressing them together. Joint widths are similar to those required for stitched seams. Seams in PTFE/glass fibre panels are formed by hot element welding rather than by stitching or bonding, with an

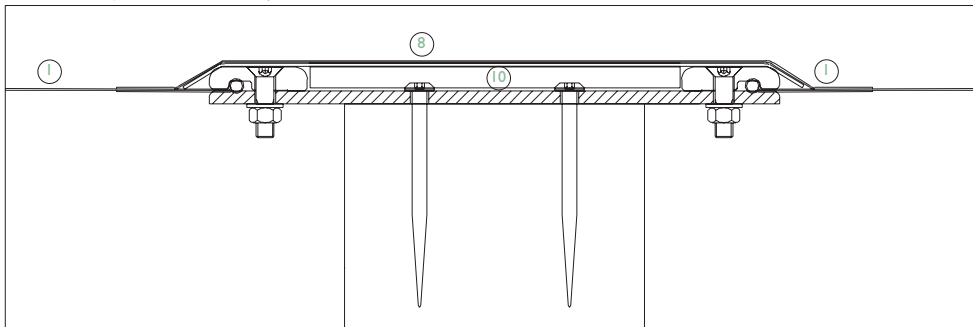
Section 1:10. Edge of roof



Isometric view of roof assembly



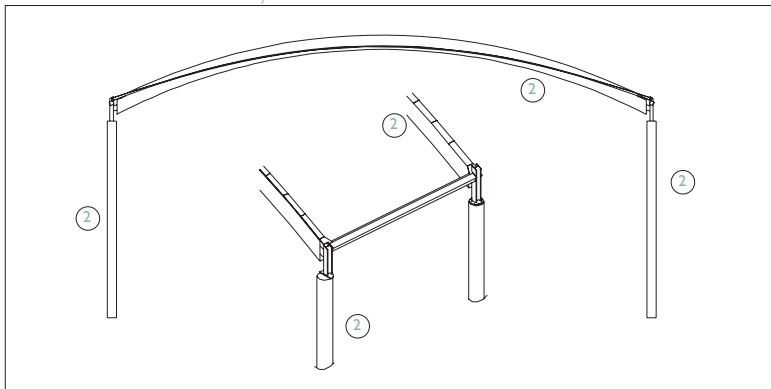
Section 1:10. Junction between panels Detail A



Details

1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. EPDM sealing tape
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Thermal insulation
11. Welding seam
12. Wind up lift cable (above membrane)

Isometric view of roof assembly



Japanese Pavilion Expo 2000, Hannover, Germany.
Architect: Shigeru Ban.

additional fabric strip added either on top or within the joint itself between the membranes to provide the required strength. For welded joints on PVC membranes, the edge of the panel being jointed has the PVDF lacquer removed before welding, which is applied again when the welding is complete to ensure that the PVC is fully welded and that the PVDF lacquer forms a continuous seal across the joint when formed. PVC/polyester can be both hot air welded and hot element welded, the advantage of hot air welding being that repair work and some complex jointing can be undertaken during erection on site. Fabric roofs with high structural loads within the membranes can be both welded and sewn to provide a

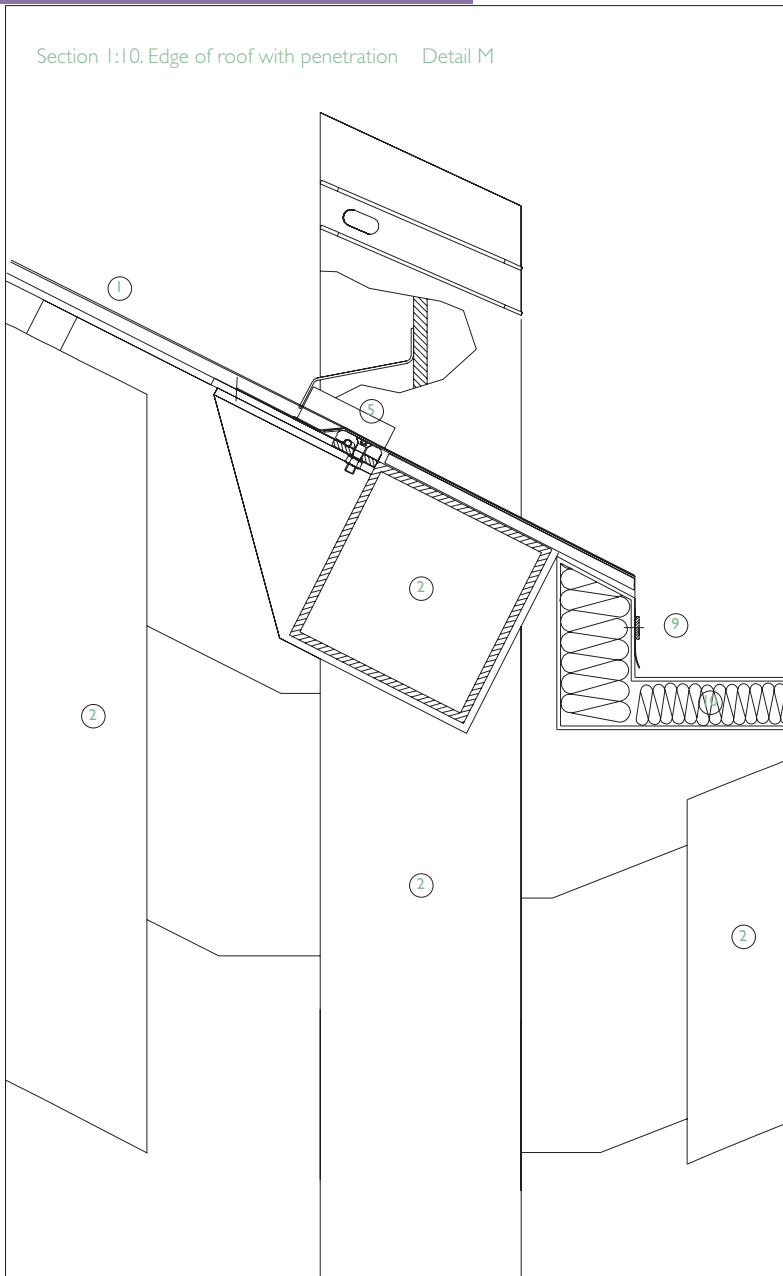
stronger joint. If the joint is first sewn then welded, this avoids the need for an additional strip to be added to the upper surface, which can enhance the visual appearance of the membrane on its outer surface. Bonding with solvents is used on PVC/polyester fabrics only, but can be done in conjunction with most lacquers used on that material.

Membrane roof edges

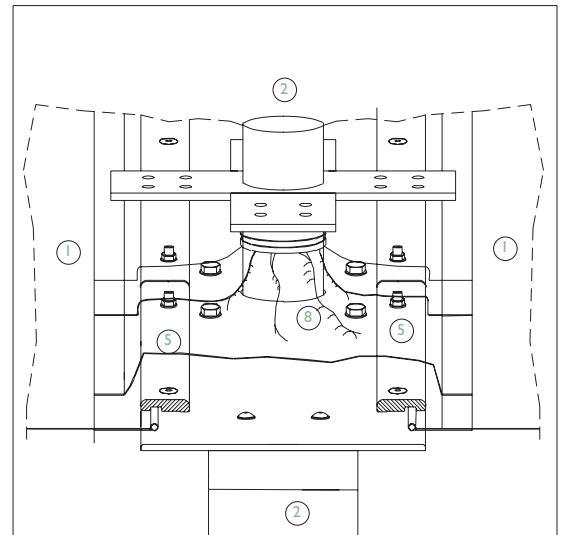
Edges of membranes are usually either gently curved or straight. Curved edges are formed with a cable held in a continuous pocket at the edges of the membrane. An alternative detail used in PTFE/glass fibre canopies is to have an exposed cable connected to the clamped edges of the mem-

brane with a series of stainless steel link plates. Straight edges are usually formed with an edge bead made from a flexible PVC or EPDM rod in a small pocket. This reinforced edge is then held captive within an aluminium clamping plate assembly similar to that used for ETFE cushions, as (A) or alternatively in a luff groove extrusion.

Cable restrained curved edges to fabric roofs usually follow a circular or catenary shape. A sleeve is formed by folding the membrane back over itself and stitching or welding it to form a continuous pocket in which a stainless steel cable is inserted. A 25mm diameter stainless steel cable is typical, depending on the structural forces. A strip of membrane material or plastic is set



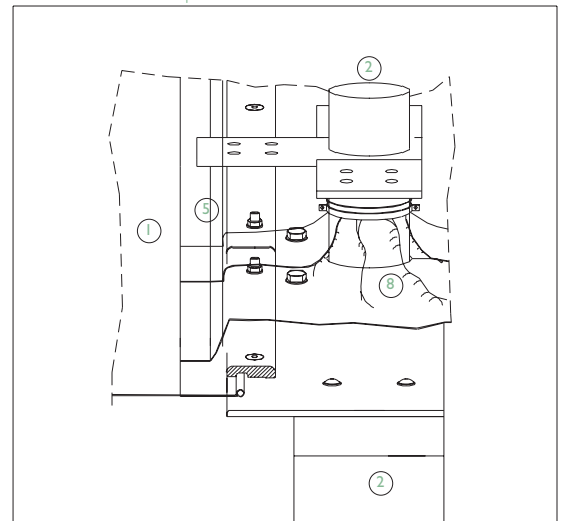
Elevation 1:10. Roof penetration



Details

1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane

Elevation 1:10. Roof penetration



between the cable and the membrane to allow the two to move independently without abrasion occurring. A reinforced plastic strip is sometimes added into the pocket but this is not visible from either above or below the roof.

Straight clamped edges use clamping plates, around 100mm wide, set back to back and bolted together, which comprise two flat, grooved plates, rather than the clamping plate and supporting extrusion used at joints between panels. The clamping plates are fixed back to either a visible cable which is set around 100mm away from the edge of the cable, which follows the edge of the membrane or, alternatively, individual brackets are fixed to a supporting wall, where no stainless

steel cable is required. The edges of the membrane have a flexible plastic or EPDM edge strip or rod, typically of 10mm diameter; that prevents the membrane from slipping within the clamping assembly. The clamps sometimes have an additional cover strip to serve as a first line of defence against rainwater penetration but any rainwater that passes into the groove, where the edge of the membrane is held captive, is drained away within the groove which also serves as a drainage channel. Water is then drained at the base of the roof.

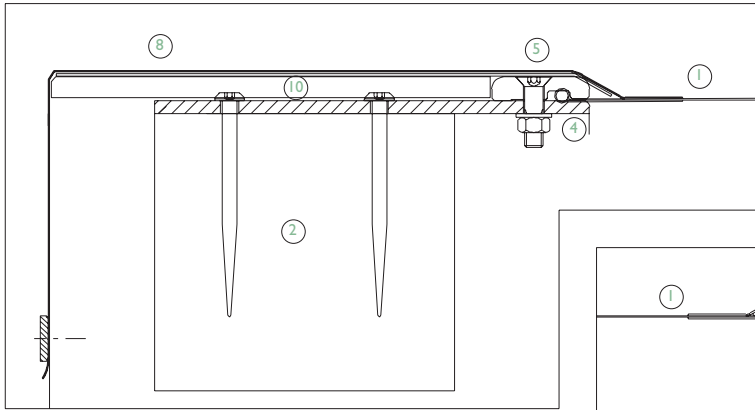
Clamping plates are also used at the junction between two areas of roof where the two parts are required to be fabricated and installed separately, usually where the

membrane has reached a maximum size for either fabrication or installation. In both cases the clamping plates are positioned to ensure that rainwater can run freely along its edge rather than creating a barrier where rainwater can collect.

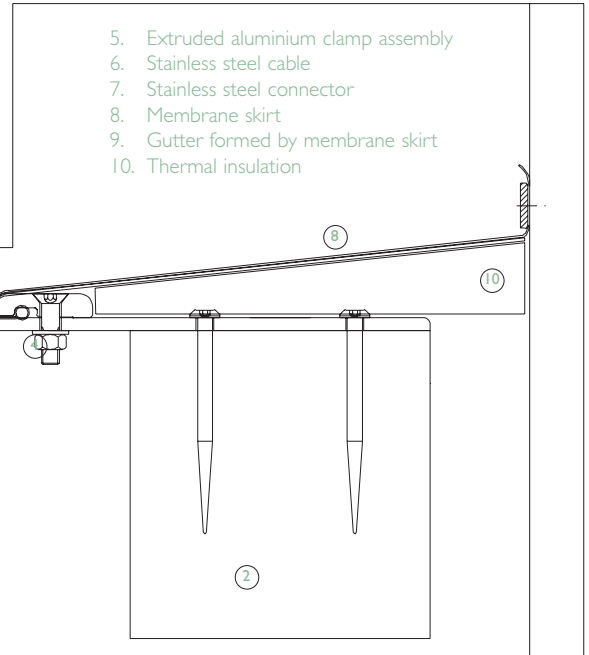
Where two cables meet at membrane corners or points, they are usually fixed to a single mild steel plate. The cable is fixed into a stainless steel cable fixing which is secured with a pin connection back to a supporting steel plate. The corner of membrane is cut to form a curved end. Additional straps are sometimes added to ensure that the membrane does not slide away from the corner.

Rainwater can be directed along the edge of a membrane, rather than being

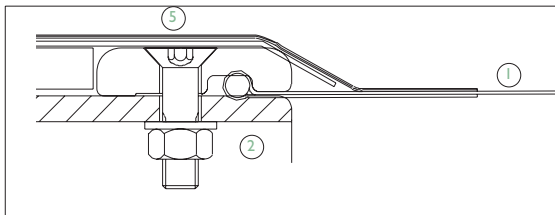
Section 1:10. Edge of roof Detail K



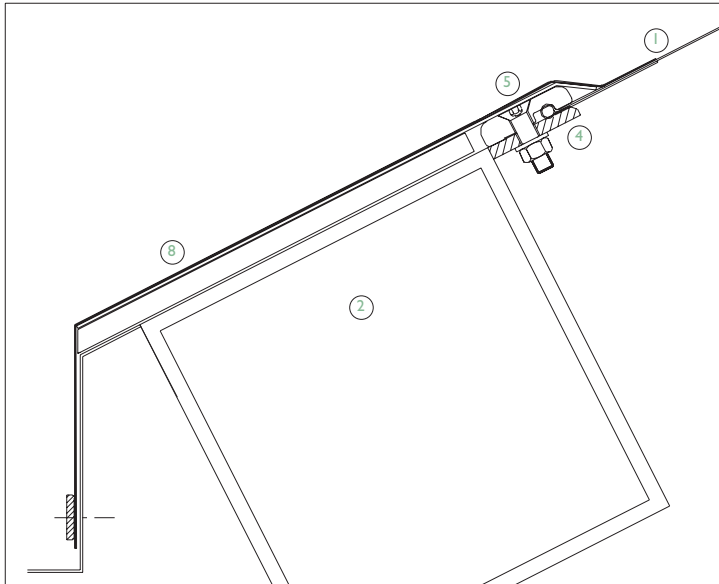
Section 1:10. Edge of roof at abutment



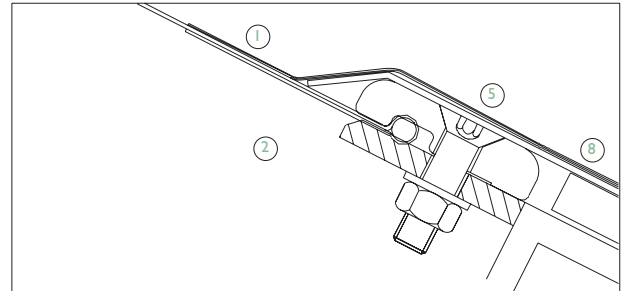
Section 1:10. Edge of roof



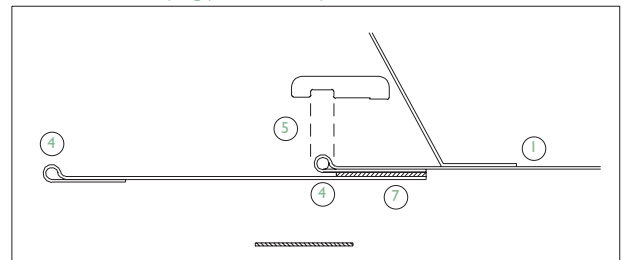
Section 1:10. Edge of roof Detail L



Section 1:5. Edge of roof



Section 1:10. Clamping plate assembly



allowed to fall directly off the edge, by introducing a standing seam adjacent to the edge. A strip of membrane is rolled around a foam strip and is welded or stitched to the membrane. This is particularly useful where building users pass beneath, as when the fabric roof forms an external canopy. Junctions with vertically-set membranes beneath the roof, are formed as flexible membrane connections to allow for movement between roof and wall.

Suspension points

Suspension points at the top of a cone-shaped fabric roof are usually formed either by a metal ring, which is fixed back to a central mast by cables or cantilevered brackets

or, alternatively, by a 'palm tree' arrangement of projecting curved metal brackets which serve to tension the continuous membrane against its supporting mast set within the building.

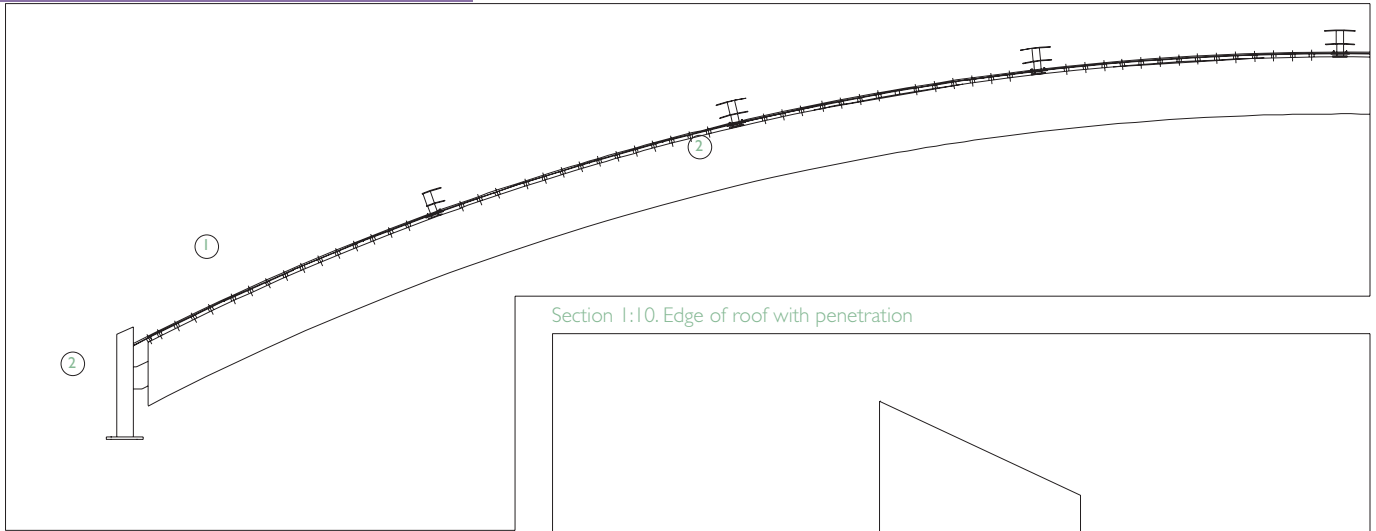
The first option with a metal ring requires an additional membrane cover piece, while the second 'palm tree' option forms a continuous membrane with a smooth curved top, without any breaks in the continuity of the membrane. In the 'ring' solution, the membrane is clamped between an inner ring and an outer ring fixed together with bolts. A second clamp is used to fix the cone-shaped membrane that covers the top of the ring. The top of the conical-shaped cover is either pulled over the top of

the central mast or clamped around it. The ring is either freely suspended from cables, or is firmly fixed to the mast with cantilevered brackets to which the ring is secured.

In the 'palm tree' supported solution, cantilevered brackets with a curved shape are set out radially in order to create a smooth curved form on which the membrane is set. The brackets are usually aligned with joints between membrane panels.

Membrane folds

In an external fold in a roof membrane, the material is draped over the supporting structure, fixed with fabric strips that are sewn or welded to the underside of the



Section I:200. Barrel-shaped fabric roof

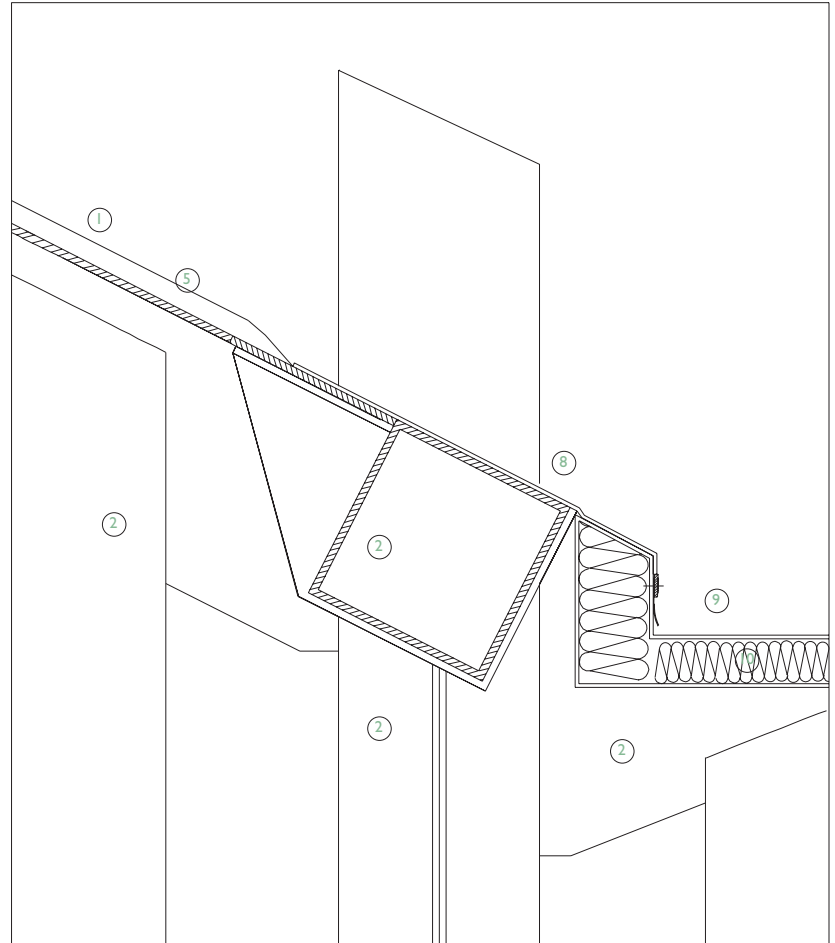
Details

1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. Stainless steel connector
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Thermal insulation

Japanese Pavilion Expo 2000, Hannover, Germany. Architect: Shigeru Ban.



Section I:10. Edge of roof with penetration



membrane and clamped to the supporting structure. An additional membrane cover strip is fixed to the top of the joint to conceal the stitching if required. An alternative method is to form a joint between two membranes at the external fold, clamping them with a pressure plate to an aluminium extrusion which is supported by the primary structure, such as a mild steel tube, curved to form the shape taken up by the membrane.

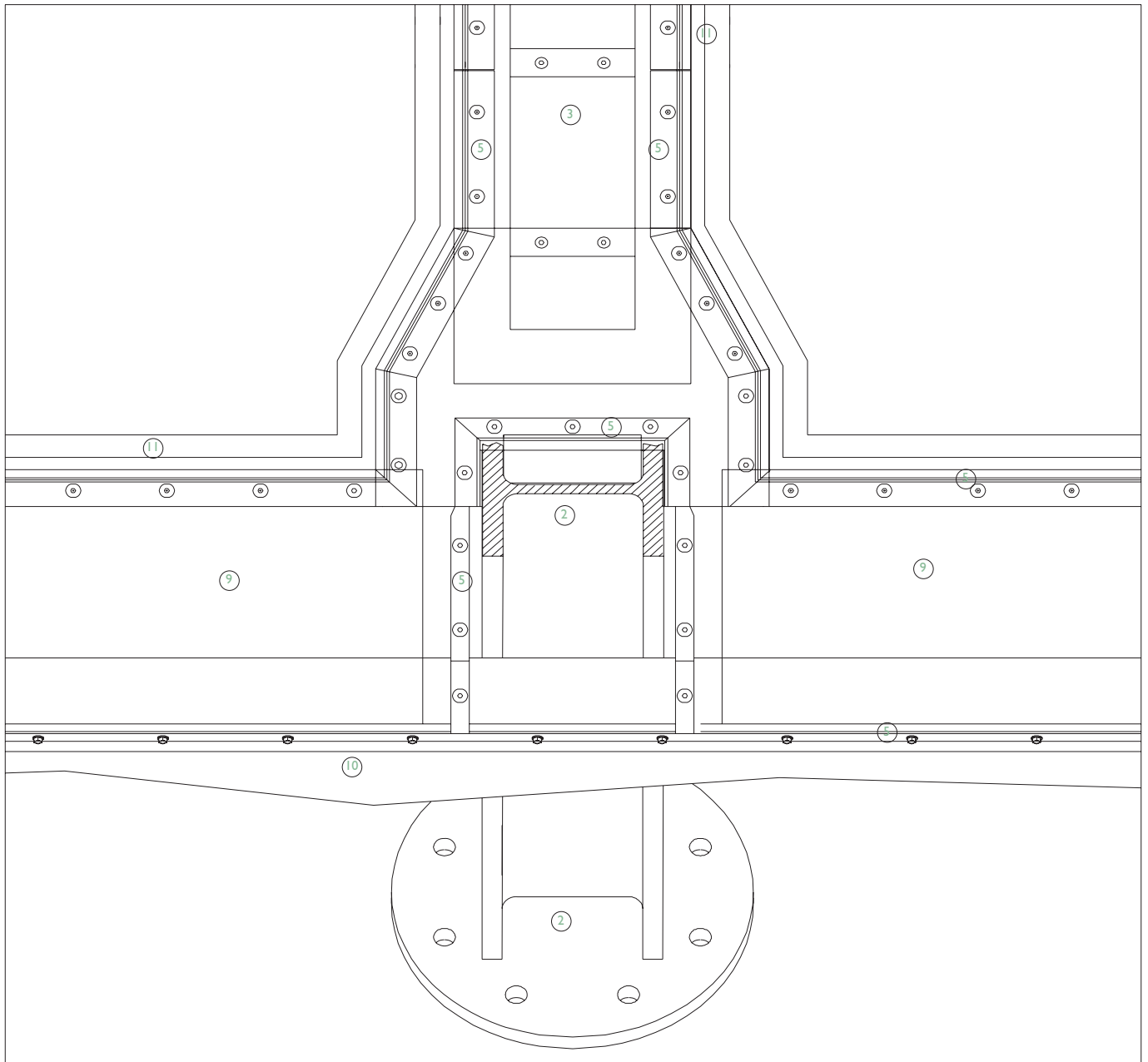
Internal folds are formed in the same way as hips, with the membrane folded outwards rather than across the ridge and downwards. In some cases the membrane may pass under the cable. These junctions are formed by clamping the ends of adjacent membranes that form the valley. The edge of

each membrane is clamped with an edge bead, while the clamp itself is fixed to a central cable. The gap between the membranes is closed by two membrane strips which are sewn or welded to the base of the strip and are clamped down to a thin pressure plate between the membranes, as (E – previous section). The clamp that closes the two membrane strips is supported off the metal straps beneath. By raising the closing strips above the height of the join, two adjacent gutters are formed, with the clamping strip securing the closing flaps being above the level of the water being drained, rather than being submerged in water if a single gutter were formed where the clamp holding the straps in place were lower than that shown.

Where two joining members form a continuous line, as (F – previous section), the same principle of sewn or welded strips can be applied, joined with a pressure plate set above the level of the adjacent roof, forming two gutters where the pressure plate joint is not submerged when functioning as a gutter.

Where a single gutter is required in an internal fold, a single membrane is sewn or welded to each side of the joint and the linking membrane is held in tension across the junction. In practice this is difficult to fix unless the strip is bonded or welded in position on site or at least one side of the membrane. The solution of two strips joined with a clamping plate allows more easily for fixing tolerances on site.

Plan 1:10. Junction between membrane roof panels



At the base of a fabric roof, a clamping plate fixed onto a base plate which is welded, or forms a continuous part of a supporting steel member; as (G – previous section), provides a sealed termination to a roof. A gutter to drain away rainwater or; alternatively, a metal sheet to shed water directly off the roof, can be added to the supporting structure. Where the clamping plate is at the base of a low pitched membrane roof, where there is a risk of water being held behind the clamping plate, an additional membrane skirt can be used to drain away water. The membrane skirt is sewn or welded to the membrane in the workshop.

Where the membrane is formed over arched supports, as in the barrel-shaped

roof, membrane skirts are used to form a junction, as (A). The same principle is applied at the roof edge, as (K), where the membrane continues over the edge of the roof where it is mechanically fixed to a metal flashing. A clamping strip is used to fix the membrane to the flashing, which also forms a watertight seal. In (L), the metal flashing is fixed to the timber arches. Thermal insulation is set between the metal flashing and the membrane to both avoid the member from becoming too hot from the effects of the sun (as a result of direct contact with the supporting steelwork) as well as to allow the two components to avoid abrasion. The same principle can be applied where a gutter is formed at the base of a roof, as (M).

The membrane skirt at the base of the roof is clamped to the side wall of an insulated gutter. Adjacent penetrations, also shown in (M), are closed with a specially formed membrane skirt that fits around the structural member that penetrates the roof. The top of the skirt is clamped to the projecting structure, while the base of the skirt is site welded or bonded to the main roof membrane panels.

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5. Mercedes Benz Design Center, Stuttgart, Germany.
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