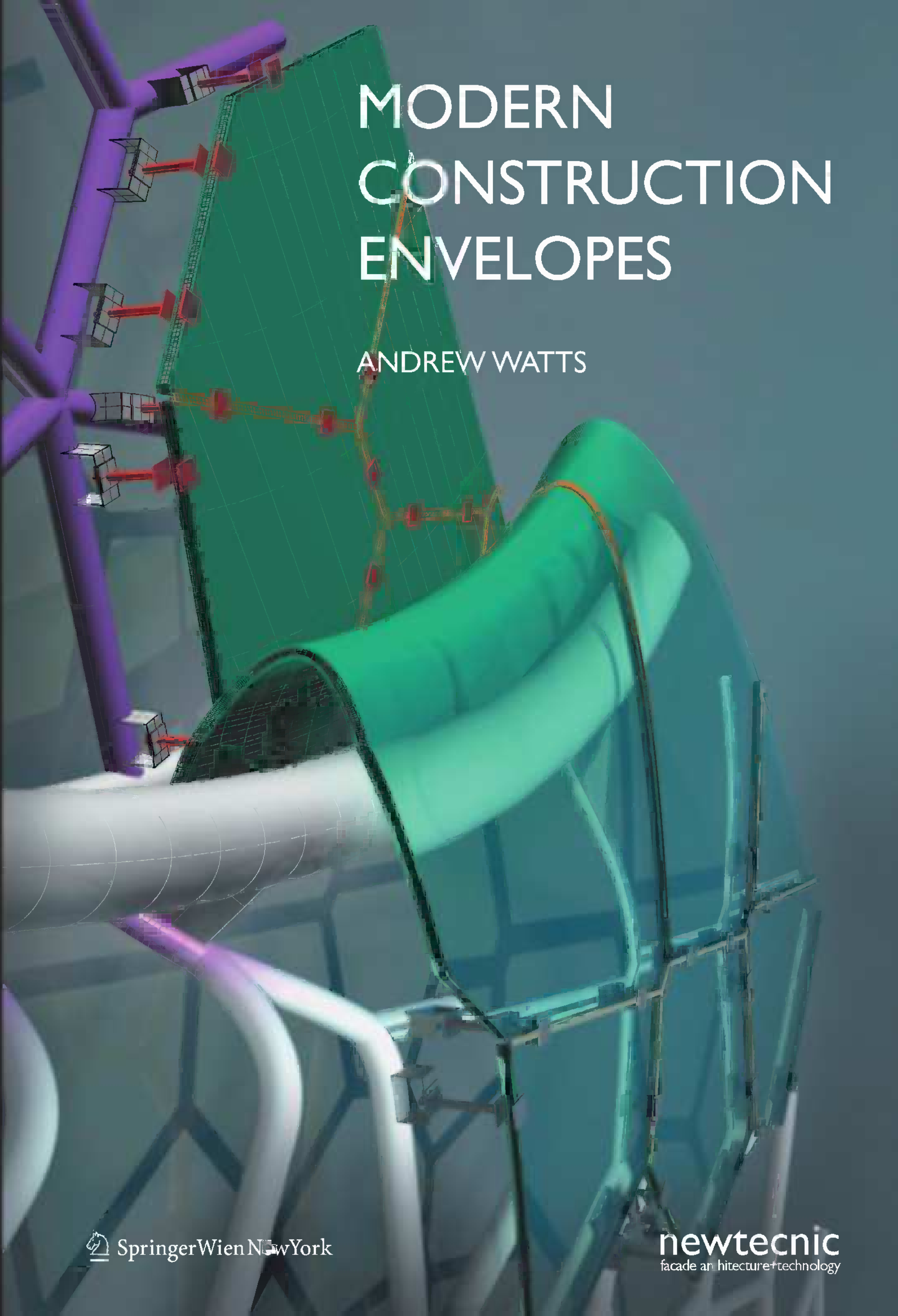

MODERN CONSTRUCTION ENVELOPES

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facade architecture+technology

MODERN CONSTRUCTION ENVELOPES

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MODERN CONSTRUCTION SERIES

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CONTENTS

CONTENTS

MODERN CONSTRUCTION SERIES

The series is based around the Modern Construction Handbook. Topics from the Walls and Roofs chapters from the MCH are developed to provide more comprehensive information. Books in the series discuss material systems based on the primary material used. The series currently comprises Modern Construction Facades, Modern Construction Roofs and Modern Construction Envelopes.

AIMS OF THIS BOOK

Modern Construction Envelopes combines the earlier Modern Construction Facades and Modern Construction Roofs into a single book with updated illustrations and more exploded views of material systems. This is a textbook for students of architecture, as well as students of structural and environmental engineering who wish to broaden their study beyond the information provided in the Walls and Roofs chapters of the Modern Construction Handbook. It shows the principles of the main facade types used today and illustrates this through typical generic details. The six chapters examine envelopes from the standpoint of the primary material used in their construction, from metal to glass, concrete, masonry, plastics and timber. Each set of five double page spreads explains a specific form of construction which is accompanied by drawn and annotated details. The techniques described can be applied internationally.

METAL WALLS
Chapter 1

The Metals chapter explores the use of sheet metal from a material fully supported on a substrate to its use as a self-supporting material in the form of profiled decking and composite panels. The use of profiled decking in thicknesses normally used for shipping containers, rather than buildings, has led to the introduction of semi-monocoque construction with this material. Some composite panel systems are being manufactured without an outer facing of metal sheet to allow a separate waterproofing layer to be added.

GLASS WALLS
Chapter 2

The Glass chapter investigates the range from framed systems to point fixed glazing. Windows and shop fronts are discussed as separate systems which can be used as full glazing systems in their own right.

CONCRETE WALLS
Chapter 3

The Concrete chapter compares in-situ (cast-in-place) concrete, and its use of formwork on site, with precast concrete and its use of moulds in a factory away from the site. In the use of either technique, the constraints of the panel sizes imposed by casting methods influence the use of the material.

MASONRY WALLS
Chapter 4

In the Masonry chapter the construction methodology is classified by wall construction: loadbearing, cavity wall or cladding attached to a backing wall. Within each construction method, the use of materials is very similar from brick to stone and concrete block. The differences in the specific use of a particular material are shown in the details.

PLASTIC WALLS
Chapter 5

The Plastics chapter explores the range of plastics from cellular materials, such as polycarbonate, to composite materials such as GRP, which is a combination of a woven fibrous material and a polymer matrix. Newer composite materials combine the economy of plastic with the durability and stiffness of metal in composite sheet materials. The recent re-introduction of plastics into mainstream construction has been possible due to the improved quality and colour durability of these materials. An advantage of plastics in wall construction is that they can provide translucency, rather than the transparency associated with glass, combined with high levels of thermal insulation.

TIMBER WALLS
Chapter 6

The Timber chapter shows both recent developments in timber walls and developments in traditional techniques. The low levels of embodied energy in this material, particularly in locally grown timber, have helped the revival in the use of this material. Traditionally shunned for large-scale applications due to its poor fire resistance, particularly in Europe, the use of timber is now better understood to reduce the spread of fire. Timber types are also discussed as their selection has considerable environmental impact.

METAL ROOFS
Chapter 7

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 employed in standing seams, profiled sheet and rainscreens. Solar shading devices formed from metal are also discussed.

GLASS ROOFS
Chapter 8

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

CONCRETE ROOFS
Chapter 9

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 ROOFS
Chapter 10

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.

PLASTIC ROOFS
Chapter 11

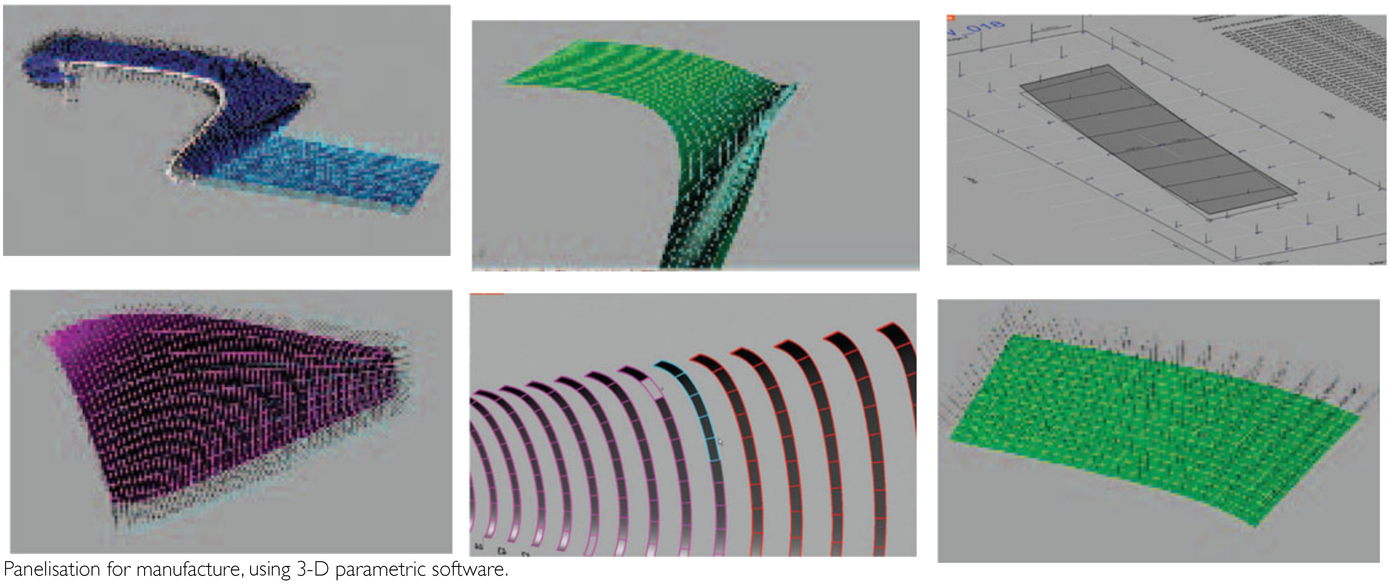
Polycarbonate panels have the advantage of providing well insulated translucent panels that are more economic than those in glass. They are much lighter than glass, allowing more visually delicate support structures to be used for these panels. Glass reinforced polyester (GRP) can produce opaque roof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

FABRIC ROOFS
Chapter 12

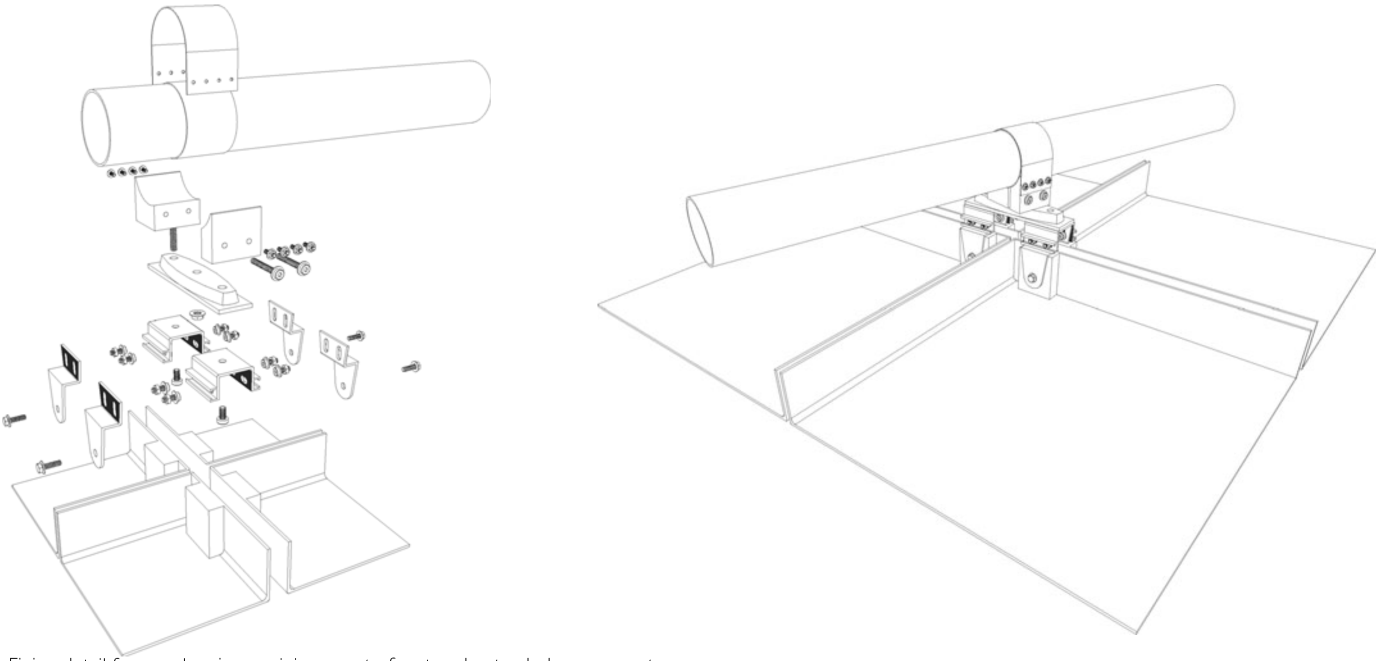
The Fabric chapter discusses tensile roof structures, air supported types and smaller scale canopies. PTFE membranes can be stretched over supporting structures, typically stainless steel cables with tubular steel supports. PTFE sheet is also used to form inflated 'air pillows' that are supported on 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

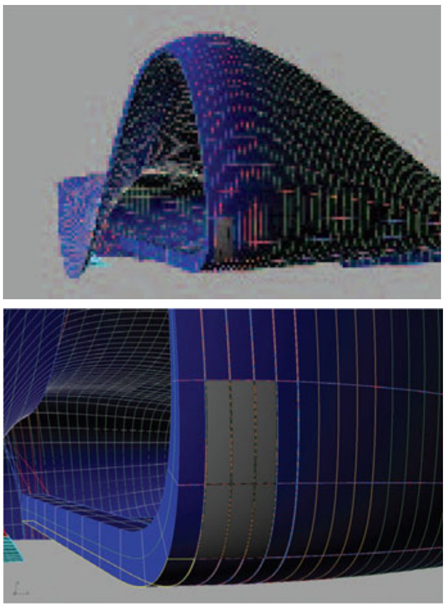
The building techniques discussed and the built examples shown are designed to last for an extended period with a relatively high performance. Consequently, buildings for exhibitions and for temporary use are excluded. In addressing an international readership, references to national legislation, building 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. All details shown aim to demonstrate continuity in thermal insulation and waterproofing, together with two defences against rainwater penetration. Where specific items are not clearly present on drawings, these principles should still be followed.



Panelisation for manufacture, using 3-D parametric software.



Fixing detail for panels using a minimum set of cast and extruded components.

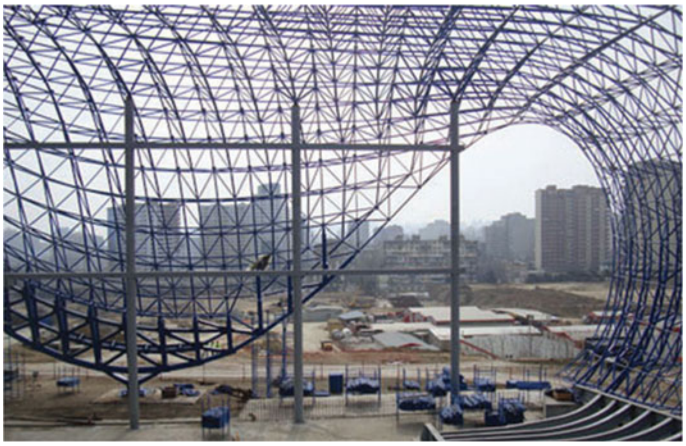


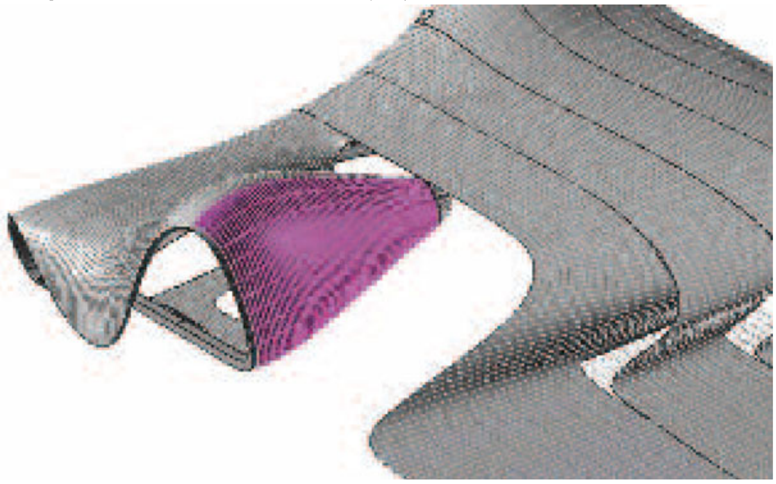
Panelisation of geometry for manufacture.

While the building envelope systems described in this book are mostly described through rectilinear building forms, they can equally be applied to complex geometries and associated mass customisation techniques described in the introduction essays in the second edition of the Modern Construction Handbook.

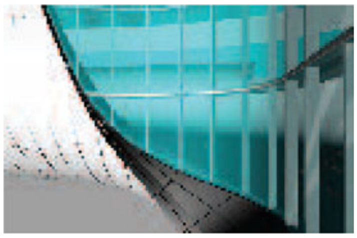
An example is described here where the author, a director of Newtecnic, facade designers based in London, worked with the United Arab Emirates' based contractor, Arabian Profiles (APL) on an external envelope of complex geometry. The project was a cultural centre in Azerbaijan, which involved the manufacture of 16,000 cladding panels. These panels were either single curved or double curved to provide a continuously curved surface made from a combination of GRC (glass reinforced concrete) and GRP (glass reinforced polymer) types. The GRC is used mainly on surfaces that are walked upon in the plaza spaces around the building, while the GRP is used as roof cladding panels which are lighter in weight and have a comparable colour and surface finish. Panels were manufactured which followed the geometry required by the architect without the need for flat or facetted panels, while being economic in the method of manufacture. This outcome was achieved by translating the digital 3D model describing the geometry into

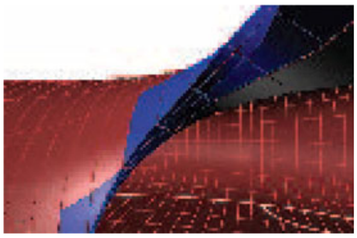
Triangulated roof structure to which envelope system if fixed

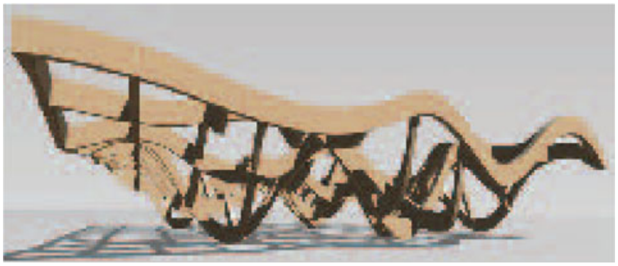




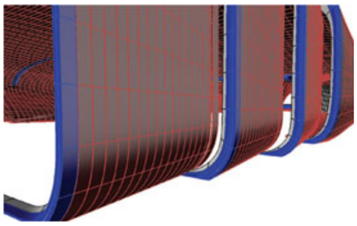
Panelisation of geometry for manufacture.







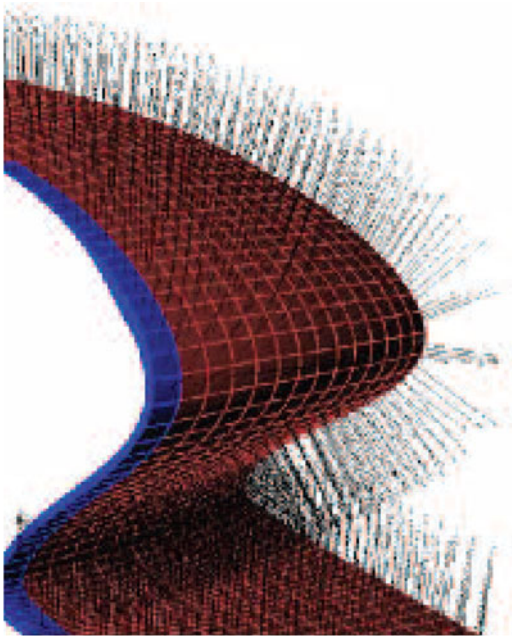
Panelisation of geometry for manufacture.



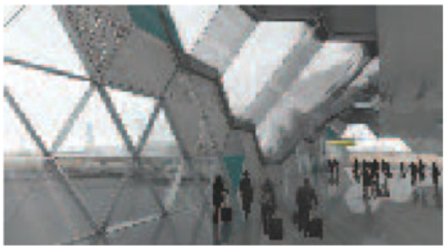
Panelisation of geometry for manufacture.

individual panels with data that could be used in flexible moulding tables to fabricate the panels using a method of mass customisation. The moulding table was designed by the manufacturer of the panels, APL, who make envelope systems that focus on realising ambitious architectural designs using mass production or mass customisation techniques. The three dimensional form was described by a grid of points linked by regular curves that create the single curved forms with non-rectilinear edges. The flexible moulding tables use digital input to create visually complex forms without the need for hand-made components with their associated fabrication tolerances.

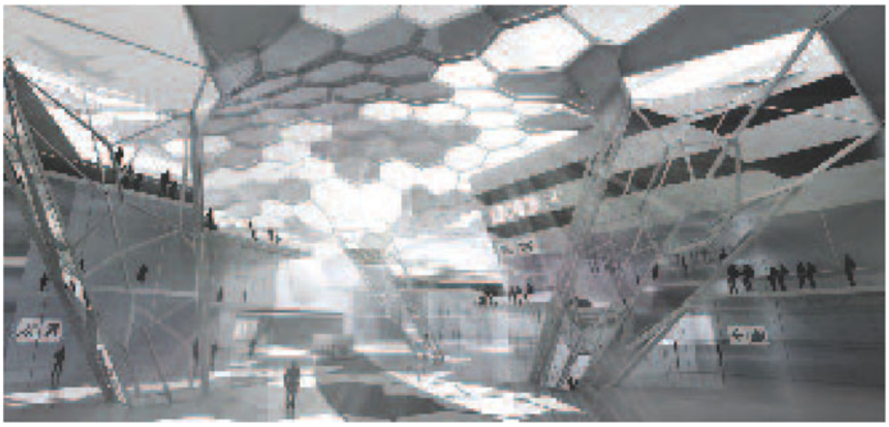
The use of a flexible moulding table allows complex panel shapes formed in single curved geometry to be manufactured quickly and economically to a high standard. Digitally controlled devices are used to adjust the shape of the panel with data provided by the 3D model. Information for edge returns for the panels, used to stiffen panels at their edges, was provided by 'developed', or unrolled, shapes offset from the curved shapes in the 3D model generated by the architect. This avoidance of purely hand crafted techniques ensures that the manufacture of systems for complex buildings can be applied to large-scale building envelopes.

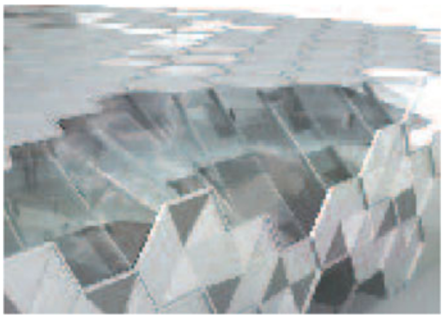


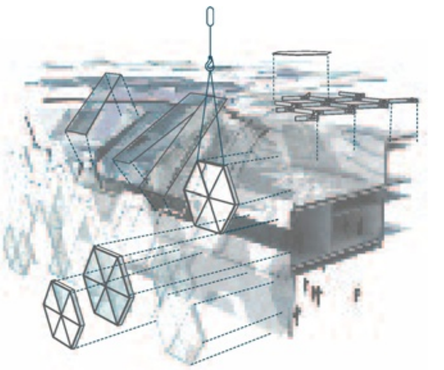
Method of identifying panels for manufacture and installation



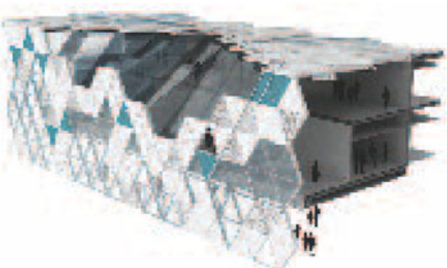
Envelope option of hexagonal unitised panels based on triangular units set into them.







Sequence of assembly

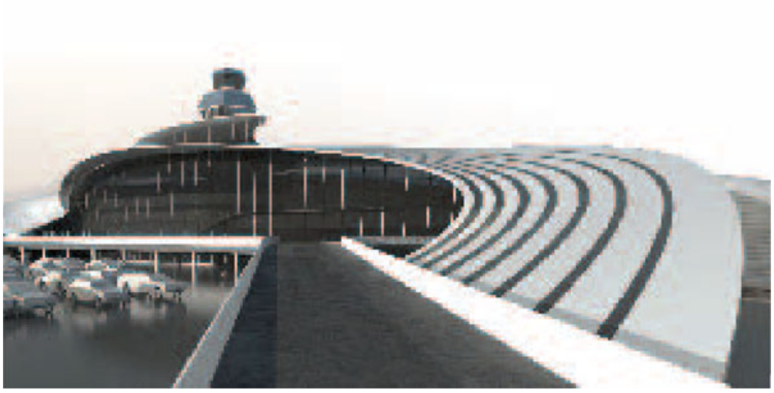


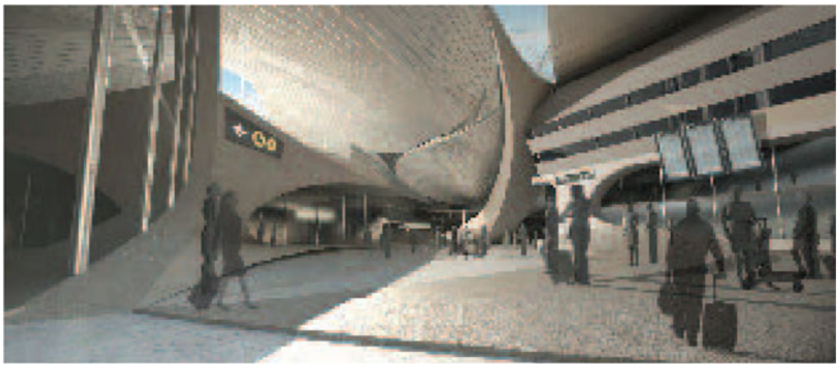
This project, designed by Newtecnic, for new facades of an existing airport building show how two quite different approaches can be taken where the external envelope is used to re-model an existing building without the need for demolishing the primary structure. This approach ensures that existing buildings can be re-used, often with quite different functions within the building.

The design on the left hand page is generated around the use of a cladding system based on the hexagonal shape of the plan of the existing primary structure, a panel geometry which lends itself in the plane of the roof. The hexagonal panel shape is also used for the facades, spanning from floor to floor. A covered atrium space is created from the central courtyard, with the interface of the roof and wall folding down to create a single set of 'shards' to create a combined structure and envelope solution. The facade geometry is composed of a unitised system of glazing, insulated panels, and integrated shading devices. This approach allows the straightforward removal of existing rectangular precast concrete cladding, with the new facade panels being lifted into position and fixed simply to the existing primary structure. This solution ensured that both facade and roof used a secondary steel support system that did not require changes to the existing primary structure.

The design on the right hand page is based on a CFD (computational fluid dynamics) study of the high-wind environment of the site. The roofscape was digitally generated by draping the existing building form and applying the prevailing wind condition to the

Envelope option of rainscreen cladding panels on a continuous waterproof metal deck. The design is based on prevailing wind movement across the site.

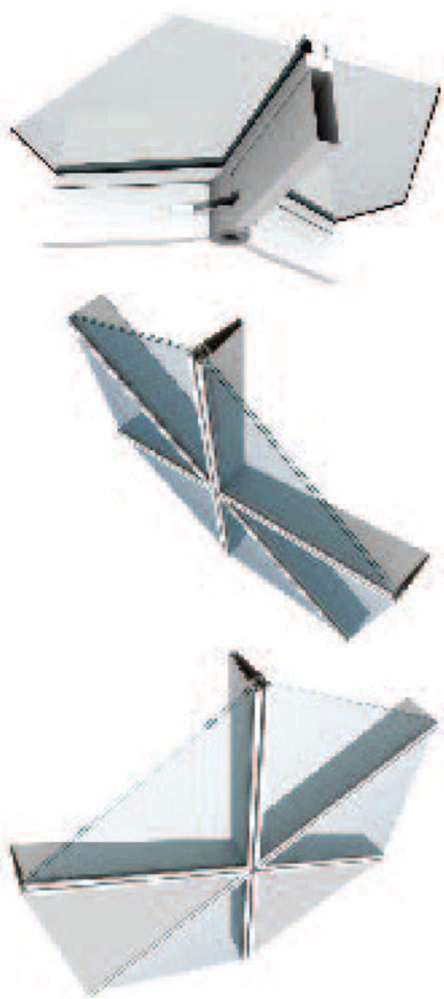




resulting surface. The flowing form, striated texture and longitudinal glazing strips follow the aerodynamic requirements of visual fluidity and air flow, ensuring that the external envelope allowed wind from the prevailing direction to slip across its surface, away from people entering the building from the adjacent car parking area.

The external envelope consists of a double-skinned rainscreen system and glazed facade connected by steel trusses. While the glazing is seen to visually 'cling' to the existing building structure, the other visually 'billows,' revealing the steel trusses that hold the external envelope in place. The glazed roof system is used to visually cut through the roof to define new spaces within the existing building structure as well as drawing light into the internal spaces. The opaque roof panels are made from GRP (glass reinforced polymer) as used in the digital fabrication example in Azerbaijan, in the previous page spread.

The design uses a lightweight rainscreen roof assembly enveloping the existing building structure. This system allows for the realisation of curved geometries as the result of a combination of supporting structure for facade and roof, creating a smooth, continuous form. The rainscreen is backed by an economic structural deck, with incorporated closed cell thermal insulation and waterproofing membrane; a construction method which provides a visual continuity to the form of the external envelope, in contrast with the panel component-based solution of the hexagonal panel design.



Panel connections for the hexagonal based option on previous page.

1

METAL WALLS

(1) **Sheet metal:**

Fixing methods
Openings
Substrates and supporting walls
Corners, parapets and cills

(2) **Profiled cladding:**

Junctions
Parapets and gutters
Window/door openings
Insulation, liner trays
Developments

(3) **Composite panels:**

Parapets and cills
Window/door openings
Developments
Corners
Thermal bridges at cills

(4) **Metal rainscreens:**

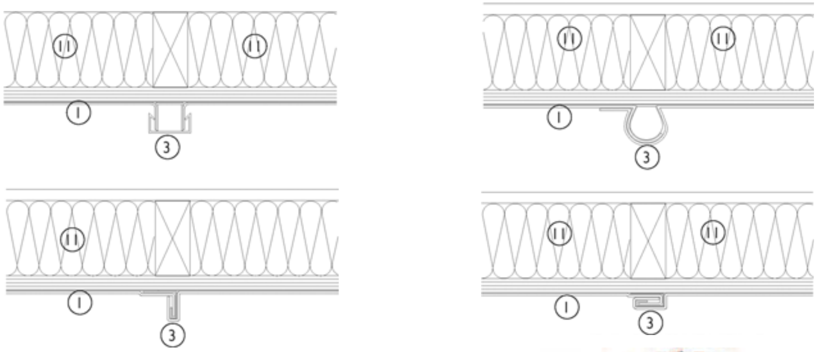
Materials
Fixing methods
Backing walls
Construction sequence
Window/door openings
Parapets and cills

(5) **Mesh screens:**

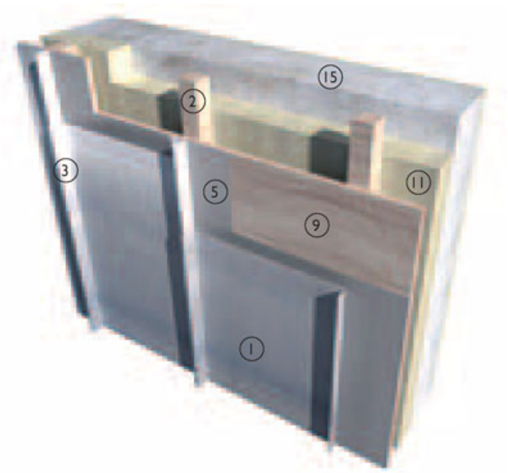
Rigid mesh
Meshes flexible in one direction
Fully flexible mesh
Mesh used on curves
Perforated metal

(6) **Louvre screens:**

Metal louvres
Glazed louvres
Solar shading
Walkways

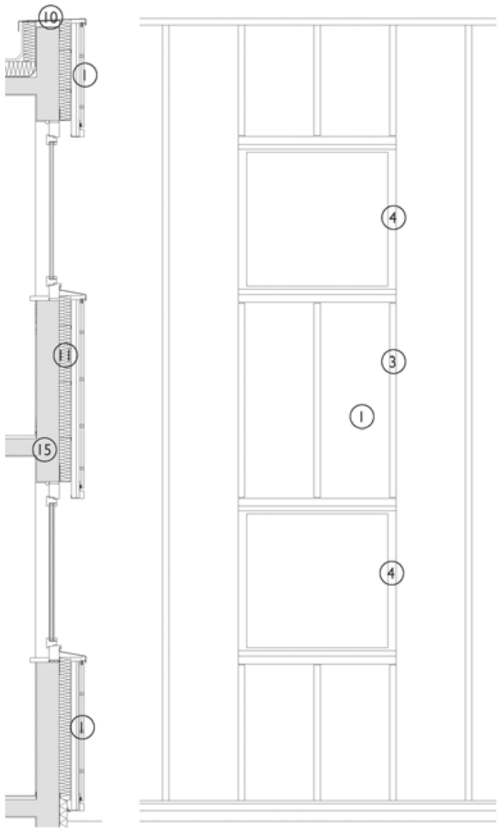


Horizontal Section 1:10. Seam profile options



3-D cut-away view of typical folded metal sheet cladding construction. Type 2

3-D view of window inserted into folded metal facade. Type 2



Vertical section & elevation 1:50. Sheet metal cladding with vertical joints

Sheet metal is used for the rich surface textures that can be achieved with relatively soft materials applied to a continuous supporting substrate. This method does not provide the sharp lines and flat surfaces associated with rainscreen panels or composite panel construction. The most common metals used are copper, lead, zinc. More recently, stainless steel has come into use, but primarily as a roofing material. Copper sheet is a ductile material, but not as malleable as lead. Its characteristic green patina when fully weathered gives a consistent appearance. Lead sheet is extremely durable, and its softness allows it to be formed over complex geometries and panels with a high amount of surface relief. Zinc is durable, though more brittle than copper but is susceptible to corrosion from its underside if not ventilated. Stainless steel is a very durable material, but it still has an uneven surface when laid that provides a richness of reflection. The main disadvantage of working in stainless steel is its hardness, making it difficult to work when forming folds in jointing.

Fixing methods

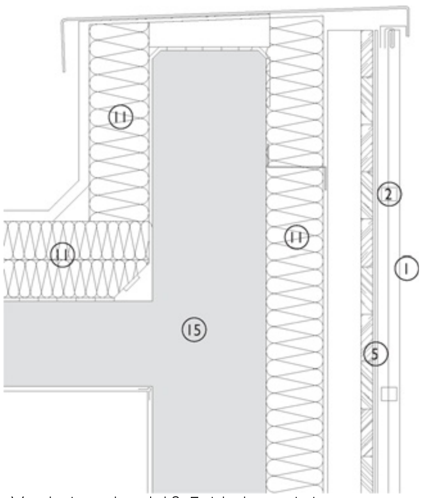
There are three fixing methods for continuously supported sheet metal walls: continuous sheet, lapped tiles and recessed joints.

Continuous sheets are laid in varying widths with standing seams in vertical joints that run continuously from top to bottom of a wall. This gives the facade a characteristic striped appearance with strong shadows across the standing seam joints in sunlight. The sheet metal is fixed on the horizontal joints with flattened seams that allow rainwater to drain off easily. Horizontal joints are at distances to suit the visual appearance of the design but 12.0 metres (39ft 4in) to 17.0 metres (55ft 9in) is the maximum depending on the metal used. Vertical joints align with the edges of windows and door openings. Horizontal joints are usually staggered to form a pattern rather than try to achieve a continuous straight line which is difficult to keep completely straight and horizontal. This is because horizontal joints are broken between each vertical seam.

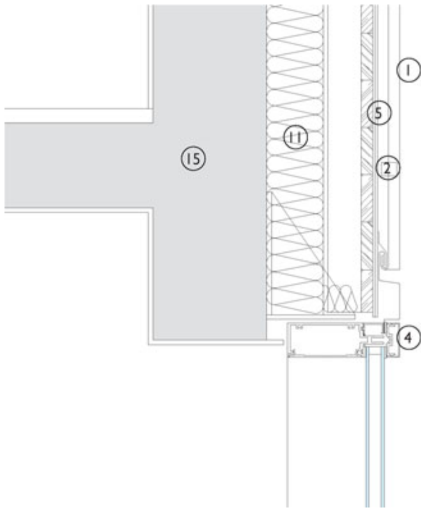
Lapped tiles are made approximately 450mm to 600mm (18inx24in) square and are set in either horizontal and vertical edges or at a 45° angle. Other angles can be used but are harder to co-ordinate with the edges of corners and openings. Window and door openings are usually enclosed in a metal strip around the reveal of the opening, with a shadow gap or projecting corner detail. Tiles are not folded into openings due to the complexity of jointing and the difficulty of getting them to fold neatly at half way across the panels. Shadows across the surface of a tiled wall have small strong lines which give a very textured appearance to the facade. Tiles are lapped on four sides to give a continuous watertight joint on all edges.

Recessed joints are formed in sheet metal laid over a specially formed substrate to produce recessed lines, which are usually horizontal. The material is occasionally recessed on four sides and set on a plywood background with projecting panels formed by the plywood. However, this technique is seldom used any more due to the increased use of metal rainscreen panels with their

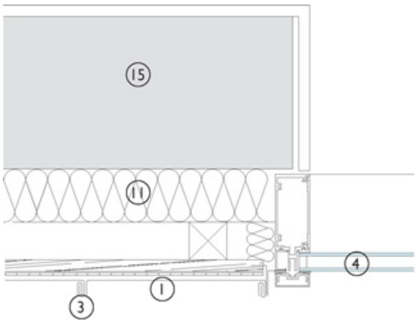
3-D views of folded metal sheet with angled seam lines



Vertical section 1:10. Folded metal sheet parapet detail



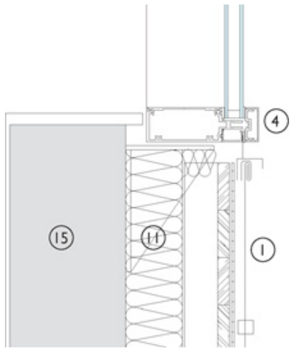
Vertical section 1:10. Folded metal sheet connection to aluminium curtain wall type window head



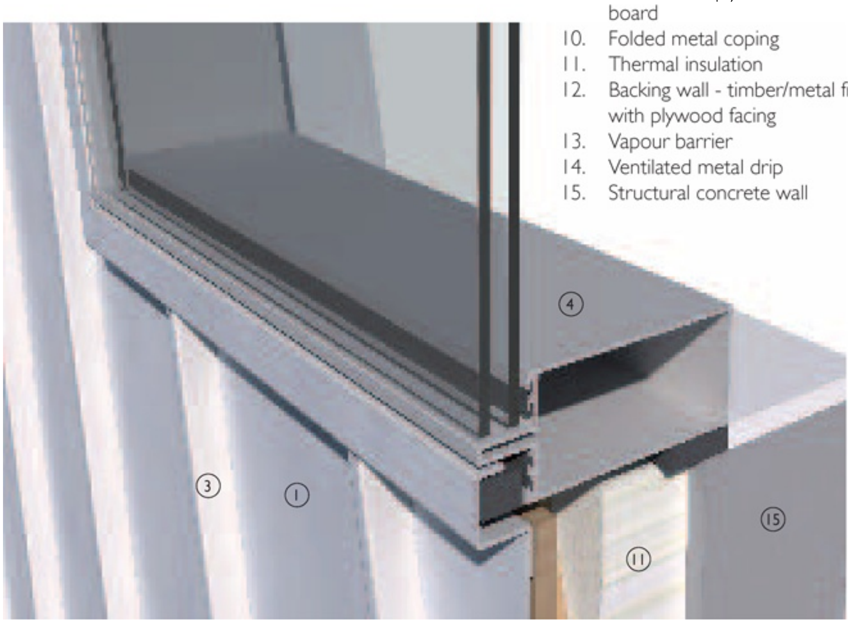
Horizontal section 1:10. Folded metal sheet connection to aluminium curtain wall type window

Details

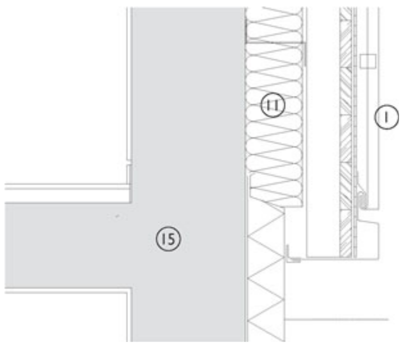
1. Folded metal sheet
2. Fixing battens
3. Standing seam joints
4. Window frame
5. Waterproof membrane, typically bitumen based paint
6. Internal finish
7. Metal clips fixed at centres
8. Timber window cill
9. Substrate in plywood or timber board
10. Folded metal coping
11. Thermal insulation
12. Backing wall - timber/metal frame with plywood facing
13. Vapour barrier
14. Ventilated metal drip
15. Structural concrete wall



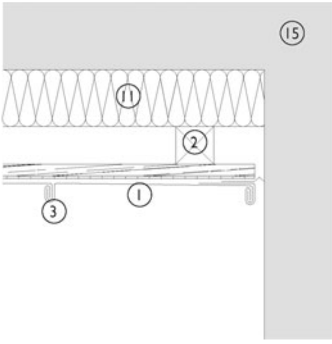
Vertical section 1:10. Folded metal sheet connection to aluminium curtain wall type window cill



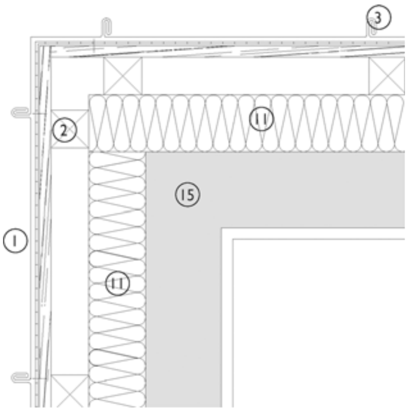
3-D view of aluminium window in folded metal cladding system



Vertical section 1:10. Ground level cill



Horizontal section 1:10. Internal corner junction with wall



Horizontal section 1:10. External corner formed from folded metal sheet

Horizontal section 1:10. Simple seam details at corners

Details

1. Folded metal sheet
2. Fixing battens
3. Standing seam joints
4. Window frame
5. Waterproof membrane, typically bitumen based paint
6. Internal finish
7. Metal clips fixed at centres
8. Timber window cill
9. Substrate in plywood or timber board
10. Folded metal coping
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12. Backing wall - timber/metal frame with plywood facing
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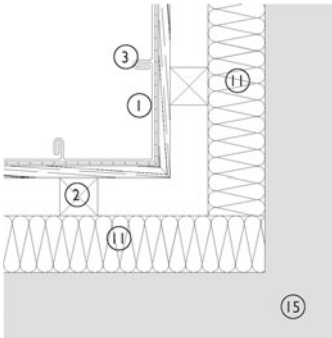
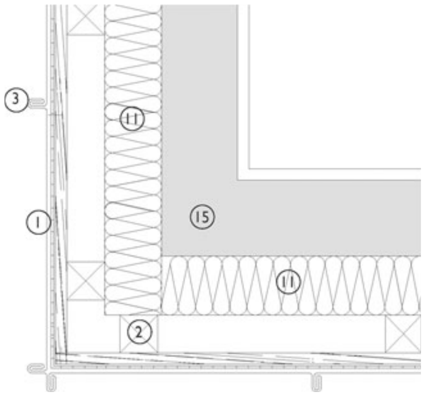


Horizontal section 1:10. Internal corner connection with folded metal sheet



Horizontal section 1:10. External corner with seam connection

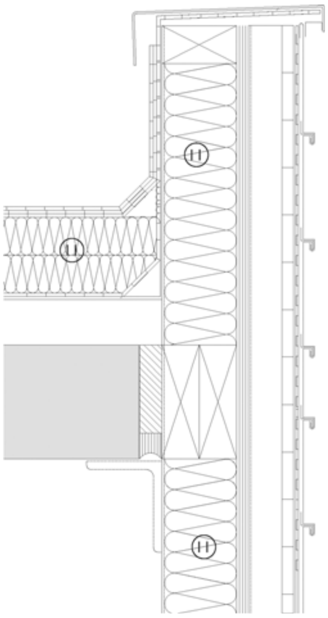
advantage of flatness of panel and close fixing tolerances, providing crisp lines at joints which are more difficult to achieve in a sheet metal continuously supported on a profiled background. However, this technique may find favour again due to its rich surface texture. Drips are incorporated at horizontal recessed joints to avoid staining occurring as a result of dirt being washed off the flat surfaces of these joints.

Openings

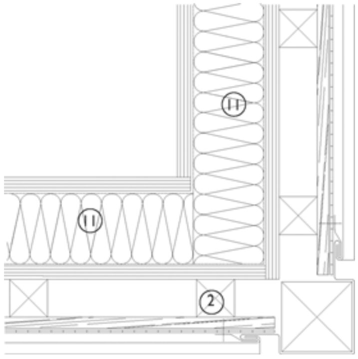
Where vertical jointed sheet metal is used, window and door openings are usually positioned so that a joint falls on the edge of an opening. This gives a clean, co-ordinated appearance to the facade, but openings that are set deliberately 'off grid' from the vertical joints also look visually dramatic. A recent development has been to use sheet metal with vertical joints inclined at angles up to 45° from the vertical so that they contrast with rectilinear window openings, giving the sheet metal the appearance of a continuous 'non-gridded' texture across a complete facade. For all orientations of sheet metal, window and door openings have separate metal sheets forming reveals on all sides. Although this can result in some awkward pieces of metal to form junctions around windows, in practice they are practical and economic to form on site due to the site-based nature of fixing metal sheet. Sheet metal cladding is ideally suited to the complex junctions associated with non-rectilinear geometries. Attempts to make the material appear too regular can produce disappointing results, particularly where a pure rectilinear grid is attempted. In this instance, metal rainscreen panels would probably be more suitable.

Windows and doors are glazed with almost any available technique, but the ever-increasing use of double glazed units both to conserve energy and avoid condensation on the window or door surface has led to thermally broken sections being used very commonly. Window frames are often clad in the same sheet metal as used in the adjacent facade, but this is expensive since the metal cladding will always be a decorative finish to a window that is designed for use without such a finish. The usual alternative is to use either a polyester powder coated or PVDF paint finish on aluminium to match the colour of the adjacent metal, or use a different material such as timber windows. A paint finish is obviously much easier to match if the sheet metal finish is pre-patinated (pre-weathered) so that its final colour will be very similar to the colour of the metal when installed. This is much more difficult in unweathered metals. The use of galvanised steel windows and doors with zinc is not so common due to the increased performance of paint coatings. However, galvanised finishes are ever-increasing in their durability and may eventually be used as a durable finish for window frames.

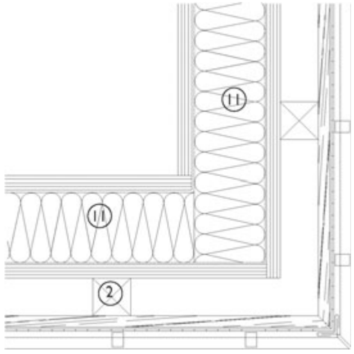
Buildings clad partly in sheet metal are beginning to use large-scale glazed openings using a completely different system such as bolt fixed glazing. Whereas these two systems previously seemed incompatible, with sheet metal as an economic system and bolt fixed



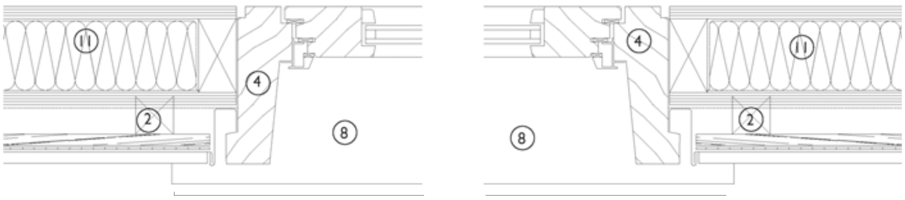
Vertical section 1:10. Parapet detail in folded metal sheet with projecting joints



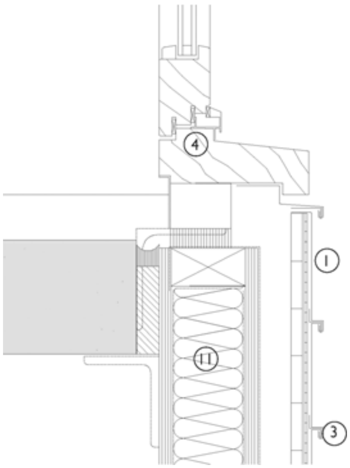
Horizontal section 1:10. External corner with seam connection



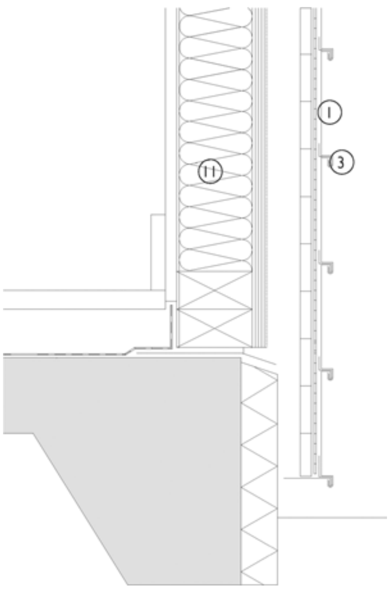
Horizontal section 1:10. External corner with seam connection



Horizontal section 1:10. Window detail in folded metal sheet with projecting joints



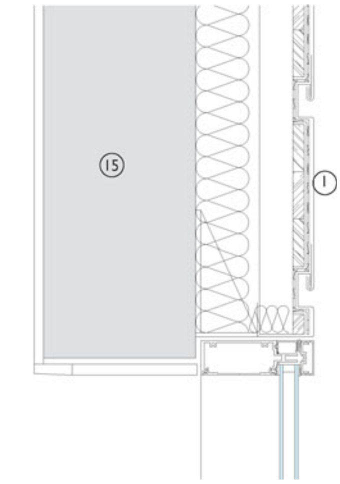
Vertical section 1:10. Timber window cill detail in folded metal sheet with projecting joints



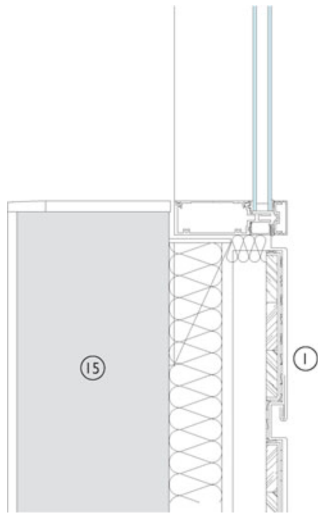
Vertical section 1:10. Ground level cill detail in folded metal sheet with projecting joints

3-D view of folded metal sheet cladding with projecting joints. Type 1

3-D view of folded metal sheet with recessed seams. Type 1



Vertical section 1:10. Aluminium window head detail in folded metal sheet with recessed joints



Vertical section 1:10. Aluminium curtain wall type window cill detail in folded metal sheet with recessed joints

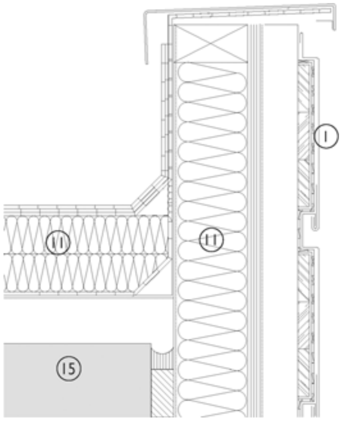
Details
1. Folded metal sheet
2. Fixing battens
3. Standing seam joints
4. Window frame
5. Waterproof membrane, typically bitumen based paint
6. Internal finish
7. Metal clips fixed at centres
8. Timber window cill
9. Substrate in plywood or timber board
10. Folded metal coping
11. Thermal insulation
12. Backing wall - timber/metal frame with plywood facing
13. Vapour barrier
14. Ventilated metal drip
15. Structural concrete wall

glazing as an expensive system, the two are now used together increasingly where a deliberate contrast of surface texture is sought. While bolt fixed glazing has a smooth, continuous surface uninterrupted by visible framing, sheet metal has joints in a direction at 400mm (1ft 4in) to 600mm (2ft) centres, with a comparatively uneven surface finish.

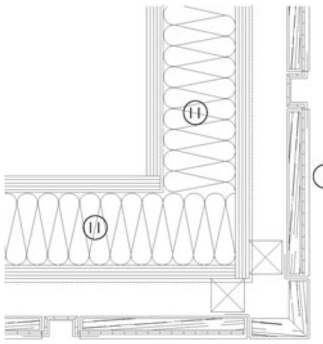
Substrates and supporting walls

Sheet metals can be laid directly onto a substrate, typically plywood, with the exception of zinc, which needs ventilation on its interior face to avoid corrosion. Plywood is preferred for its durability, since if it becomes wet before a repair can be undertaken, the material can dry out without being damaged. Other materials such as particle boards are not resistant to moisture penetration and so are not used. Timber boards are used but are usually more expensive, as is profiled metal sheet. Where timber framing is used for the wall construction, the timber substrate forms an integral part of the external wall, providing diaphragm stiffness in the frame. Profiled metal sheet is increasingly used as a substrate for zinc, since zinc is more rigid than other metals such as copper or lead. Profiled metal sheet can span the gap between the peaks of the cladding, while providing a ventilated zone behind to avoid corrosion of the zinc. The addition of a ventilation mat provides a full gap between the zinc and the profiled metal.

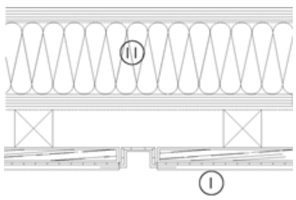
Sheet metal is increasingly fixed to walls constructed in a wide range of materials: timber frames, precast concrete, concrete block and lightweight steel frames made in cold



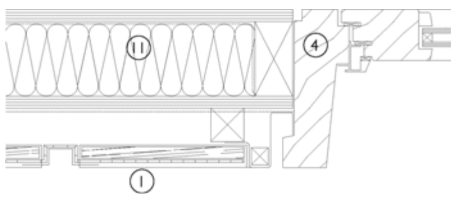
Vertical section 1:10. Parapet detail in folded metal sheet with recessed joints



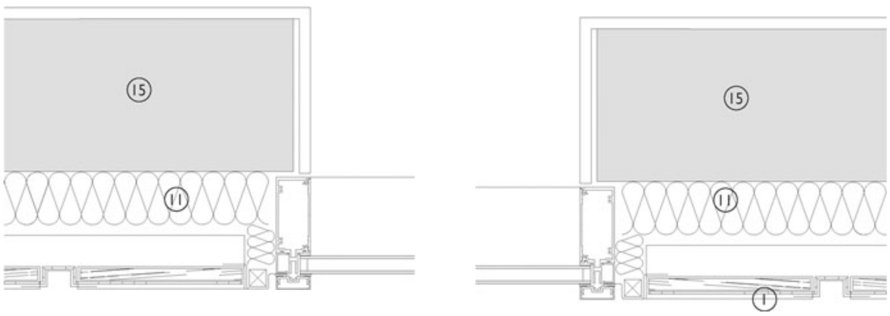
Horizontal section 1:10. External corner detail in folded metal sheet with recessed joints



Horizontal section 1:10. Panel to panel junction with recessed joint



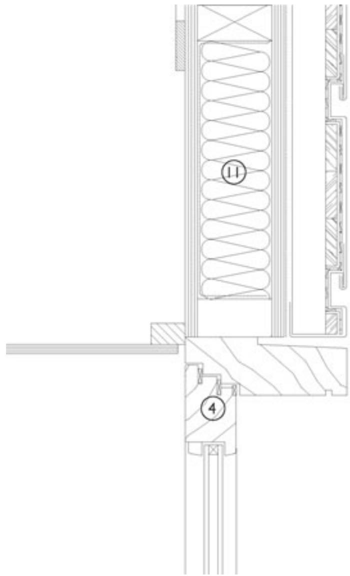
Horizontal section 1:10. Junction between timber window and folded metal sheets with recessed junctions



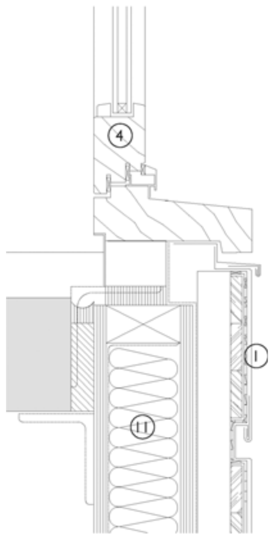
Horizontal section 1:10. Junction between curtain wall type window and folded metal sheets with recessed junctions

formed sections.

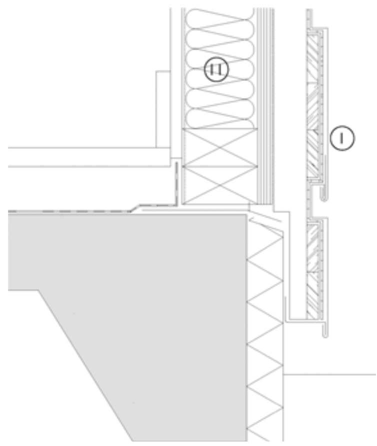
In Type 1, timber frames use sheet metal as a cladding in a fairly traditional form of construction, or as infill panels to a timber, concrete or steel frame. The overall cross section of the wall remains thin due to the inclusion of thermal insulation within the frame rather than on an outside face. A vapour barrier is needed on the warm-in-winter side (in a temperate climate) to avoid vapour reaching the insulation from inside. The vapour barrier is needed in the same place in Type 3, where pressed steel, or 'light gauge' steel sections are used. The all-metal construction of Type 3 is undergoing refinement for use in housing, where almost all its components can be either recycled or unbolted and modified with the same kit of parts during its lifetime. Its flatness of appearance combined with small-scale standing seam joints make it ideal for a sealed metal cladding where profiled metal sheet or composite panels have too 'industrial' an appearance. In Type 2, thermal insulation is set on the outside of the concrete structure in order to use its thermal mass as well as to keep the structure at as even a temperature as possible. The metal cladding is then set forward of the insulation. A new development is the use of profiled metal cladding as a substrate in Type 4. Where zinc is used the void formed by the profiled sheet provides a ventilation zone without the use of timber. A plastic-based drainage mat is set between the zinc and the profiled sheet to complete the ventilation.



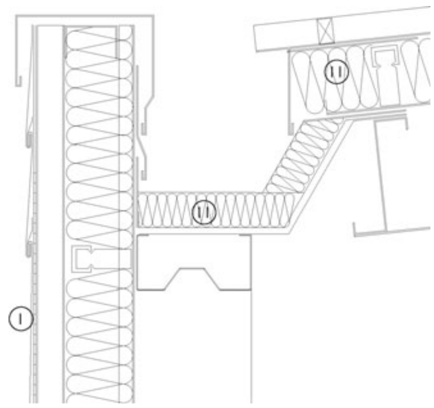
Vertical section 1:10. Timber window head detail in folded metal sheet with recessed joints



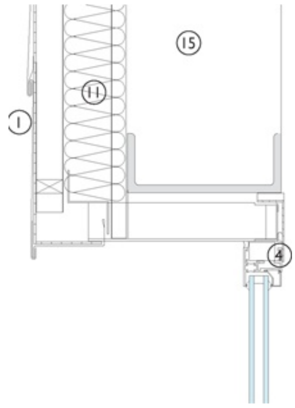
Vertical section 1:10. Timber window cill detail in folded metal sheet with recessed joints

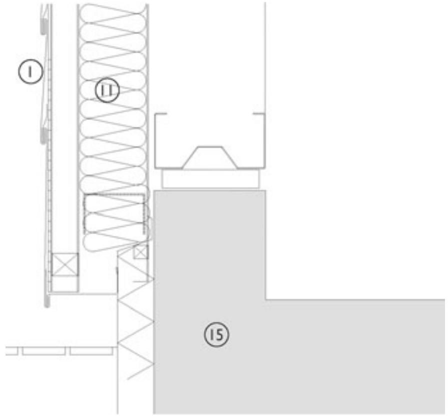


Vertical section 1:10. Ground level cill detail in folded metal sheet with recessed joints

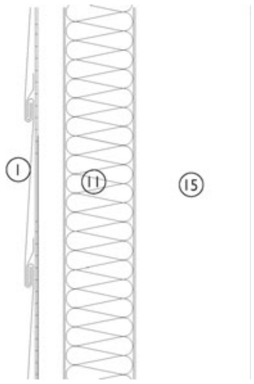


Vertical section 1:10. Parapet detail with interlocking folded metal sheets

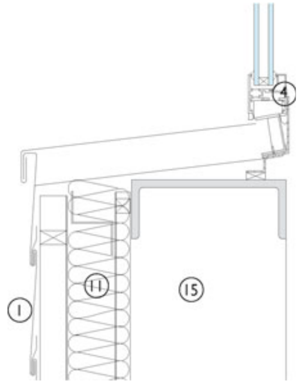




Vertical section 1:10. Ground level cill detail with interlocking folded metal panels. Type 3



Vertical section 1:10. Typical wall build-up with interlocking folded metal panels



Vertical section 1:10. Recessed aluminium window in interlocking folded metal facade

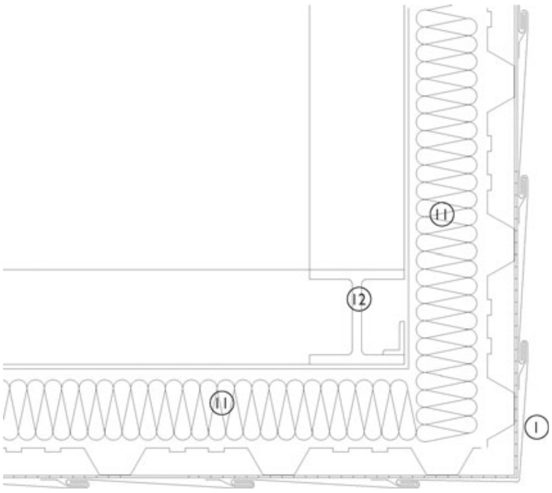
Details
1. Folded metal sheet
2. Fixing battens
3. Standing seam joints
4. Window frame
5. Waterproof membrane, typically bitumen based paint
6. Internal finish
7. Metal clips fixed at centres
8. Timber window cill
9. Substrate in plywood or timber board
10. Folded metal coping
11. Thermal insulation
12. Backing wall - timber/metal frame with plywood facing
13. Vapour barrier
14. Ventilated metal drip
15. Structural concrete wall

Corners, parapets and cills

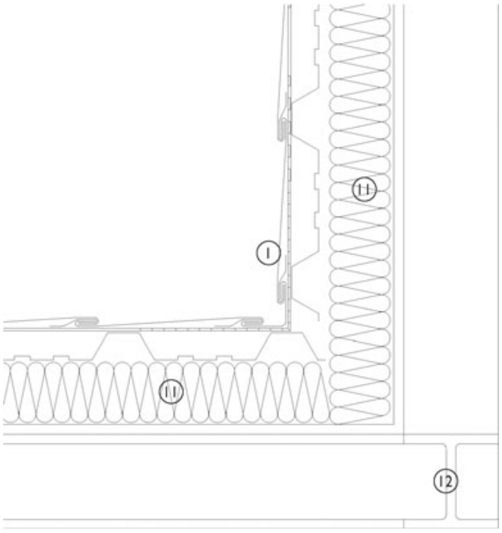
Sheet metal can be joined at corners in facades with either recessed or projecting coverstrips. The covers need a timber or plywood support under them to provide rigidity. Corners for vertically set metal sheet can also be formed by setting standing seam joints at the corner, or close to the corner on either side of the edge. With tiled sheets, corners usually wrap around, ignoring the corner like a continuous pattern folded around the corner. Alternatively, corners can have coverstrips that break the pattern from one facade to another. There is an increased use of pressed metal clips and rails, as used in profiled metal cladding, to support sheet metal substrates, typically plywood. Clips and rails are made as proprietary systems which can be fixed to the backing wall quickly and easily adjusted to correct vertical or inclined alignment.

An advantage of sheet metal is that parapet copings and cill drips at the base of walls at windows can be formed in the same material with an identical finish. This is unlike many other metal cladding systems, where extruded aluminium or pressed steel or aluminium are most commonly used for parapets and cills. The ability to form metal on site in junctions of sheet metal walls with parapet copings is used either to form a recessed joint, which allows the standing seam joint in the cladding to be tapered down to the line of the coping, or a projecting parapet coping which allows the standing seam to butt up to the underside of the coping. With either solution, an undercloak flashing or waterproof layer is needed underneath the coping to provide additional waterproofing.

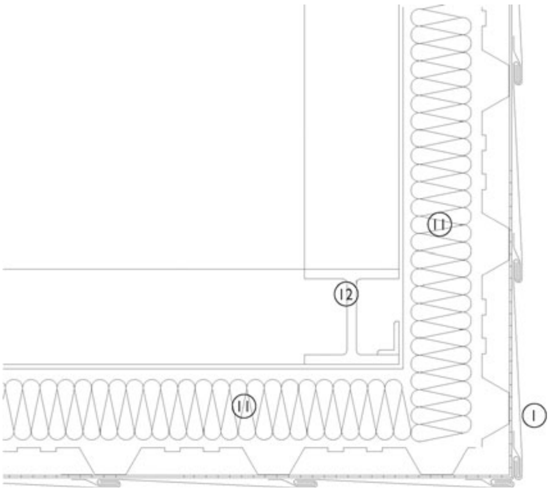
Cills are formed in a similar way, but with projecting or flush drips to throw water clear of the base of the cladding. Where unweathered metal is used, care should be taken that rainwater runoff from oxidising metal does not stain paved surfaces at the base of the wall. Slot drains or gravel edges can be used both to provide drainage and avoid visible staining. Drips are often reinforced with a steel or aluminium angle to create a strong, straight edge. Compatibility between the cladding material and support material must be ensured to avoid bimetallic corrosion. Where the void behind metal cladding is used for ventilation, parapets and cills are used to introduce fresh air. Insect mesh is introduced within the joint, but its presence does not alter air flow rates significantly.



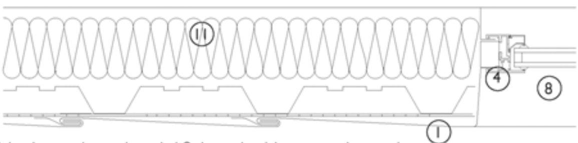
Horizontal section 1:10. Interlocking metal panels.
External corner with metal fold



Horizontal section 1:10. Interlocking metal panels.
Internal corner with joint

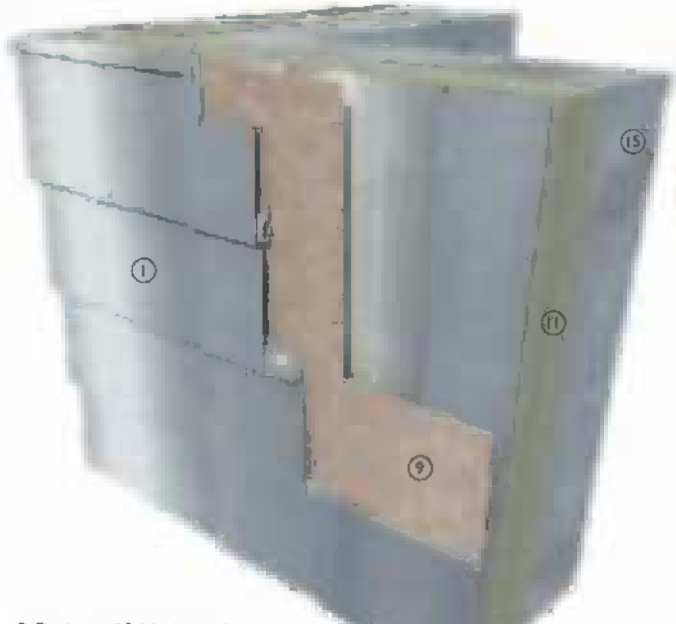


Horizontal section 1:10. Interlocking metal panels.
External corner with joint

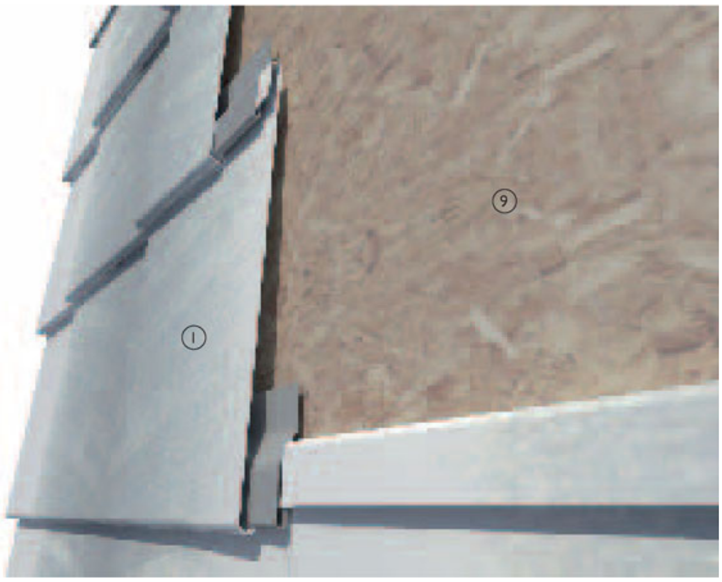


Horizontal section 1:10. Interlocking metal panels.
Window junction

3-D view of folded metal sheet
with recessed seams.
Type 4



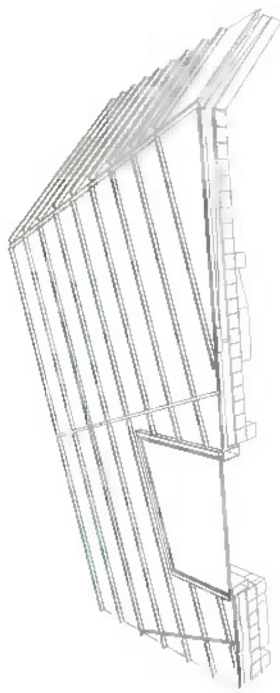
3-D view of folded metal
sheet with recessed seams.
Type 4



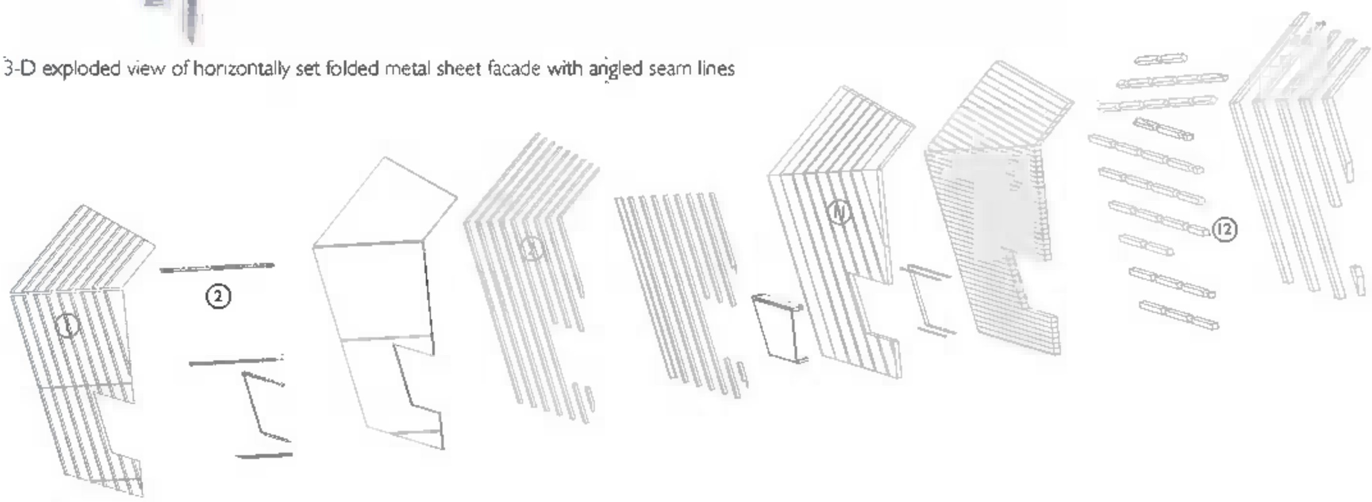
3-D view of folded metal sheet with recessed seams

Details

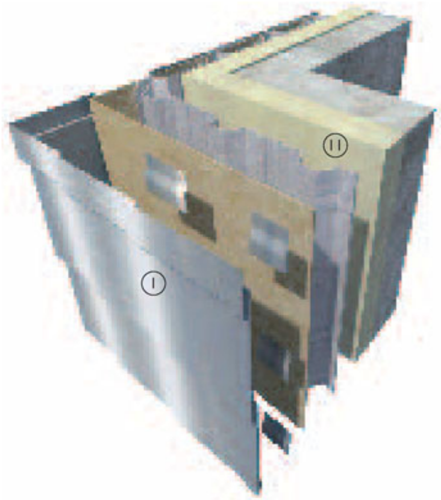
1. Folded metal sheet
2. Fixing battens
3. Standing seam joints
4. Window frame
5. Waterproof membrane, typically bitumen based paint
6. Internal finish
7. Metal clips fixed at centres
8. Timber window cill
9. Substrate in plywood or timber board
10. Folded metal coping
11. Thermal insulation
12. Backing wall - timber/metal frame with plywood facing
13. Vapour barrier
14. Ventilated metal drip



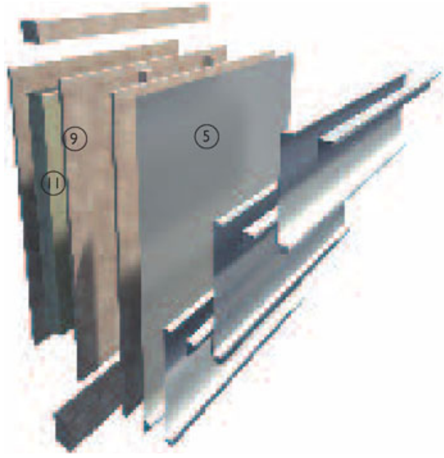
3-D exploded view of horizontally set folded metal sheet facade with angled seam lines



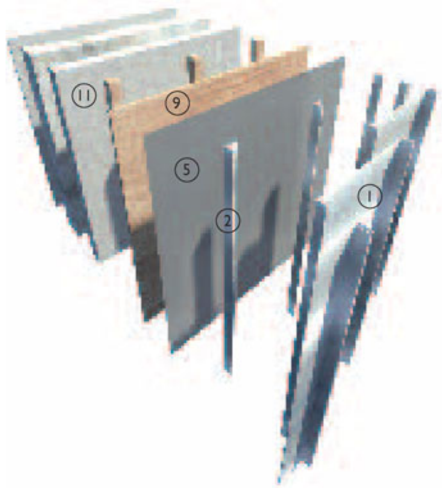
3-D exploded view of horizontally set folded metal sheet facade with angled seam lines



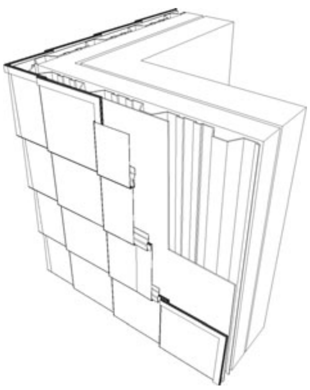
3-D exploded view of corner condition in tiled metal rainscreen system



3-D exploded view of folded metal sheet with horizontal recessed seams

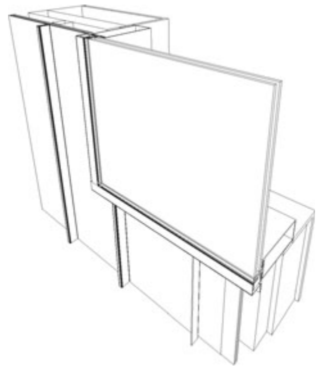


3-D exploded view of folded metal sheet with vertical recessed seams

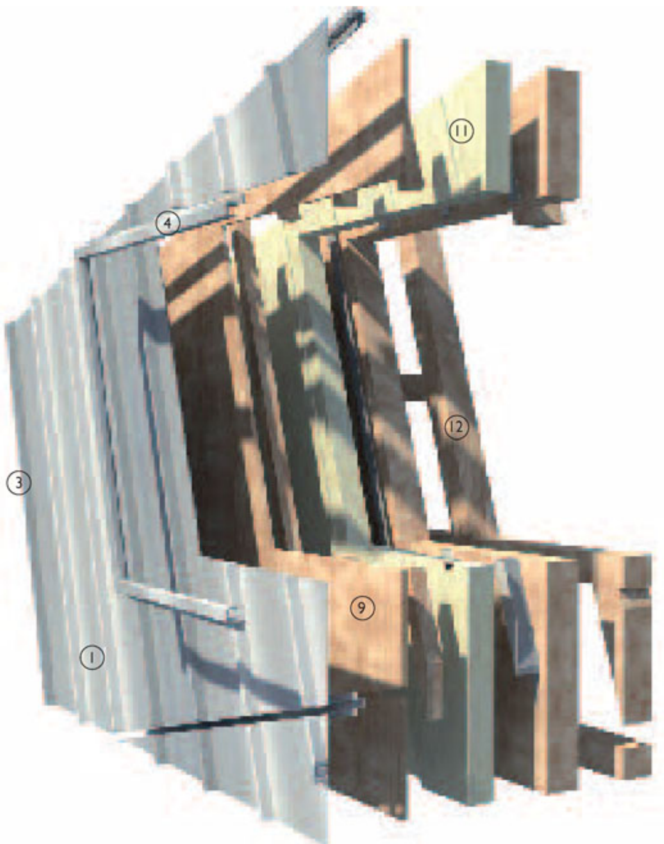


3-D exploded view of corner condition in tiled metal rainscreen system

3-D view of folded metal sheet with recessed seams



3-D view of folded metal sheet with recessed seams



3-D exploded view of construction of horizontally set folded metal sheet facade with angled seam lines

3-D exploded view of window opening in horizontally set folded metal sheet facade with vertical seam lines

3-D view of horizontally set profiled metal sheet

3-D view of vertically set profiled metal sheet

An advantage of profiled metal cladding is that it can be easily integrated with a similar system used for cladding the roof. Also, small areas of roof can be easily accommodated as steps within the facade with simple junctions between vertical and shallow pitch roofs. At the junction with the top of the roof an undercloak flashing is used to ensure water running off the wall is sent on down the roof and not into the joint at the base. At the bottom of the roof, either an exposed gutter or a concealed parapet gutter is used to collect the rainwater. Very small areas of roof can be drained without a gutter by projecting the roof beyond the cladding, allowing the rainwater to be thrown clear of the cladding and avoiding staining of the wall below. The effect of throwing water clear of the building needs to be integrated within the overall design.

Profiled metal cladding is most commonly used in large single storey buildings such as factories or warehouses where it spans vertically from ground to roof without the need for additional support. This makes it a very economical solution for enclosing these building types. Although profiled metal cladding is used mainly for industrial buildings in conjunction with a portal frame in either steel or concrete, it provides an economic cladding system for larger framed structures.

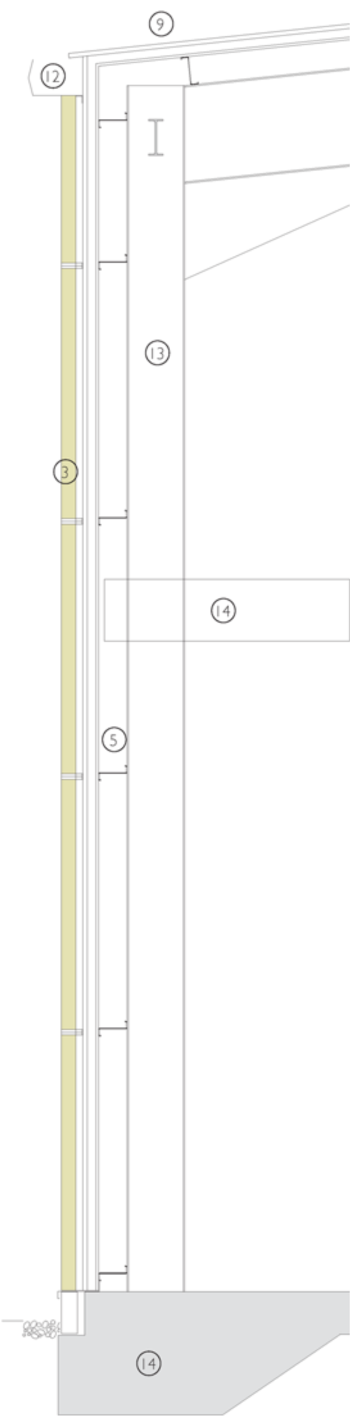
The material can be set either vertically or horizontally to suit the design.

Horizontally-set cladding is used where its strong horizontal lines are used for linear emphasis. Like vertically-set cladding, the profiled sheet is supported at 3.0 to 5.0 metre (10ft to 16ft 6in) centres by posts or structural columns. This direction allows the material to enclose a building with a curved section. A useful aspect of profiled metal sheeting is its ability to be curved in one direction. This makes it an ideal cladding material for buildings with a curved vertical section. Slight irregularities in the surface finish or setting out of the curve are concealed by the profile itself. Polished stainless steel has been used for horizontally-set cladding in public buildings where its high cost is balanced by longer durability than coated aluminium or coated mild steel types.

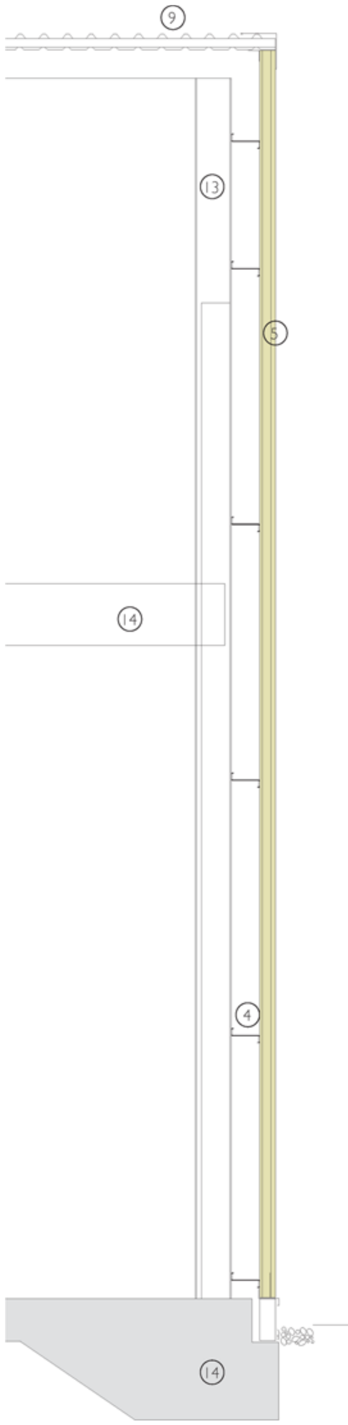
Vertically-set sheeting has horizontal cladding rails at 3.0 metre to 5.0 metre (10ft to 16ft 6in) centres, depending on the floor height. In buildings of more than one storey, an inner lining to the wall is usually added since the gap created between the cladding and the floor slab is difficult to seal economically at floor level in a way that will allow people to walk on it. The additional inner lining may extend up to 1.0 metres (3ft 3in) above the finished floor level and may be either a metal lining tray forming part of the proprietary cladding system, or be a concrete blockwork wall around 100mm (4in) thick. A smoke seal or fire barrier may be required between the floors enclosed by the cladding but this is very much dependent upon its particular application. Although horizontal rails can be set at wide centres, additional rails may be needed either to accommodate windows and doors or to increase the stiffness of the wall without using a much deeper profile, which would also increase stiffness.

Junctions

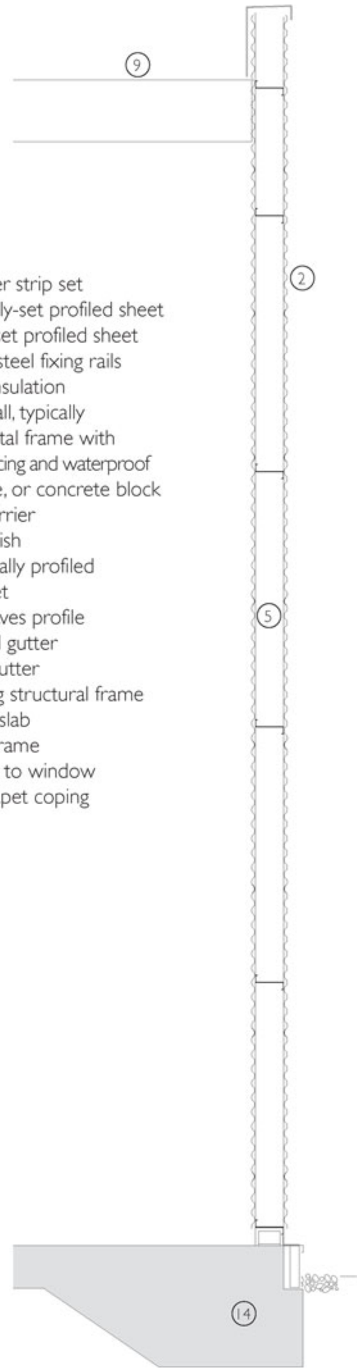
When laid vertically, sheets are joined by lapping them by around 150mm (6in) at vertical joints. Horizontal joints are also lapped with



Vertical section 1:25. Vertically set profiled metal cladding with gutter



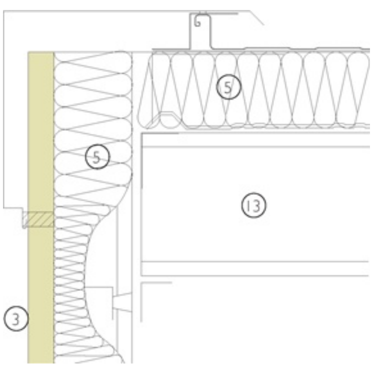
Vertical section 1:25. Vertically set profiled metal cladding with gable end



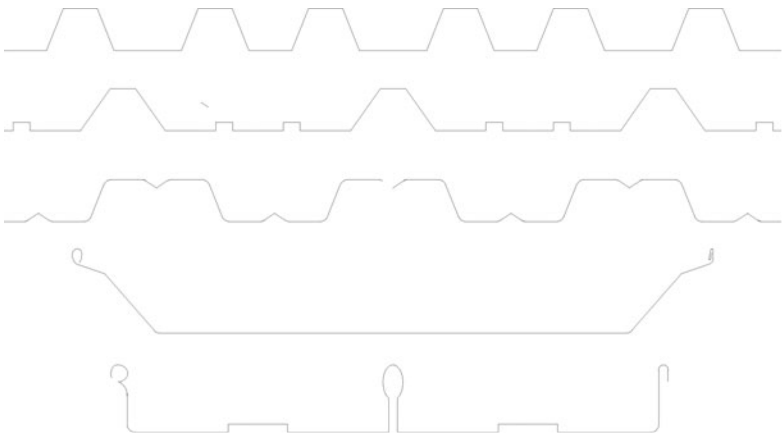
Vertical section 1:25. Horizontally set profiled metal cladding with parapet

Details

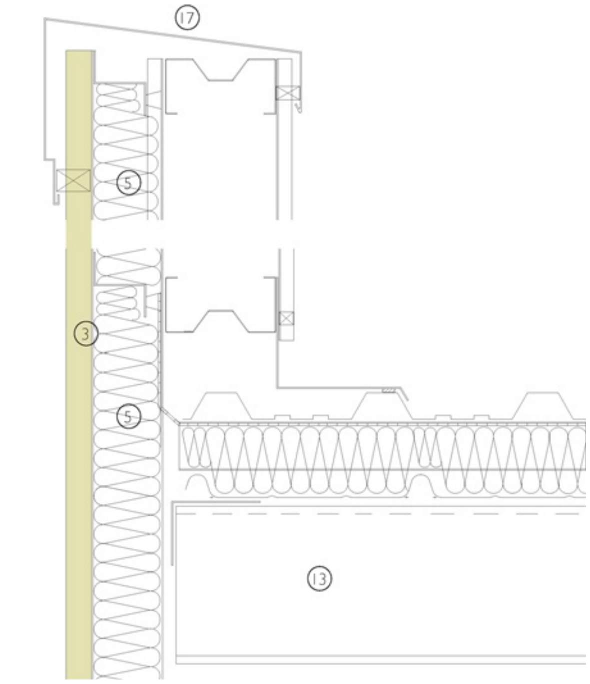
1. Metal cover strip set
2. Horizontally-set profiled sheet
3. Vertically-set profiled sheet
4. Z section steel fixing rails
5. Thermal insulation
6. Backing wall, typically timber/metal frame with plywood facing and waterproof membrane, or concrete block
7. Vapour barrier
8. Internal finish
9. Roof, typically profiled metal sheet
10. Curved eaves profile
11. Concealed gutter
12. Exposed gutter
13. Supporting structural frame
14. Structural slab
15. Window frame
16. Metal trim to window
17. Metal parapet coping



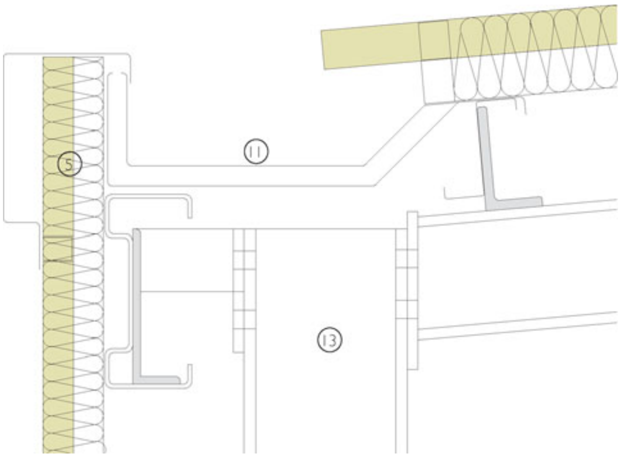
Vertical section 1:10. Roof junction at gable end



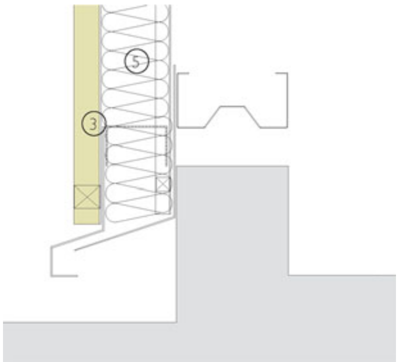
Typical profiled sheet profiles



Vertical section 1:10. Parapet detail

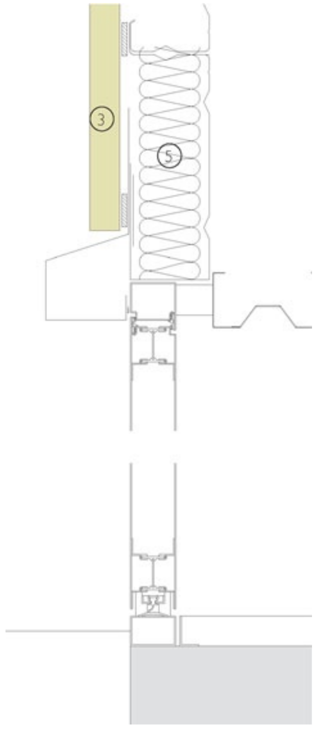


Vertical section 1:10. Gutter detail for large span enclosure



Vertical section 1:10. Ground level cill detail

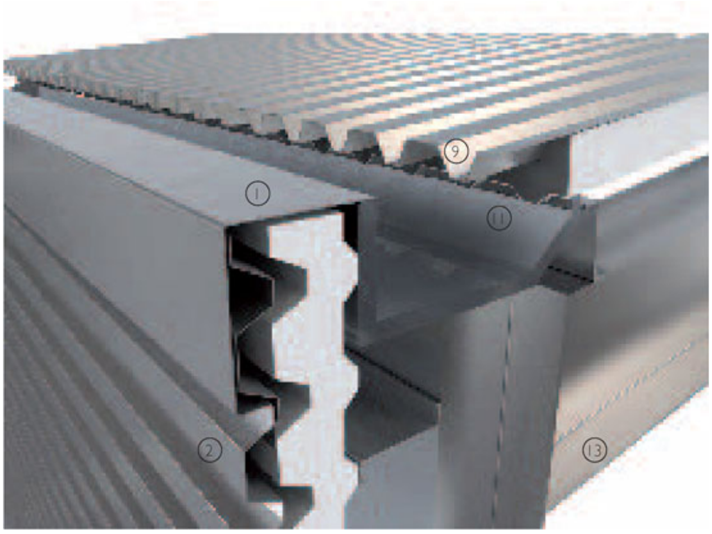
3-D view of profiled metal sheet as roof material



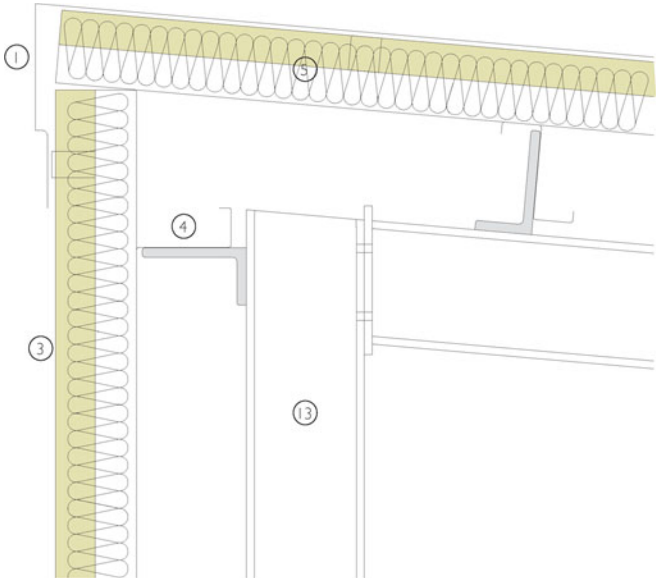
Vertical section 1:10. Metal door detail

the upper sheet set over the lower one in the traditional manner. When laid horizontally, horizontal joints are formed with laps as when laid vertically, but horizontal joints are not usually lapped in the same way. This is mainly because it is difficult to form a continuous straight line in a joint that moves in and out with the shape of the profile. Instead a recessed top hat section or projecting coverplate is used. The profiled sheet is butted up to the C-shaped section and sealed with silicone or mastic. The same principle is used for a projecting coverplate.

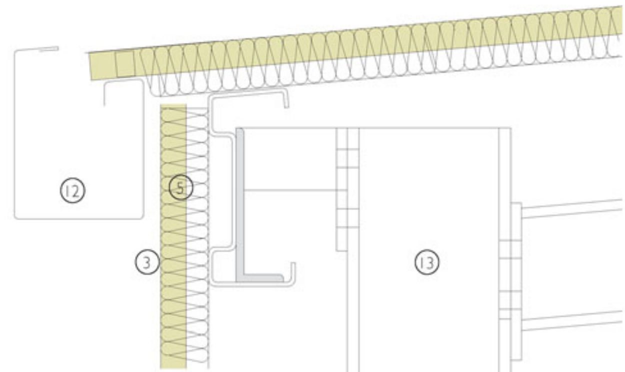
Corners are treated in a similar way. Corners to vertically- and horizontally-set cladding use projecting or recessed coverstrips. The profiled sheets that meet are lapped however, to provide a weathertight seal and the coverplate, provides both an additional seal along a potentially vulnerable joint as well as a crisp line to the corner. Regardless of sheet orientation, edging and jointing pieces are clearly visible, making them an important part of the design. Whereas profiled sheet can be lapped to give a continuous appearance on a large area of facade, the edging and jointing pieces of parapets, cills and corners are clearly visible. The visual impact of these junctions can be reduced with recessed joints. The use of curved eaves sheets and curved (in plan) corner sheets was developed to avoid the need for visible corner pieces. 90° corner sheets are now available, from some manufacturers, that can be lapped smoothly over adjacent profiled metal sheets.



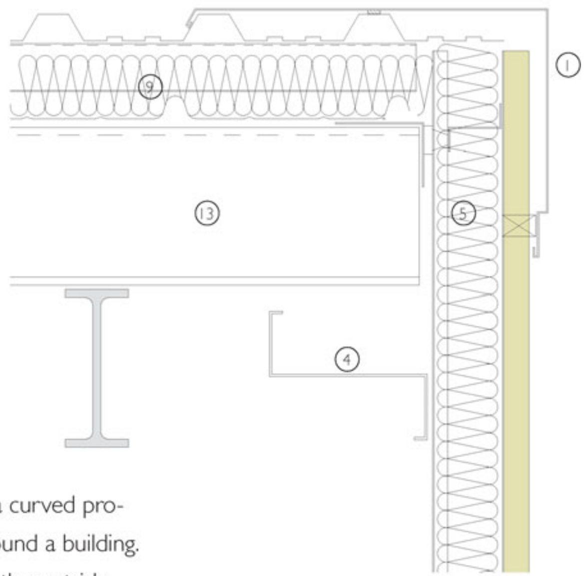
3-D view of gutter at connection between profiled metal wall and roof system



Vertical section 1:10. Sloping roof junction at gable end



Vertical section 1:10. Gable end with external metal gutter



Vertical section 1:10. Roof junction at gable end

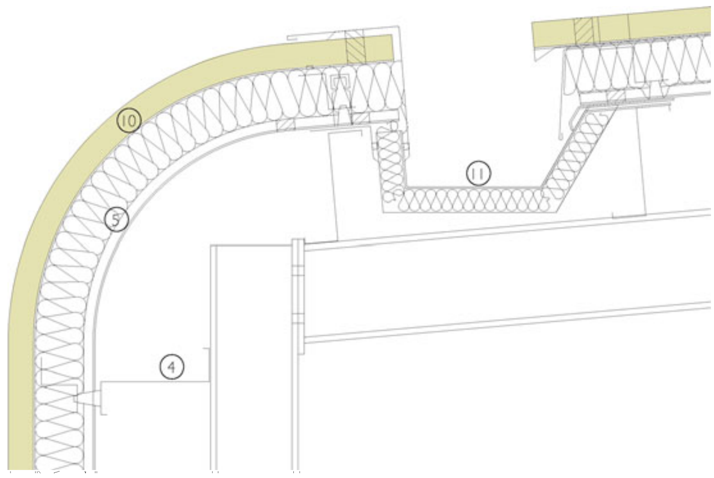
Parapets and gutters

Parapets are usually formed by either projecting the profiled sheet above the roof line in order to conceal the roof completely, which is often in the same material in the case of industrial buildings. Alternatively, a low parapet is formed at the level of the intersection of wall and roof, with a recessed gutter set immediately behind the parapet. A variation on this latter solution is to use curved eaves to give the idea of complete continuity between walls and roof with only a recessed gutter creating a line between the two. The recessed gutter in any of these configurations is useful when a pitched roof is used. On the gable elevation the parapet can remain the same height while the roof rises and falls independently of the continuing line of the parapet on all sides. Curved eaves have mitred corner panels to allow a curved profile to be used continuously around a building.

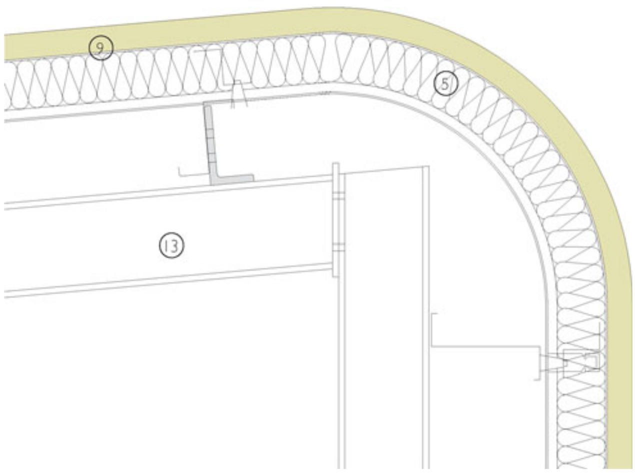
Visible gutters are fixed on the outside face of the cladding. The roof projects over the top of the cladding in order to drain rainwater into the gutter, resulting in the roof visually projecting forward of the wall, unlike a parapet gutter. An advantage of this method is that rainwater is kept outside the building, avoiding the need to run vertical rainwater pipes within a building, then running rainwater back out through the foundations below ground level. Since gutters are needed only at the base of roof slopes, gutters are often not needed on all facades, giving an uneven appearance to the building. A solution to making gutters work on all facades is to design a hipped roof that drains equally into all gutters, but this can complicate roof

Details

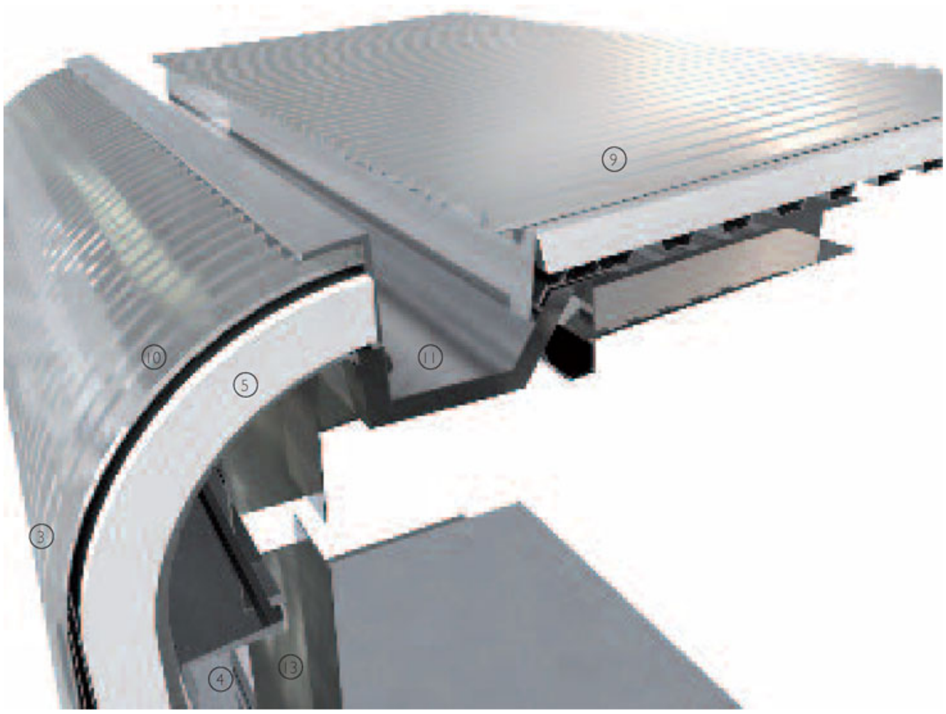
1. Metal cover strip set
2. Horizontally-set profiled sheet
3. Vertically-set profiled sheet
4. Z section steel fixing rails
5. Thermal insulation
6. Backing wall, typically timber/metal frame with plywood facing and waterproof membrane, or concrete block
7. Vapour barrier
8. Internal finish
9. Roof, typically profiled metal sheet
10. Curved eaves profile
11. Concealed gutter
12. Exposed gutter



Vertical section 1:10. Curved eaves with hidden gutter



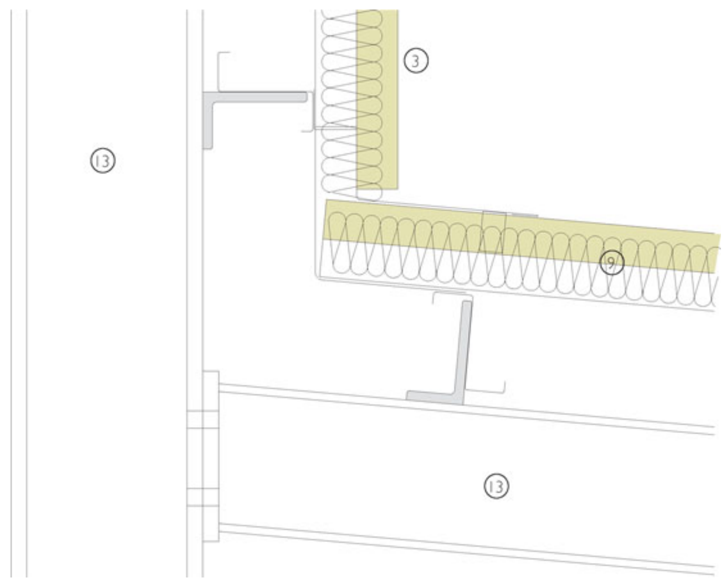
Vertical section 1:10. Curved eaves without gutter



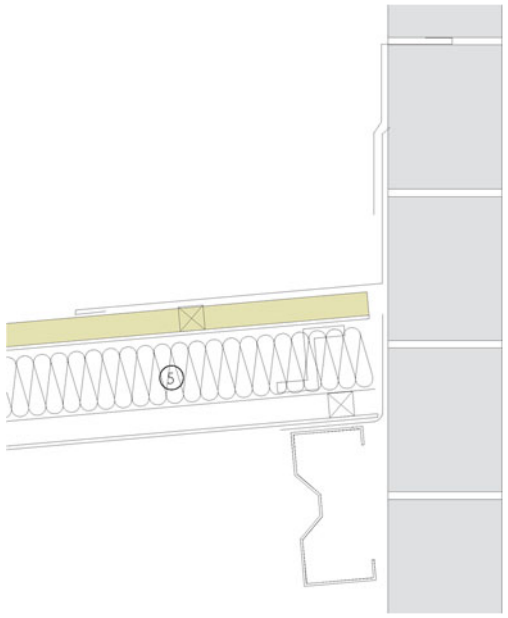
3-D view of curved eaves connection with hidden gutter

Details

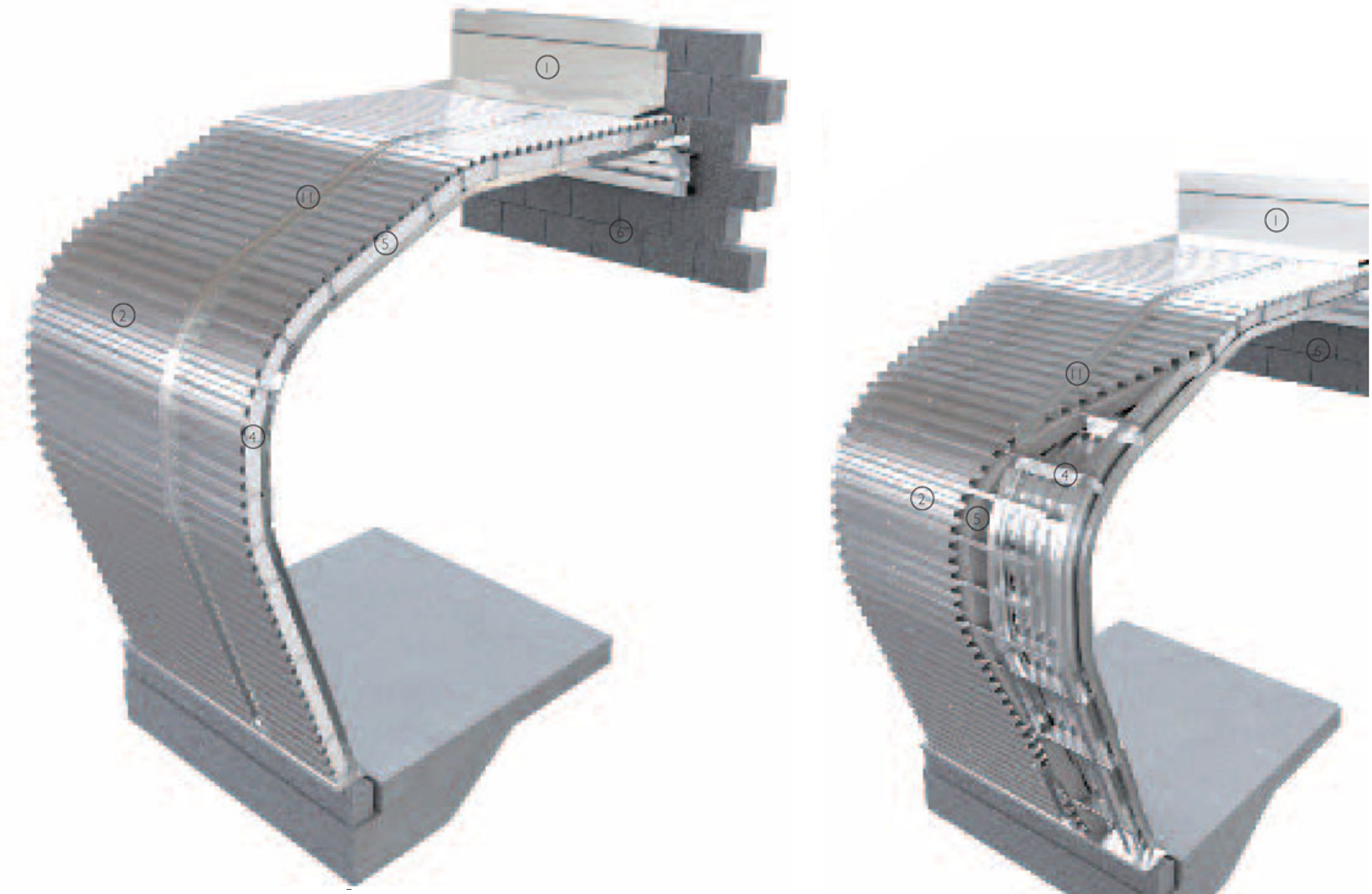
1. Metal cover strip set
2. Horizontally-set profiled sheet
3. Vertically-set profiled sheet
4. Z section steel fixing rails
5. Thermal insulation
6. Backing wall, typically timber/metal frame with plywood facing and waterproof membrane, or concrete block
7. Vapour barrier
8. Internal finish
9. Roof, typically profiled metal sheet
10. Curved eaves profile
11. Concealed gutter
12. Exposed gutter
13. Supporting structural frame
14. Structural slab
15. Window frame
16. Metal trim to window
17. Metal parapet coping



Vertical section 1:10. Junction with roof



Vertical section 1:10. Roof junction at abutting wall



3-D view and cut-away of profiled metal sheet assembly with gutter

design. Gutters require support by brackets back to primary structure in order to support the weight of water when in use. The supporting brackets usually need to penetrate the cladding, requiring seals around the penetrations in order to make them weathertight. If the roof construction is required to be ventilated then the depth of the gutter will increase if the roof is intended to be hidden from view. Deep gutters have a strong visual presence on the facade.

Window and door openings

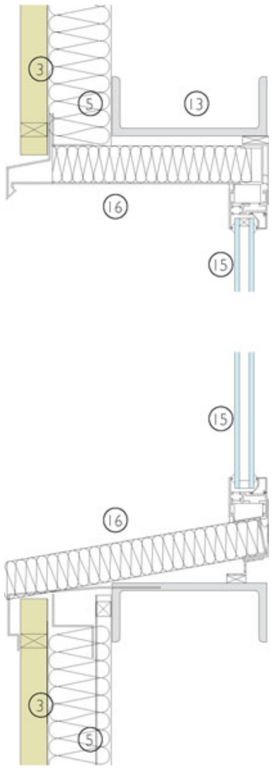
The reveals for windows and doors are formed in flat metal sheet, usually the same metal and same colour as the profiled sheeting. In practice the colour matching can be difficult if the coating (usually polyester powder coating or PVDF) is applied in different workshops or by different coating applicators. Contrasting colours are sometimes chosen for this reason. This is also true of window sections, which are usually supplied predated by a different manufacturer. Close co-ordination is needed between contractors to ensure a consistent colour throughout the project. An alternative approach is to reduce reveals to a small depth and use a colour for the windows different from that of the adjacent cladding. For example, with a silver metallic finish for cladding, a darker grey might be used for window frames without creating any contrast between the two colours used.

Cills are formed in pressed metal which is inclined to drain water from its horizontal surface and has a projecting drip to avoid dirt, washed off the cill, running onto the cladding below, which would cause staining. Some drips have rising edges at the sides to avoid water running off at the sides that causes streaking in lines below the edges of the openings. Cills at ground level or at the base of the cladding are either flush or projecting, to suit visual requirements. As with sheet metal cladding, the cill is usually reinforced both to ensure it lies in a straight line and protect it from accidental damage.

Insulation and liner trays

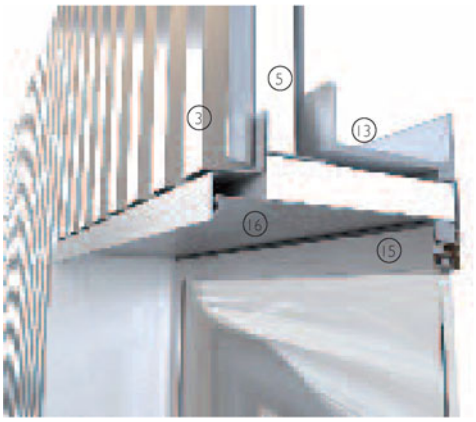
Although profiled metal sheet is capable of long vertical spans, the thermal insulation and internal finish material require additional support. The insulation cannot be fixed directly to the metal sheet without being bonded to it. Fixing brackets to the profiled sheet would involve penetrating the sheet, creating a possible point for water ingress. Welding a support bracket would be both expensive and easily distort the surface of the cladding. Bonding the insulation to the liner would be the next practical method, but this is done as a composite panel, which has constraints and is dealt with in the next section.

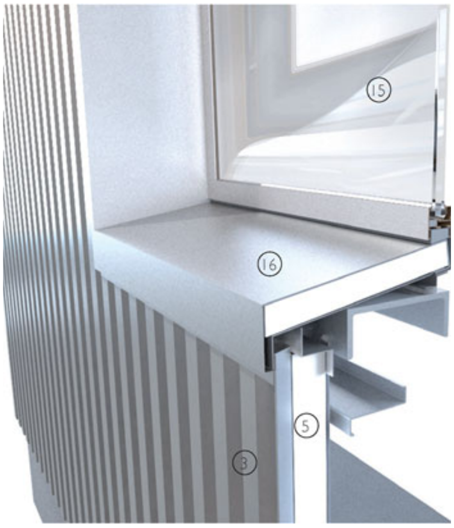
Flexible insulation quilt is fixed to intermediary sheeting rails that are also used to support an inner metal lining sheet. Sheeting rails are made from pressed steel sections. Since the lining sheets are usually flat, to create a smooth finish within the building, they do not span very far and require sheeting rails set at close centres. The rails can be used to give additional rigidity to the outer profiled sheet, but this requires penetrating the sheet



Vertical section 1:10. Aluminium window recessed into profiled metal cladding system

3-D view of recessed aluminium window in profiled metal facade





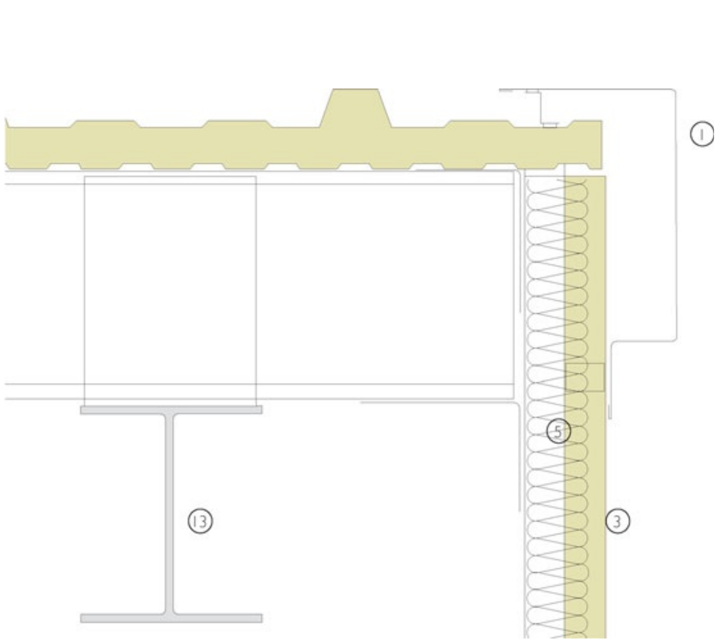
3-D views of head and cill details of recessed aluminium window in profiled metal facade

with screw fixings which are sealed from the outside with plastic caps and washers.

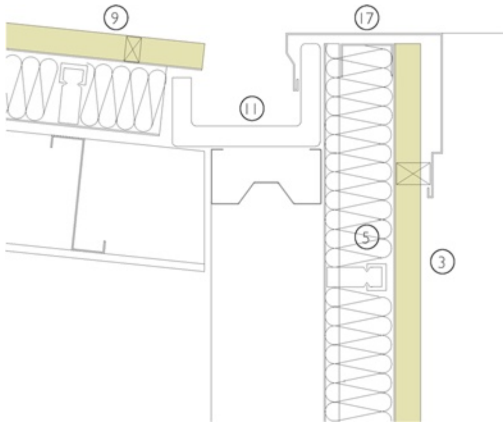
An inner lining tray can also be formed from the same metal profiled sheet, as used in warehouse buildings where a smooth inner wall finish is not needed. Some intermediary sheeting rails are still required to support the thermal insulation. A more economic form of lining wall that does not interfere with the outer profiled cladding is concrete blockwork. In this instance, closed cell thermal insulation is fixed to the outside face of the wall.

Developments

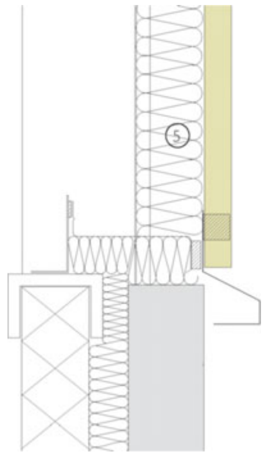
The range of profile types is steadily increasing, with wider, deeper profiles that were originally designed for use as roof decking being used as wall cladding. However, some of the interlocking types used on roofs are not suited to cladding since the standing seam joint, which is not designed to be tightly folded together, does not work when set in the vertical plane. This principle is also true of wall cladding types which are lapped and are not suited to use in roofs, where the seam is not high enough to be submerged under water during rain. A recent development has been the use of flat metal rainscreen panels fixed directly to a profiled sheet. This provides a smooth finish visually to the outside face of the cladding, while maintaining the economy and structural efficiency of the profiled sheet. Although the outer metal panel is fixed to the profiled sheet with screws or rivets that penetrate it, the pin jointed rainscreen configuration protects the fixings from the worst effects of windblown rain.



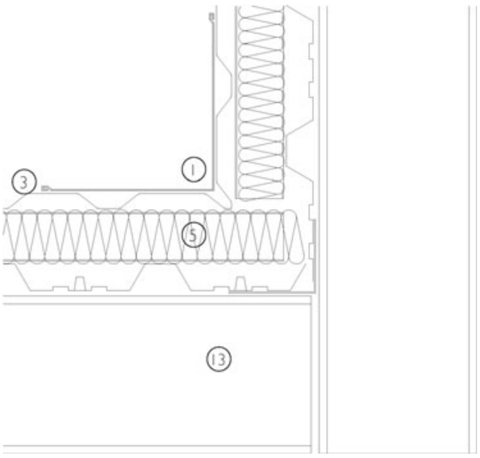
Vertical section 1:10. Roof connection to composite metal roof system



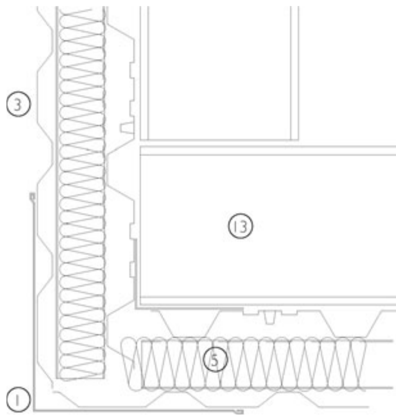
Vertical section 1:10. Gutter detail for small span enclosure



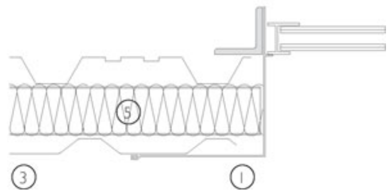
Vertical section 1:10. Cill connection to concrete upstand



Horizontal section 1:10. Internal corner



Horizontal section 1:10. External corner

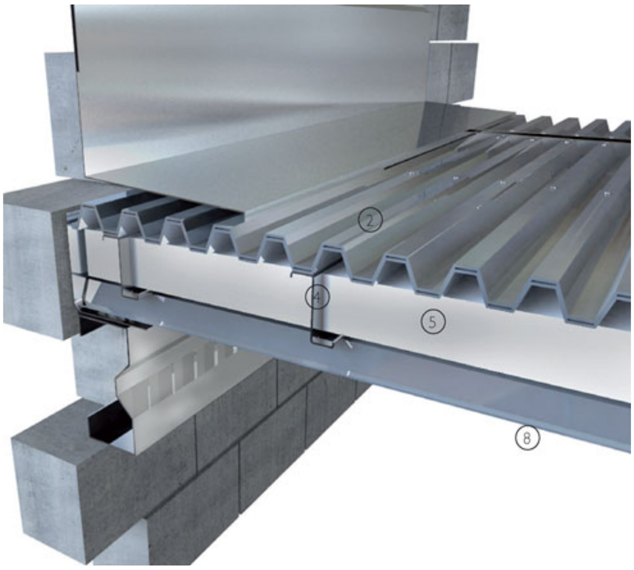


Horizontal section 1:10. Connection to metal door

3-D view of rear of recessed aluminium window in profiled metal facade

Details

1. Metal cover strip set
2. Horizontally-set profiled sheet
3. Vertically-set profiled sheet
4. Z section steel fixing rails
5. Thermal insulation
6. Backing wall, typically timber/metal frame with plywood facing and waterproof membrane, or concrete block
7. Vapour barrier
8. Internal finish
9. Roof, typically profiled metal sheet
10. Curved eaves profile
11. Concealed gutter
12. Exposed gutter
13. Supporting structural frame
14. Structural slab
15. Window frame
16. Metal trim to window
17. Metal parapet coping

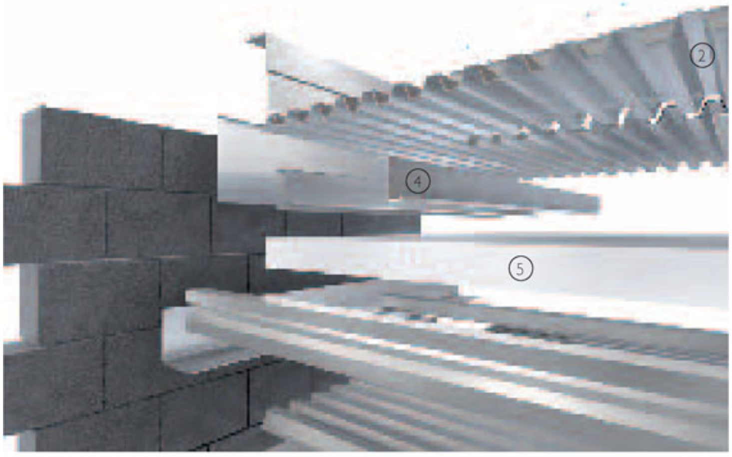


3-D detail view of profiled metal sheet connection to blockwork wall

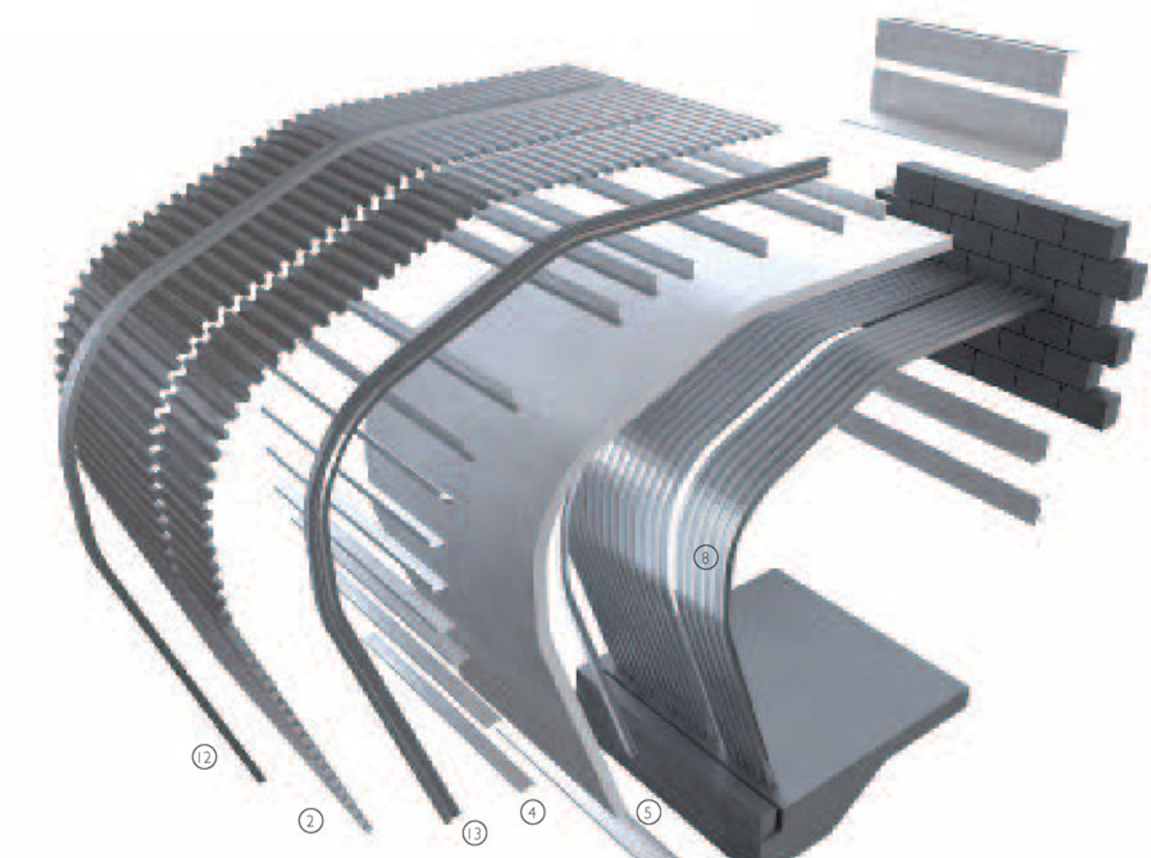
Details

1. Metal cover strip set
2. Horizontally-set profiled sheet
3. Vertically-set profiled sheet
4. Z section steel fixing rails
5. Thermal insulation
6. Backing wall, typically timber/metal frame with plywood facing and waterproof membrane, or concrete block
7. Vapour barrier
8. Internal finish
9. Roof, typically profiled metal sheet
10. Curved eaves profile
11. Concealed gutter
12. Exposed gutter
13. Supporting structural frame
14. Structural slab
15. Window frame
16. Metal trim to window
17. Metal parapet coping

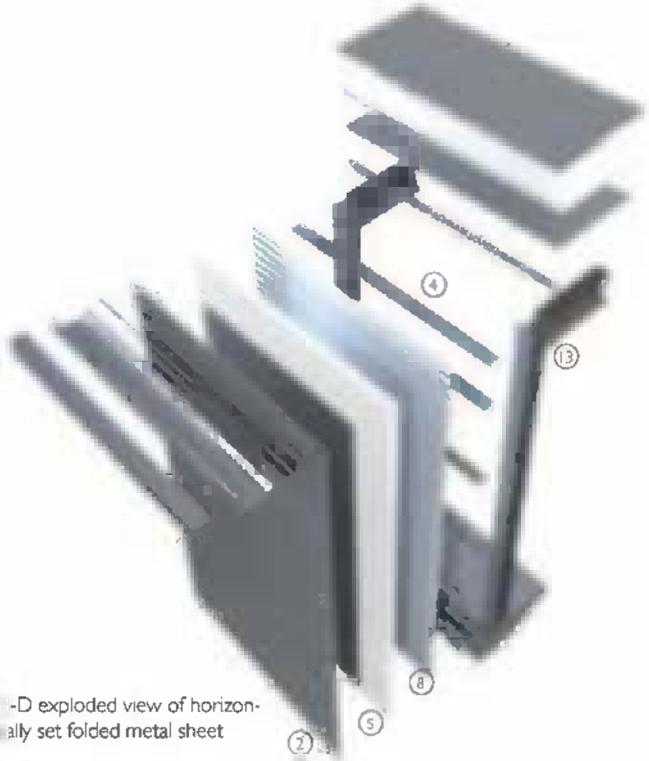
3-D detail view of profiled metal sheet with gutter



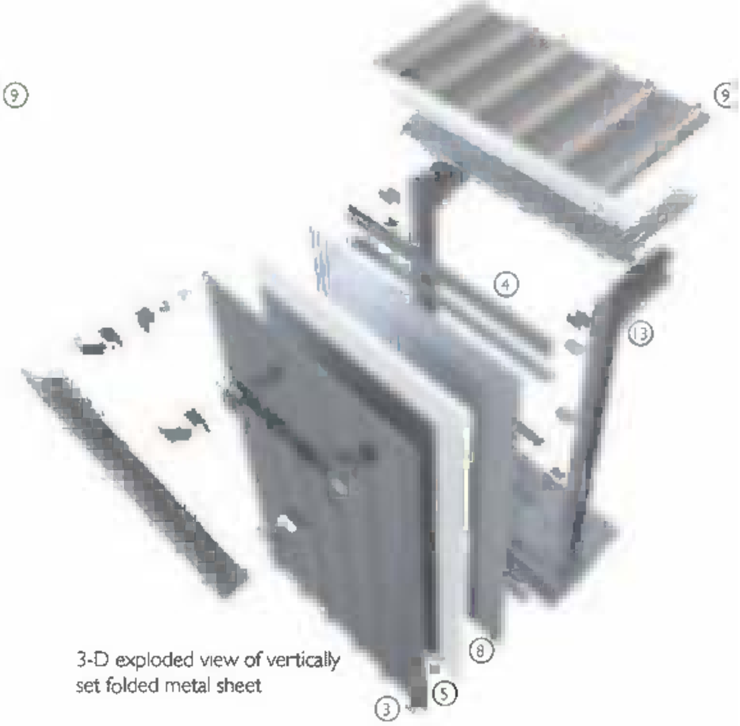
3-D exploded detail view of profiled metal sheet connection to blockwork wall



3-D exploded view of profiled metal sheet assembly with gutter



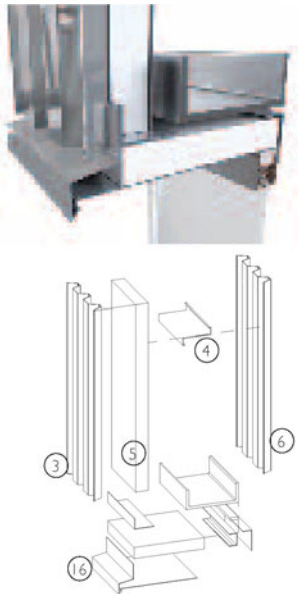
-D exploded view of horizon-
ally set folded metal sheet



3-D exploded view of vertically
set folded metal sheet

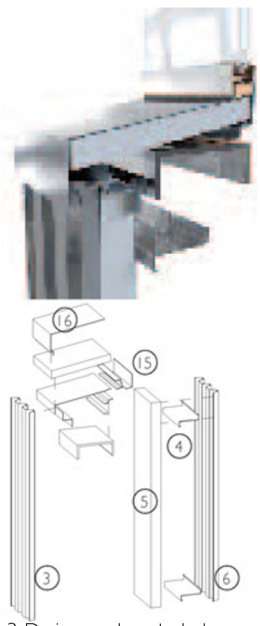
3-D view of recessed aluminium window in
profiled metal facade

3-D exploded view of recessed aluminium window in profiled metal facade

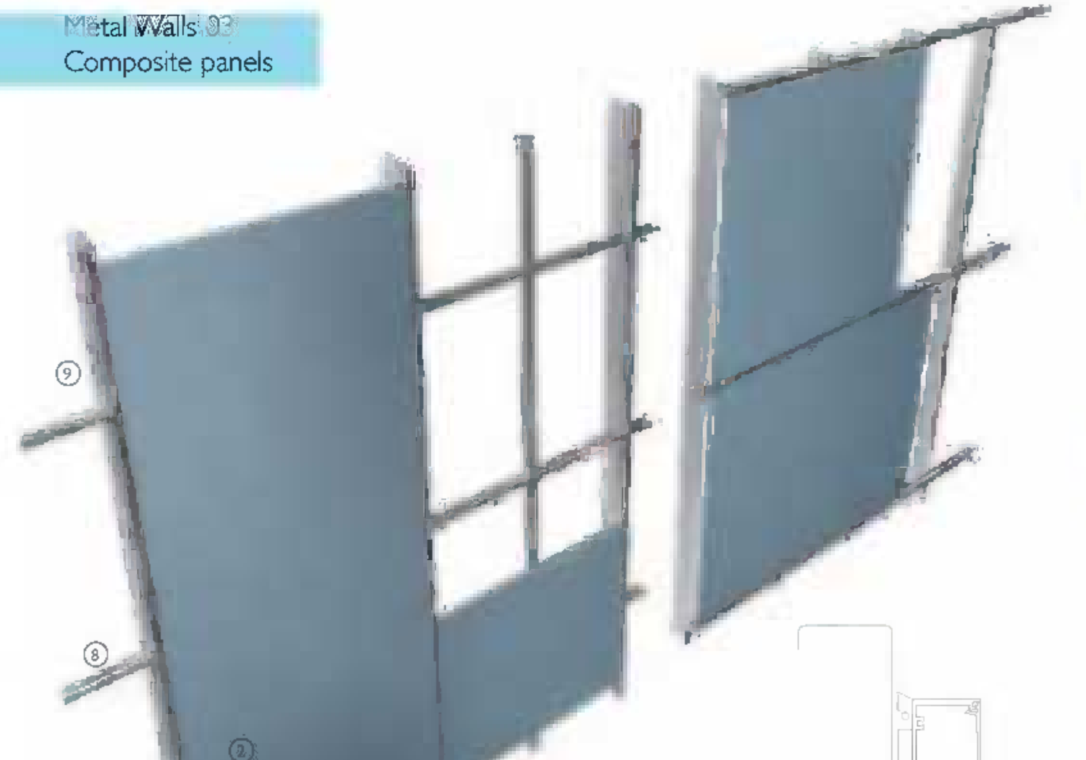


3-D view and exploded axono-
metric of window head detail

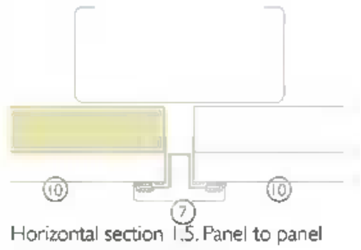
3-D section of recessed aluminium
window in profiled metal facade



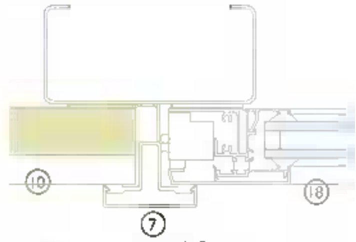
3-D view and exploded axono-
metric of window cill detail



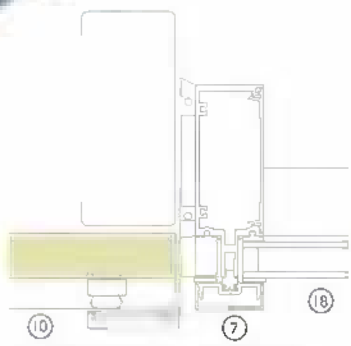
3-D view of composite panels fixed to aluminium supporting frame with interlocking joints on two sides with vertical (right) and horizontal (left) capping pieces



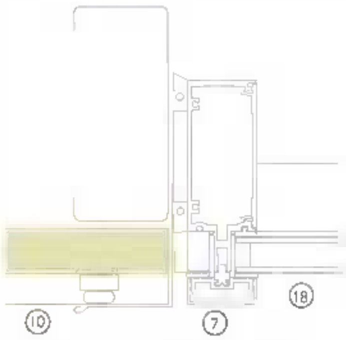
Horizontal section 1:5. Panel to panel connection with visible cap.



Horizontal section 1:5. Panel to window connection with visible cap



Horizontal section 1:5 Connection between composite panel and curtain wall type glazing with cap



Horizontal section 1:5. Connection between composite panel and curtain wall type glazing with metal flashing

Composite metal panels require fewer components than for the 'kit of parts' used in the assembly of profiled metal cladding. Like profiled metal, panels are set either vertically or horizontally. Some panels interlock on two sides, while others interlock on four sides. Four-sided panels require no separate interface components for jointing but it is more difficult later to remove a damaged panel.

Horizontally-set composite panels can be easily integrated with ribbon windows and suit building facades covering several floors. Panels are stacked one above the other with their vertical joints closed by rubber-based gaskets, recessed channel sections in aluminium, or projecting coverstrips in aluminium. Panels are fixed back to the primary structure or on a secondary steel frame, typically box sections, fixed to the sides of floor slabs if columns are spaced too far apart or columns are not positioned on the edge of floor slabs.

Where windows are used in a facade, additional support is needed to frame the opening. This is because windows are not supported by the composite panels except where made specifically as part of a proprietary system. In practice, windows are usually supplied by a specialist manufacturer.

The steel support framing is set on the face of the slab, making it easier to take up deflections in floor slabs. However, as is the case with curtain walling, the gap between composite panel and floor slab needs filling with a smoke seal or fire barrier. The floor finish usually has a metal angle to close off the gap at slab level and at the soffit level below. Four-sided interlocking panels use the same principle for fixing on all four sides. This also makes it easier to integrate windows within the system since a window panel is locked in like any other panel.

Vertically-set composite panels are more common in single storey applications, but multi-storey applications are used increasingly. Panels are interlocked at vertical joints, while horizontal joints are formed by using a cill-type detail similar to that used in a transition from vertical panel to low pitched roof. A cill in extruded or folded aluminium or steel (depending on which metal is used for the composite panel faces) is used. The front of the trim projects beyond the face of the cladding to throw water clear and prevent staining to panels below. The back of the drip projects up the back of the upper panel to prevent water from penetrating the joint. Panels are also supported on either an interlocking frame or occasionally they span between columns if panels are stiff enough to span unassisted. An additional method of fixing panels is to position them between floor slabs spanning from floor to ceiling when used as part of a rainscreen system. Panels sit on the floor slab with their outer face flush with the edge of the slab. The outer rainscreen is set forward of the composite panel, concealing both the panels and the edge of the floor slab.

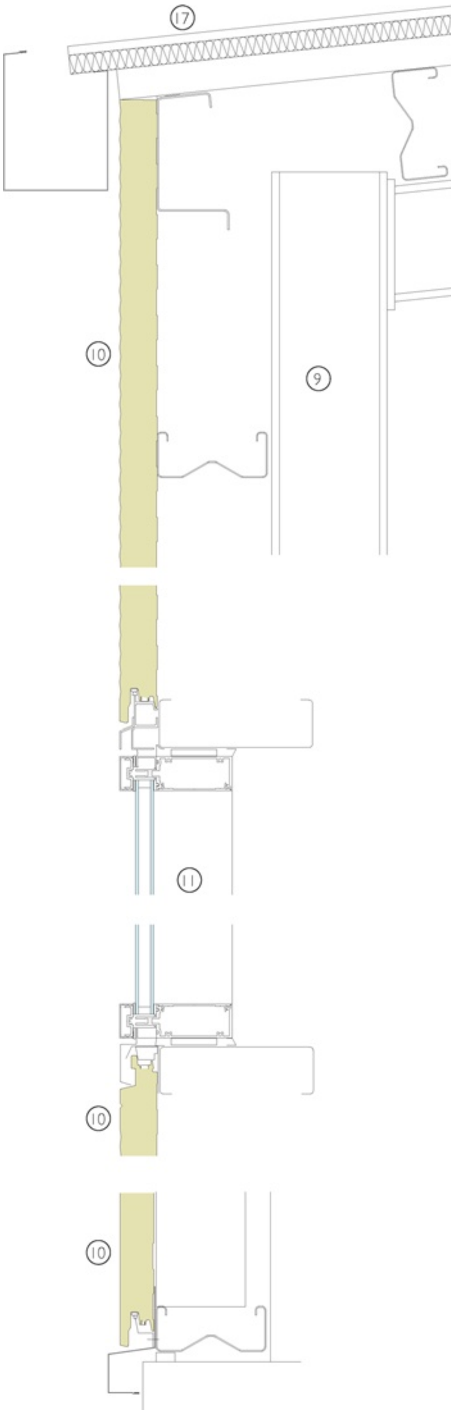
Interlocking vertically-set panels are of several types, unlike horizontally-set types, which have a stepped joint to avoid rainwater penetration. The most common type for vertical joints is also a stepped joint with a recess on the outer face. An alternative is to have projecting nibs on the sides of the panel to which a coverplate is fixed over the gap between the two panels. Rubber-based seals

3-D view of framework supporting composite panels interlocking horizontally with vertical capping piece

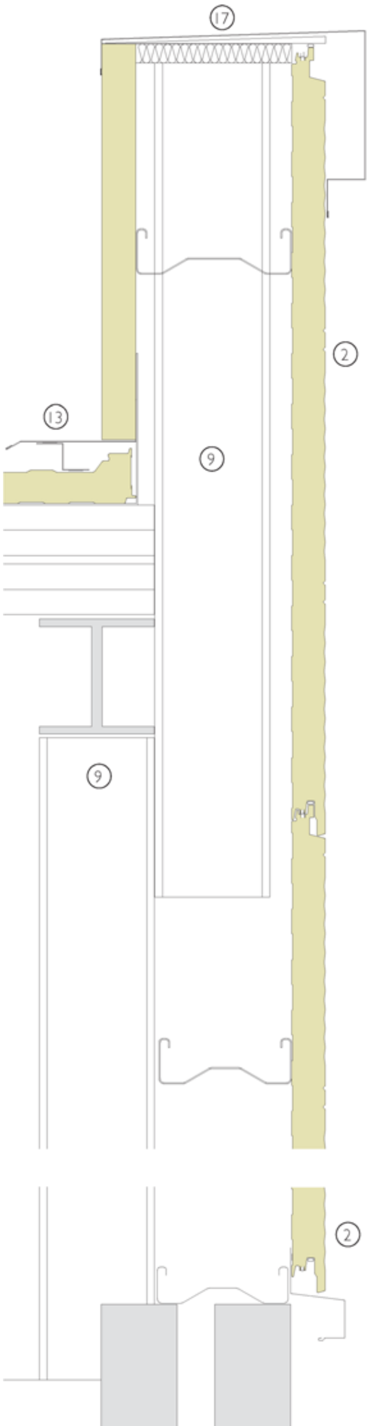
3-D view of framework supporting composite panels interlocking horizontally with vertical capping piece

Details

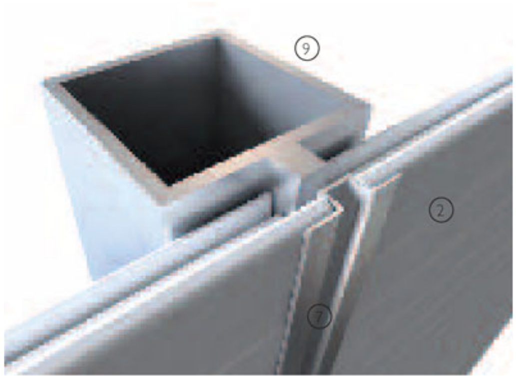
1. Vertically-set composite panel
2. Horizontally-set composite panel
3. Silicone-based seal
4. Outer metal facing
5. Inner metal facing
6. Inner insulation core
7. Metal capping
8. Concealed fixing
9. Supporting structure
10. 4-way interlocking composite panel
11. Window frame
12. Sectional roller shutter formed from composite panels
13. Roof construction, composite panels are shown
14. Metal trim
15. Exposed gutter
16. Concealed gutter
17. Metal parapet coping
18. Stick glazed curtain walling
19. Door frame



Vertical section 1:10. Parapet and cill with curtain walling type window set into cladding. Typical in industrial applications



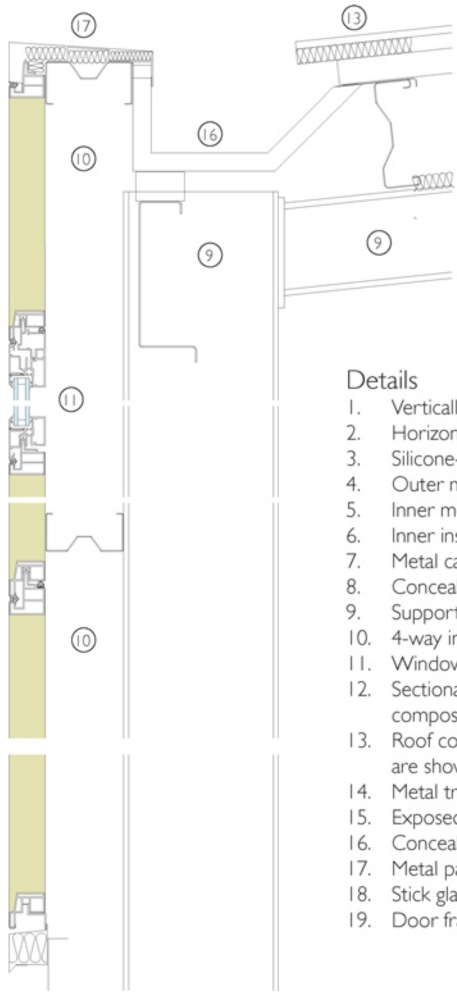
Vertical section 1:10. Parapet and ground level cill



3-D view of profiled composite panel fixed to steel supporting structure with vertical capping piece

3-D view of horizontal interlocking joint between profiled composite metal panels

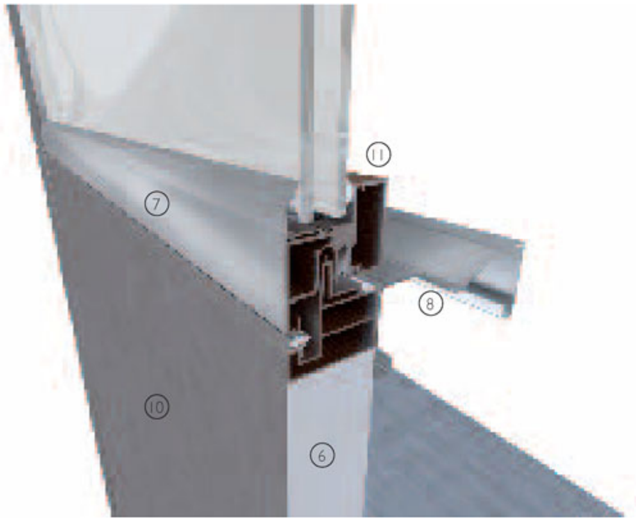
3-D view of concealed gutter detail



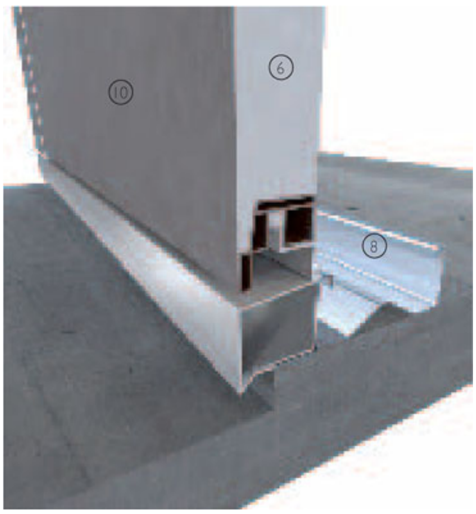
Details

1. Vertically-set composite panel
2. Horizontally-set composite panel
3. Silicone-based seal
4. Outer metal facing
5. Inner metal facing
6. Inner insulation core
7. Metal capping
8. Concealed fixing
9. Supporting structure
10. 4-way interlocking composite panel
11. Window frame
12. Sectional roller shutter formed from composite panels
13. Roof construction, composite panels are shown
14. Metal trim
15. Exposed gutter
16. Concealed gutter
17. Metal parapet coping
18. Stick glazed curtain walling
19. Door frame

Vertical section 1:10. Junction with roof including concealed gutter. Integrated windows flush with face of composite panels



3-D view of junction with window frame



3-D view of junction with ground slab

are set into the depths of all these joint types. Another joint is a C-shaped channel profile which interlocks with the profile of the adjacent panel. The outside face of the panel has a slightly projecting edge instead of a recessed joint in the stepped joint types.

All these panel types use jointing methods that avoid thermal bridges. Drips often penetrate from outside but the low condensation risk is assessed during the design stage.

Parapets and cills

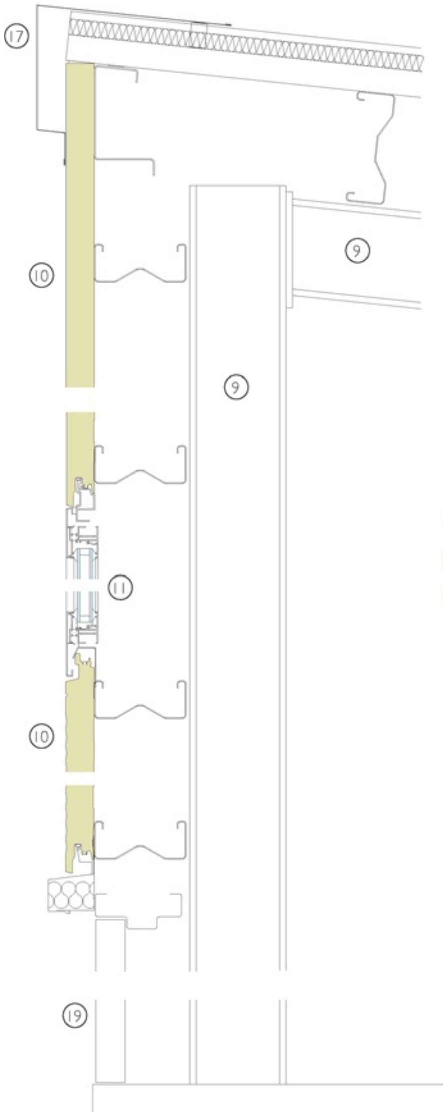
Parapet copings and drips at ground level can also be made as composite panels, forming an integrated part of a proprietary system. This can be an advantage when seeking a seamless effect across a facade, but sets limitations on the variety of junctions (in terms of width and height) at parapet and base due to the need for repetition in specially made panels. A large number of different panel types cannot be produced economically for a single project. Although folded metal flashings and extrusions can appear more visually intrusive than a specially made composite panel, this method is far more flexible for dealing with varied parapet and ground level junctions, particularly for complex junctions.

Like fully supported sheet metal facades, parapets can be set either level with the roof, to create a continuous smooth envelope, or be stepped to allow the roof profile to be concealed. The same principles apply as those for continuously supported sheet metal parapets and cills.

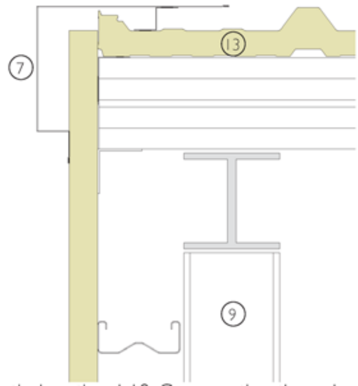
Windows and door openings

There are two methods of creating an opening in a composite panel for both horizontally- and vertically-set panels. The first method

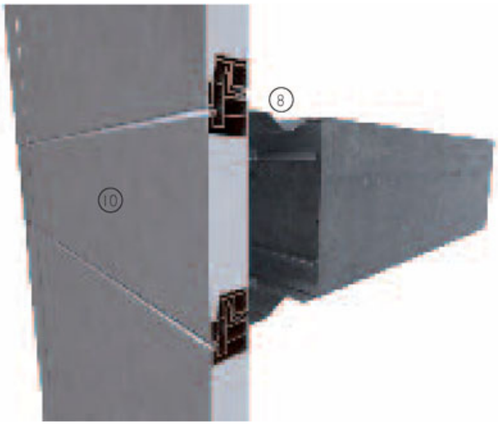
3-D view of composite panel facade assembly with flush glazing and concealed parapet



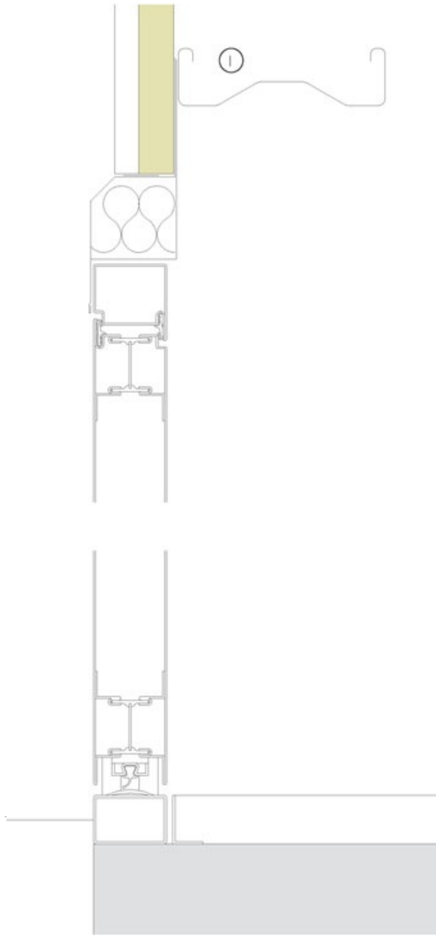
Vertical section 1:10. Integrated parapet, window and doors all flush with face of composite panels.



Vertical section 1:10. Cross section through roof with integrated parapet



3-D view of spandrel panel connection

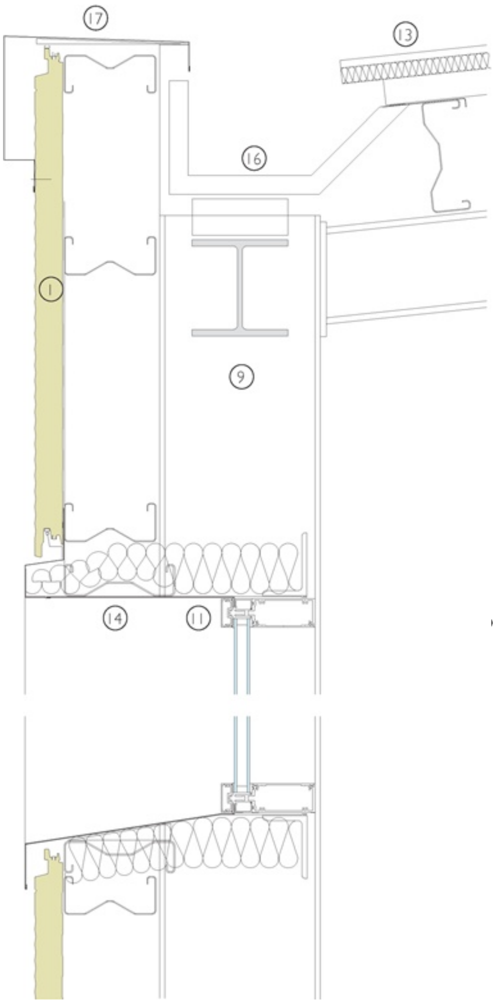


Vertical section 1:5. Metal door set flush with face of composite metal panel

is a special reveal panel that interlocks with the composite panels. With vertically-set panels the window interlocks into vertical joints and has coverstrips on horizontal joints. Where horizontally-set panels are used, the window interlocks with the horizontal joints and has coverstrips applied on the vertical joints. The second method is to use metal sheet to form a reveal. A single sheet of metal, 1200 or 1500mm wide coil (4ft or 5ft), is fixed to a light gauge steel frame which is insulated. The inner framed wall has a vapour barrier and an inner metal sheet, usually matching the adjacent inner face of the panels.

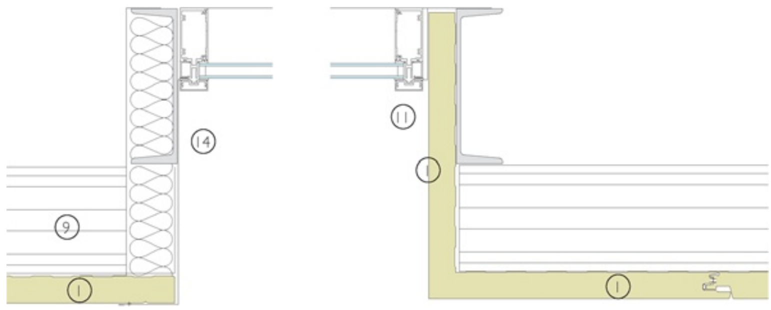
Heads and cills of openings are formed in the same way with either a purpose-made corner panel (the cill is an inclined surface) or with sheet metal and thermal insulation. However, the lightweight metal frame is not usually fixed back to the composite in order to avoid penetrating either outer or inner face of the panels. Instead it is fixed back to a floor slab or to the primary structure.

Since the inclusion of reveals is not really in the nature of composite panel detailing, and the wall has little depth, the additional frame is also used to support the window, typically aluminium framed with a thermal break and double glazed units. More often, windows and doors are fixed with the outer face of the glass or door aligned with the outer face of the adjacent composite panels. An alternative form of glazing to windows and doors is to use curtain walling. Thermally broken stick systems are fixed directly against the adjacent composite panels with a seal set against the primary structure forming the opening (typically vertical sheeting rails). If horizontally-set panels are used, then the curtain walling can be sealed against adjacent



Vertical section 1:10. Parapet with concealed gutter and curtain wall type window recessed with deep metal reveal.

views of composite panel curtain wall with recessed window with deep metal reveal, with cill and gutter detail



Horizontal section 1:10. Door jamb with metal sheet forming panel in door reveal.

Details

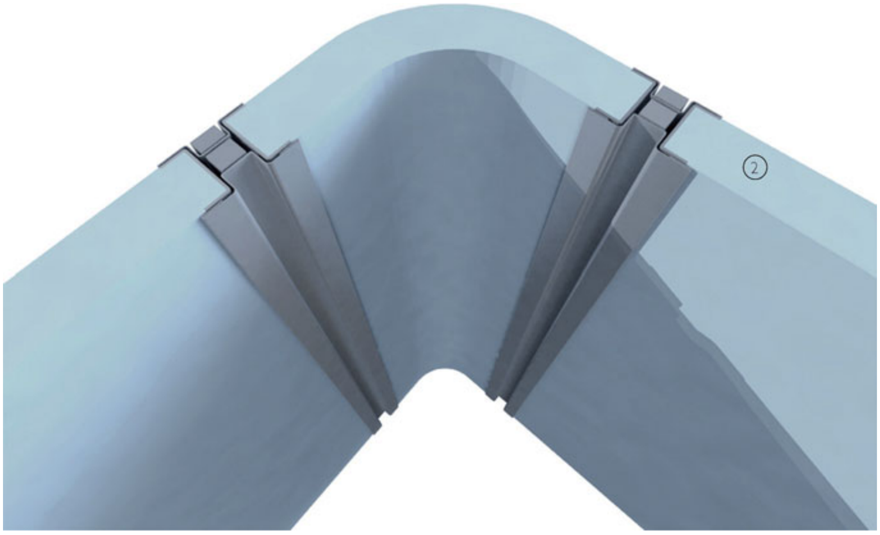
1. Vertically-set composite panel
2. Horizontally-set composite panel
3. Silicone-based seal
4. Outer metal facing
5. Inner metal facing
6. Inner insulation core
7. Metal capping
8. Concealed fixing
9. Supporting structure
10. 4-way interlocking composite panel
11. Window frame
12. Sectional roller shutter formed from composite panels
13. Roof construction, composite panels are shown
14. Metal trim
15. Exposed gutter
16. Concealed gutter
17. Metal parapet coping
18. Stick glazed curtain walling
19. Door frame

composite panels with a vertical cover strip used for all vertical joints.

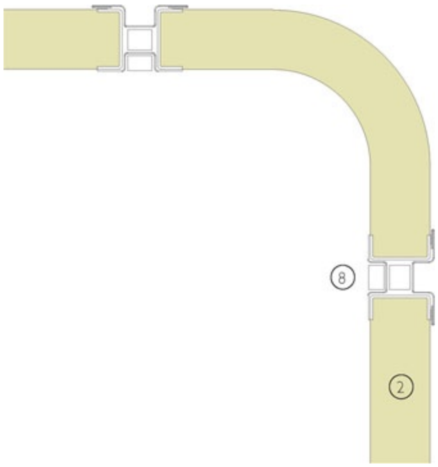
Where many windows are required at a particular height on a facade, as when providing light into an upper floor, it is common to create a continuous ribbon of windows to avoid small infills of composite panels between windows. The continuous line of windows is fixed back to a secondary frame of steel box sections, which may be exposed in the building or be concealed behind an inner finish such as a plasterboard lining. Continuous windows can also be glazed into horizontally-set panels interlocking on two sides, or four-sided panels. This can avoid the need for additional support framing. In this instance the windows are braced back in the same way as the composite panels.

Developments

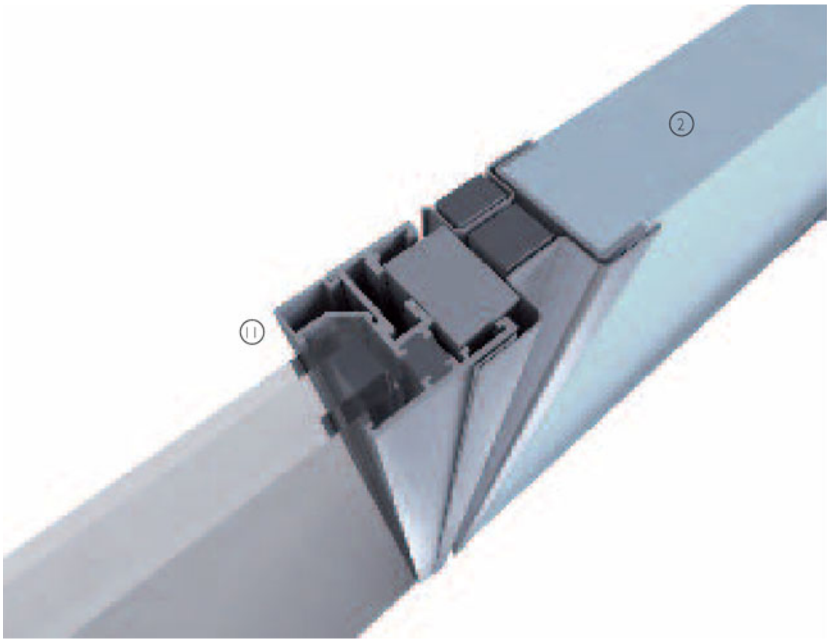
The use of composite metal panels is increasing into building types beyond industrial buildings, into office buildings and sports facilities. In the case of office buildings, they provide an economic spandrel panel where curtain walling is not always effective. In sports facilities, composite panels enclose large indoor spaces with a durable, crisply-made and relatively economic cladding system. Although the appearance of the external face is smooth and gridded, the supporting structure is visible and usually set on the inside face to avoid penetrations to the outside through the joints between panels. If the exposed structure is enclosed with an economic lining wall concealing the structure, this additional element can add considerable cost



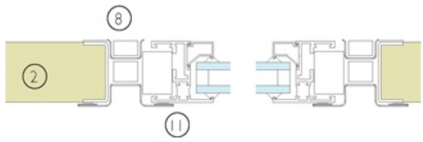
3-D view of curved internal corner panel with partially interlocking joints



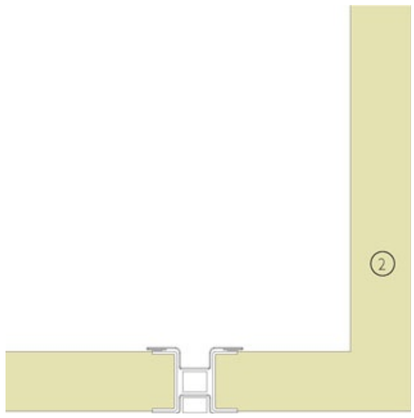
Horizontal section 1:5. Partially interlocking curved internal corner



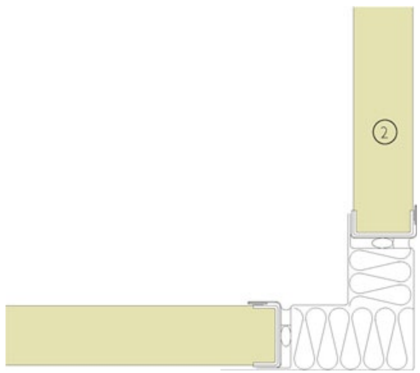
3-D view of partially interlocking joint between composite panel and window



Horizontal section 1:5. Partially interlocking connection between composite metal panel and window



Horizontal section 1:5. Partially interlocking external corner



Horizontal section 1:5. Insulated corner connection detail

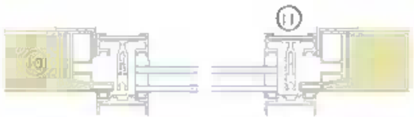
to the cladding, making it much less economic.

For this reason, supporting structure that is designed to be seen, such as tubular steel posts, is increasingly used. The composite panels span between steel posts or trusses with little or no interlocking supporting structure. In order to keep the supporting structure as visually elegant as possible, trusses or posts are spaced as far apart as possible. This has led to panels getting longer, with a maximum length currently around 15 metres (49ft). Some proprietary systems include edges to panels which are deeper, making the continuous vertical joints and horizontal joints more rigid, allowing them to span greater distances, and thus reducing the amount of visible supporting structure needed.

Increasingly, window openings need not be dictated by the direction in which panels are laid. Horizontally-set panels do not have windows arranged horizontally. Transitions between window openings and composite panels are becoming more economic with standard extrusions and rubber-based seals. This is ever-more the case with four-sided, interlocking panels, where window panels and metal panels are fixed in the same way. Increasingly, irregular facade grids are being developed in designs to create a richer mix of panel sizes in visual patchwork of different sizes of panels.

Horizontal section 1:5. Joint between composite panels with fully interlocking connection

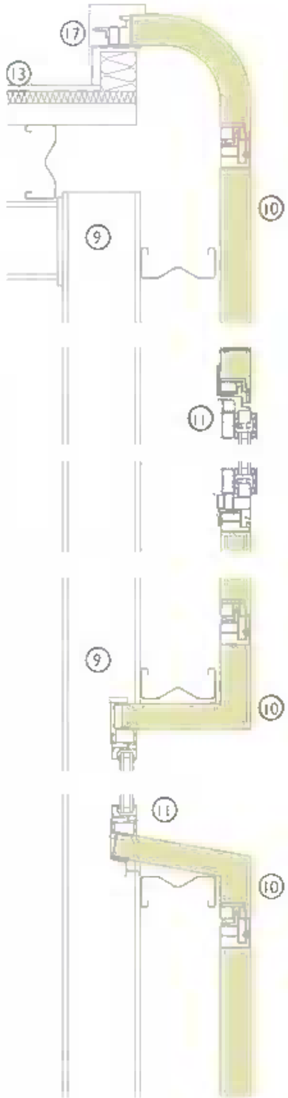
Horizontal section 1:5 Panels interlocking on 4 sides spanning either vertically or horizontally



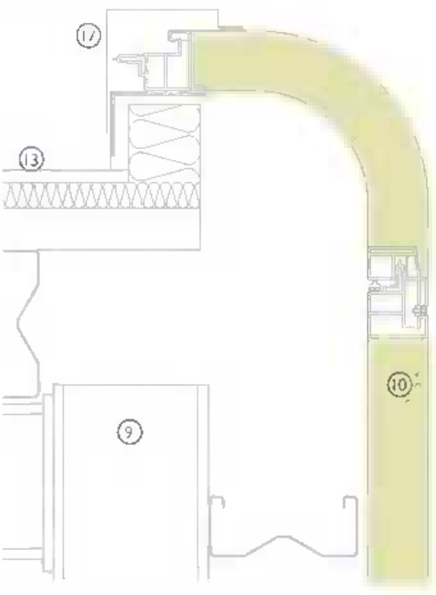
Horizontal section 1:5. Joint between composite panel and curtain wall type glazing with fully interlocking connection

Horizontal section 1:5. Joint between composite panel and concrete wall with fully interlocking connection

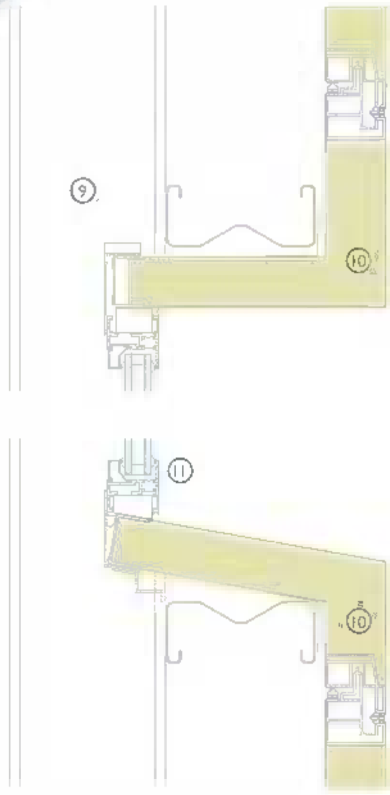
3-D view of partially interlocking panels with flush window and curved corner panel



Vertical section 1:10. Fully interlocking composite panels with curved cill and window set into reveal in cladding



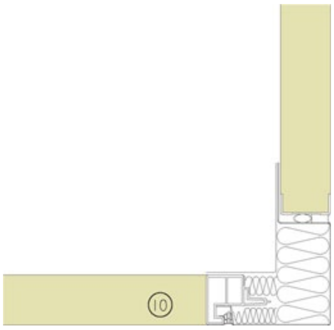
Vertical section 1:5 Curved parapet detail with fully interlocking connections



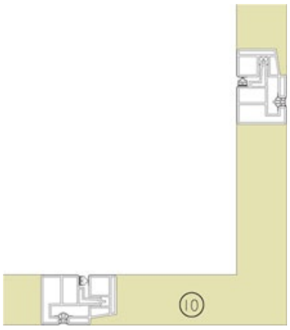
Vertical section 1:5. Aluminium window set into reveal in cladding

Corners

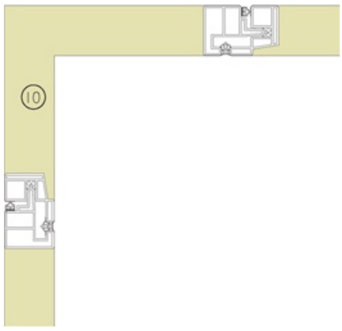
Composite panels are connected at corners by one of two methods. Either specially made corner panels are used (typically why 90° is standard) or a coverstrip is added to cover the junction where the panels meet. Corner panels are more suited to vertically-set arrangements, though panels for horizontally-laid panels are sometimes used for visual effect. Where corner coverstrips are used, their appearance resembles that of profiled metal cladding, which can give a facade an overall framed appearance. Metal trims at the parapet, base and corners can give this appearance. For this reason, the special corner panels and parapet panels are used increasingly.



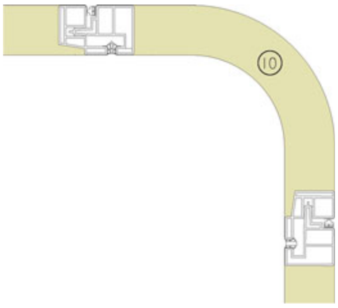
Horizontal section 1:5. Insulated corner connection between composite panels with fully interlocking connection



Horizontal section 1:5. Fully interlocking external corner panel



Horizontal section 1:5. Fully interlocking internal corner panel



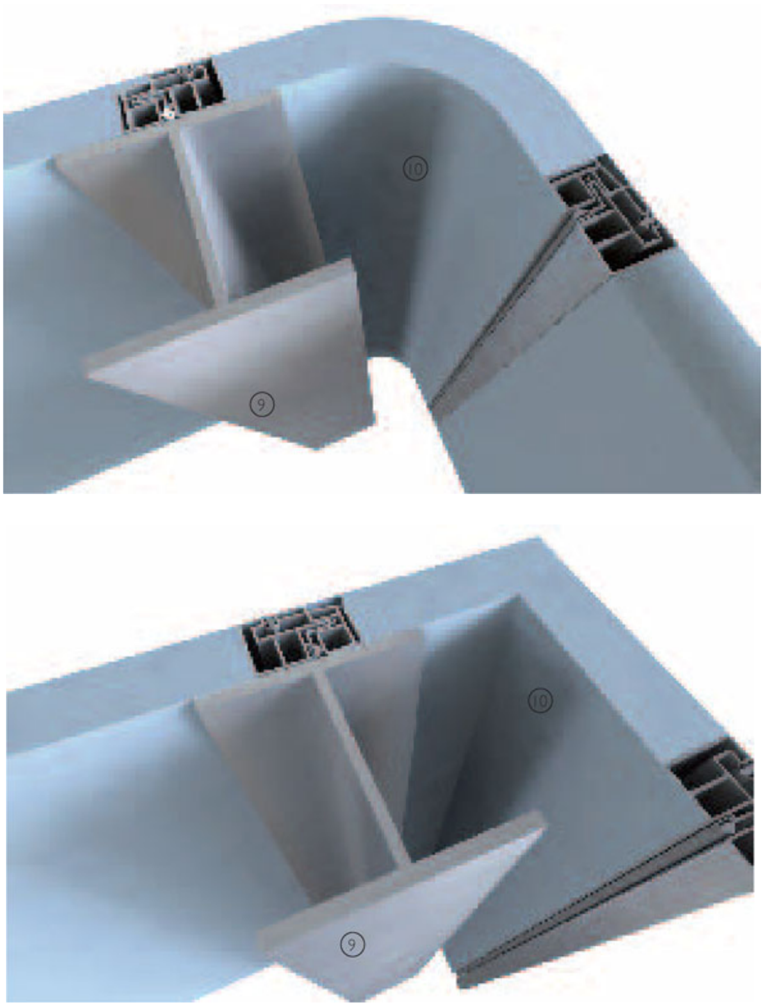
Horizontal section 1:5. Fully interlocking curved internal corner panel

Horizontal section 1:5. Fully interlocking curved external corner panel

Details
1. Vertically-set composite panel
2. Horizontally-set composite panel
3. Silicone-based seal
4. Outer metal facing
5. Inner metal facing
6. Inner insulation core
7. Metal capping
8. Concealed fixing
9. Supporting structure
10. 4-way interlocking composite panel
11. Window frame
12. Sectional roller shutter formed from composite panels
13. Roof construction, composite panels are shown
14. Metal trim
15. Exposed gutter
16. Concealed gutter
17. Metal parapet coping
18. Stick glazed curtain walling
19. Door frame

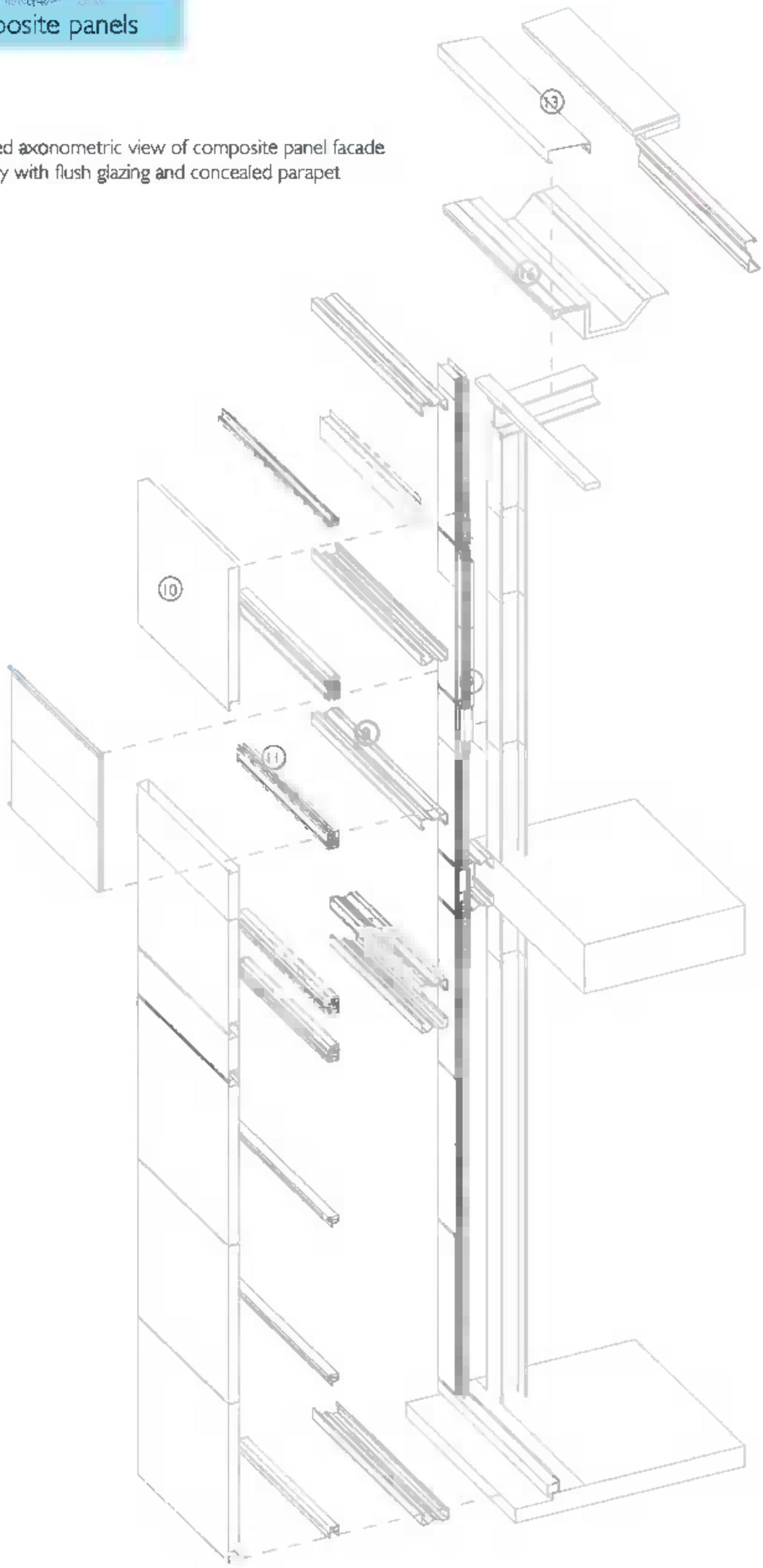
Thermal bridges at cills

A weakness in composite panels systems has been the use of pressed metal sections or aluminium extrusions that pass from outside to inside without a thermal break. This is being remedied by the use of insulated cills, made in the manner of composite panels. This reduces the thermal bridge, in some cases a break in the section from outside to inside can be formed by turning the metal cill into the injected foam or polystyrene in the same way as a composite panel.

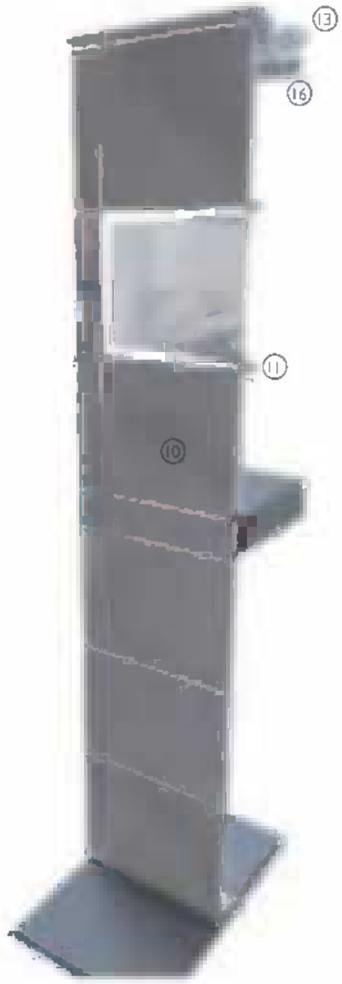


3-D views of fully interlocking corner pieces with square and rounded corners

Exploded axonometric view of composite panel facade assembly with flush glazing and concealed parapet

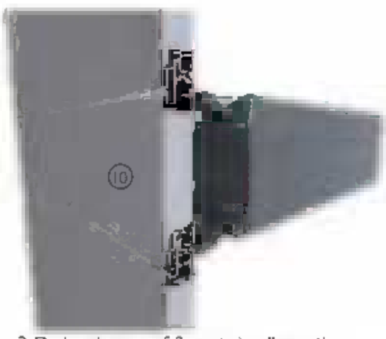


3-D view of composite panel facade with flush glazing and concealed parapet



Details

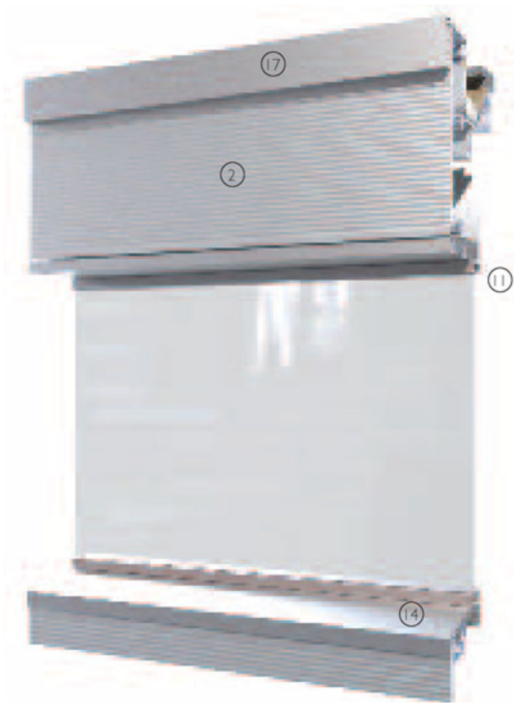
1 Vertically-set composite panel
2. Horizontally-set composite panel
3. Silicone-based seal
4. Outer metal facing
5. Inner metal facing
6. Inner insulation core
7. Metal capping
8. Concealed fixing
9. Supporting structure
10. 4-way interlocking composite panel
11 Window frame
12 Sectional roller shutter formed from composite panels
13. Roof construction, composite panels are shown
14 Metal trim
15 Exposed gutter
16. Concealed gutter
17. Metal parapet coping
18. Stick glazed curtain walling
19. Door frame



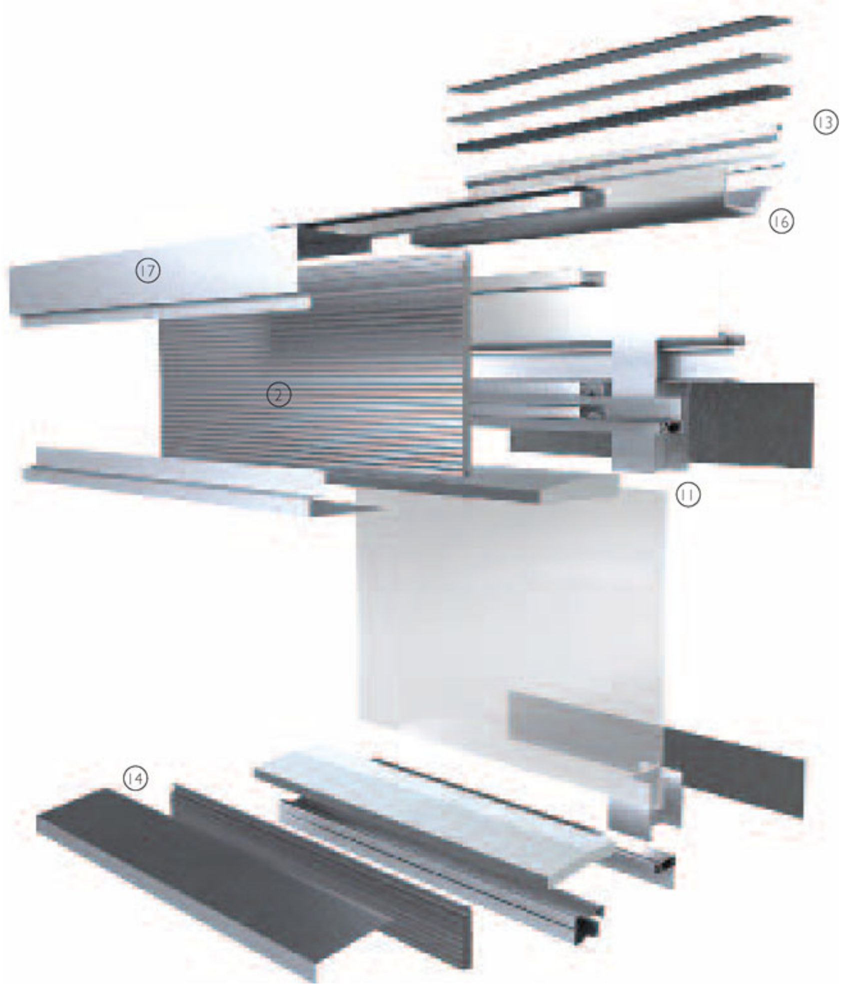
3-D detail view of floor to wall junction

3-D detail view of window frame and supporting structure

3-D detail view of gutter



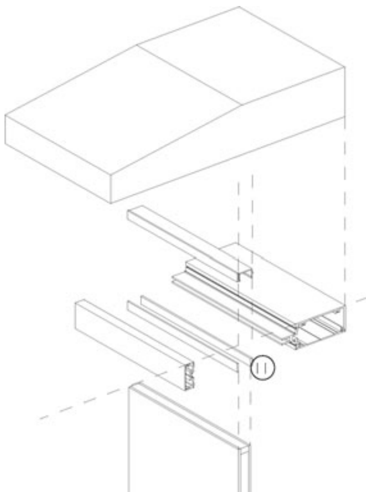
3-D view of composite panel curtain wall with recessed window with deep metal reveal



3-D exploded view of composite panel curtain wall with recessed window with deep metal reveal

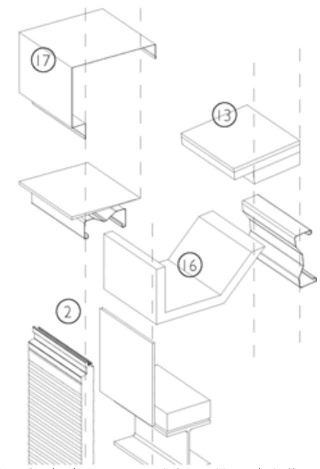
3-D section of composite panel curtain type wall with recessed window with deep metal reveal

3-D view of frame detail

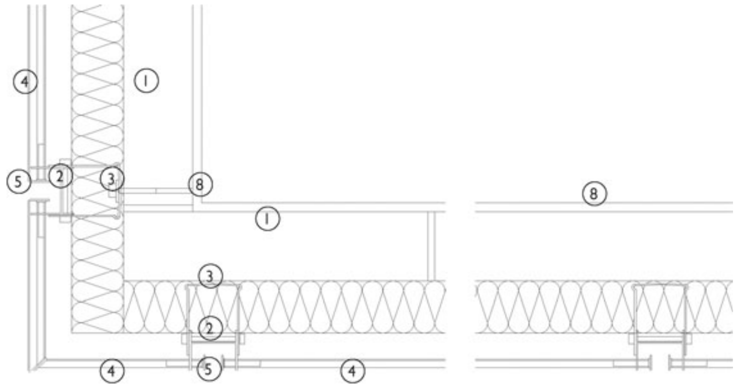


Exploded axonometric frame detail

3-D view of gutter detail

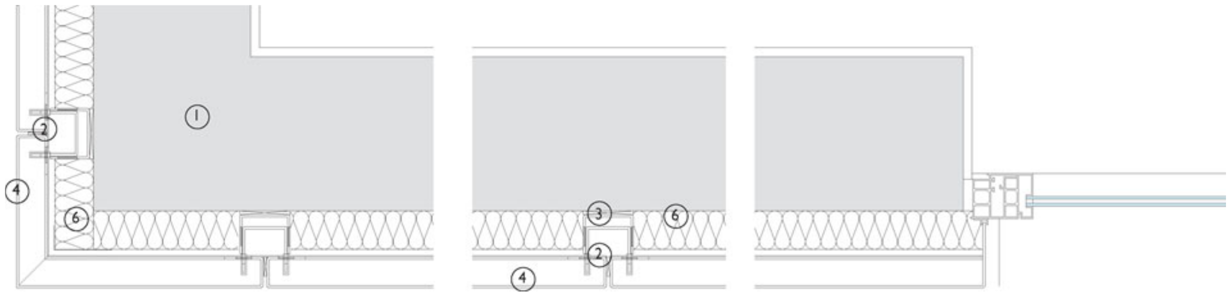


Exploded axonometric gutter detail



Horizontal section 1:10. External corner connection between rainscreen panels

Details
1. Backing wall or structural wall supporting rainscreen
2. Supporting Frame
3. Support Bracket
4. Metal rainscreen panel
5. Open joint
6. Closed cell thermal insulation
7. Waterproof membrane
8. Internal finish
9. Supporting structure
10. Pressed metal cill
11. Pressed metal coping
12. Continuity of waterproofing layers of wall and roof



Horizontal section 1:10. External corner connection between rainscreen panels and junction with window

A much wider range of materials is used in rainscreens than was the case five years ago. Copper and zinc have the advantage of being easier to form than steel or aluminium, particularly where site-based construction methods are preferred for either economy or in dealing with complex or curved geometries. This method of fixing rainscreens avoids the need for off-site fabrication of a large number of different panel types with different curved geometries. They can be made economically on-site.

The 'tiling' or 'shingling' of panels in copper has been developed from sheet metal cladding. This departs from metal rainscreen designs in that the surface appearance has a deliberately uneven texture that emphasises the oil-canning effect that gives the appearance of a layered, tiled surface. The move away from the emphasis on flat metal panels in rainscreen construction includes an increased use of profiled and curved metal panels. A major advantage is that fixings can be concealed by semi-interlocking panels in the manner of sheet metal cladding or in the manner of traditional roof coverings.

There has been a recent increased use of semi-lapped assemblies that conceal the void behind the metal cladding. These usually have visible fixings at panel joints but allow the joints between panels to be less in shadow than is the case with other fixing methods. There has been a gradual development of rainscreens as visual screens rather than as weather-excluding panels. For example, perforated metal screens in mild steel or aluminium are used to create both modelling to a facade and solar shading set forward of glazed walling. In such designs the back of the rainscreen panel is visually as important as the outer visible face where the panel is seen through glazed openings in a facade. Fixings for such rainscreen panels often have screws and bolts that are set into the fixing rather than having projecting threaded bolt and exposed nuts.

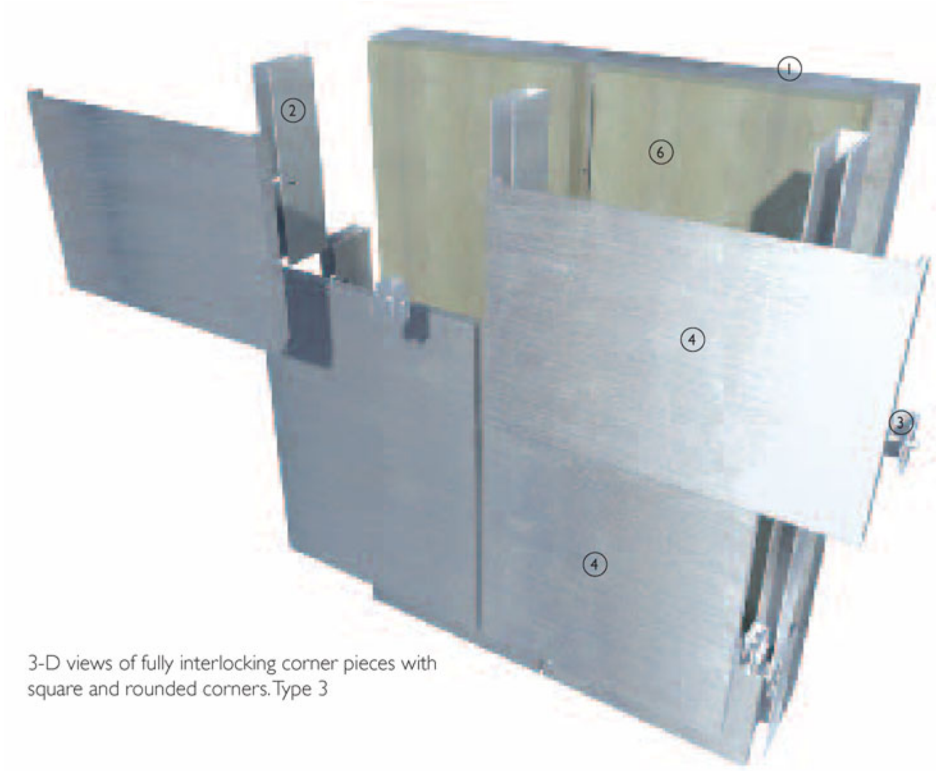
Materials

Rainscreen panels can have a flatness that is difficult to achieve with other methods. Panel flatness is achieved by either use of composites such as proprietary laminates where two sheets of aluminium are bonded on both sides of an inner core sheet of plastic of thickness 3-5mm (0.118in to 0.2in) or by a minimum 3mm (0.118in) thick aluminium sheet, or approximately 1mm thick steel sheet, depending on panel size. Honeycomb panels are also being used. A metal honeycomb layer, about 5mm (0.2in) thick, is bonded to thin metal sheets on either side. Aluminium is most commonly used. One of the outer sheets is factory paint coated from the rolled coil from which it is cut, giving the material a high level of colour consistency over large areas of panel.

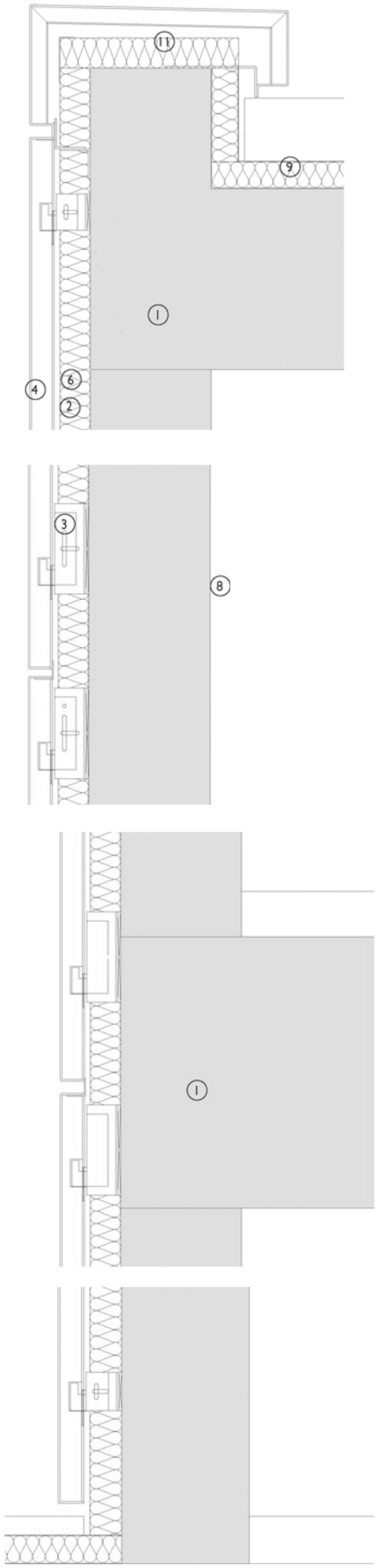
Fixing methods

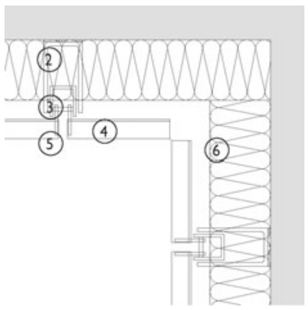
The three main fixing types used for metal rainscreens are (1) visible point fixed, (2) horizontal or vertical rails with partially exposed brackets (hung panels) and (3) vertical and horizontal rails with partially interlocking panels and concealed fixings.

The choice of fixing method is often determined by what is seen through the joint from the outside. If dark shadows are sought at the joint then the backing wall should have

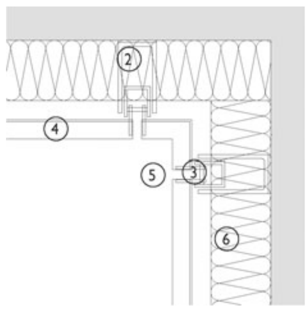


3-D views of fully interlocking corner pieces with square and rounded corners. Type 3

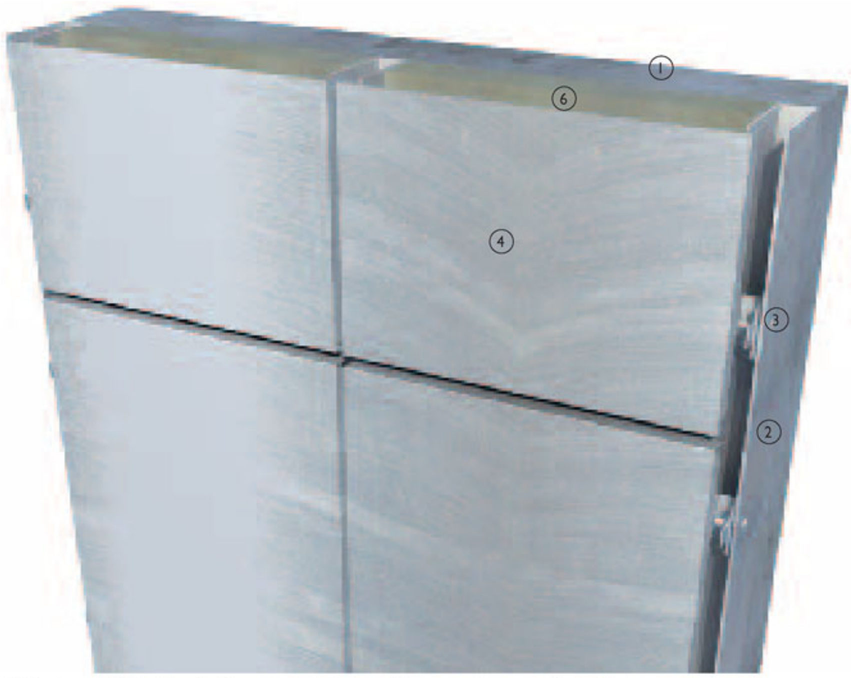




Horizontal section 1:10. Internal corner connection between rainscreen panels

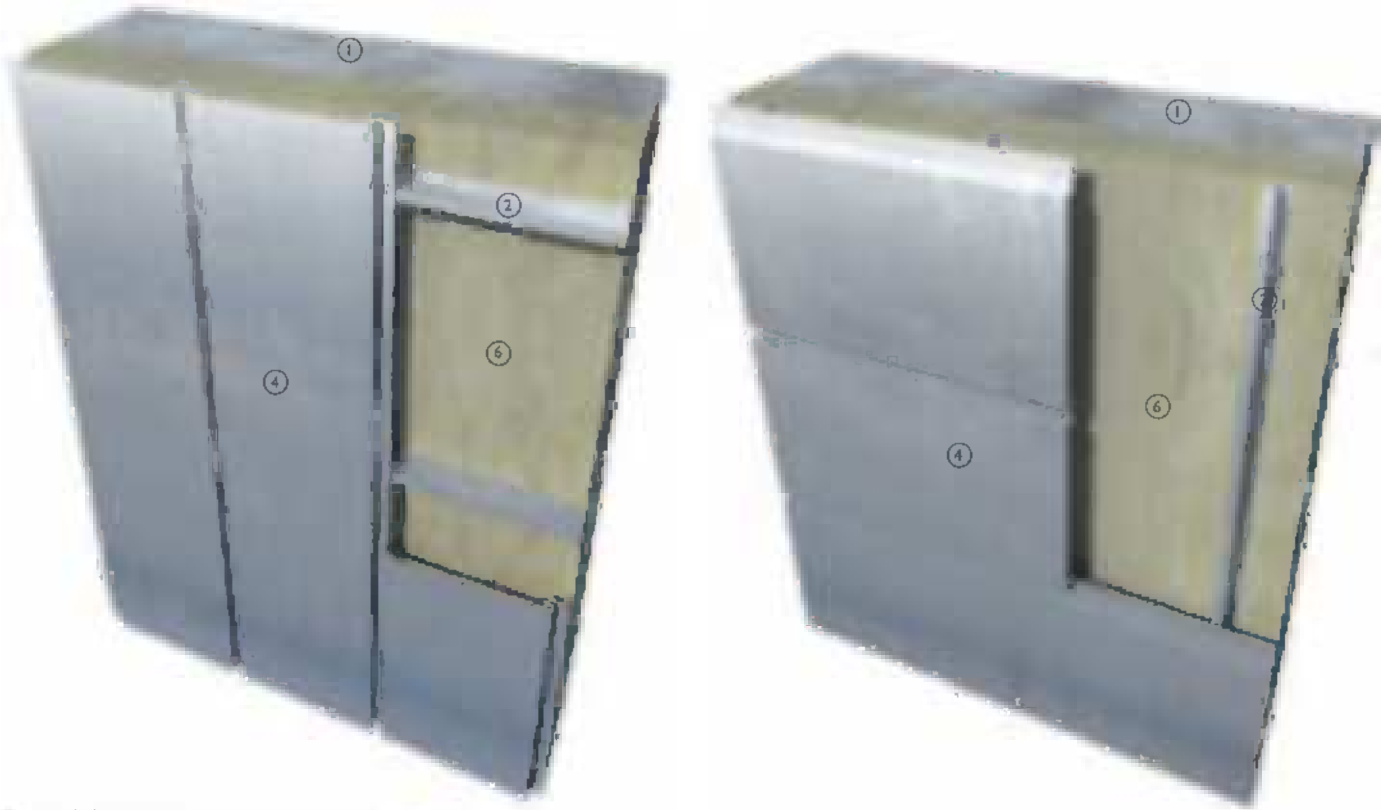


Horizontal section 1:10. Internal corner connection between rainscreen panels



3-D views of fully interlocking corner pieces with square corners. Type 3

Vertical section 1:10. Metal rainscreen wall assembly



-D views of semi interlocking rainscreen panels. Type 2
eft: Horizontal rails support cladding panels with vertical interlocking joints
ight: Vertical rails support cladding panels with horizontal interlocking joints

a consistent dark colour. In this case, short lengths of bracket may be sufficient to support the panels, since they will not be visible. If the backing wall is likely to be visible through the open joints, such as if the backing wall is clad in exposed polystyrene insulation board, then the joints will need to be screened by a continuous channel.

Panels which are point fixed have either countersunk screws set flush with the panel face, or dome headed screws which make a visible feature of them. The screws are fixed into rails set to suit their position. Vertical rails are often preferred since water can easily drain down them.

Hung panels are hooked onto supporting brackets. Panels are fixed by cutting slots into the sides of the rainscreen panel during manufacture and hooking them onto dowels projecting from C-shaped brackets. These brackets are in turn secured to vertical rails set at vertical joints between panels. The rails also act as screens to close off views into the cavity. Horizontal joints are formed by an upstand formed in the top or bottom edge of a panel.

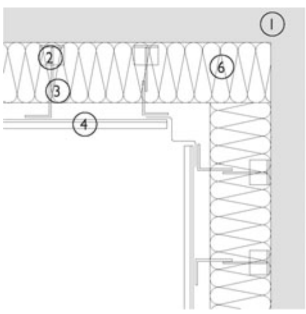
Semi-interlocking panels are fixed by screwing the top of the panel to horizontal rails to suit the orientation of the panels. The adjacent panel is lapped into the panel next to it, both to secure it and conceal the fixing. The joint in the other direction is either fixed with a similar semi-interlocking edge to form a tiled appearance, or has a cover strip.

Unlike masonry-based rainscreens such as terracotta or stone, metal rainscreen panels are lightweight in comparison and need to be mechanically fixed at a minimum of one or two points, usually at the bottom of the panel if the panel is hung from the top. Fixing screws are usually applied at the joint, unless it is fixed with exposed fixings through the panel itself. This means that part of the bracket is usually visible. Short lengths of brackets then become visible and need to be incorporated as a visible part of the design.

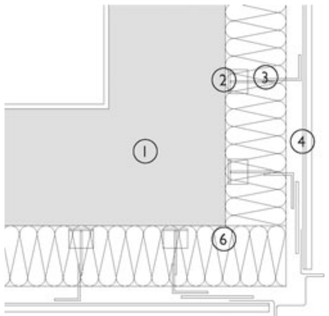
Backing walls

Supporting walls to rainscreen panels are usually concrete block, which allows supporting panels to be fixed at any point across its surface, or framed, where rainscreen fixings are secured to the framing members rather than the outer skin of the backing wall. In some cases, if the outer skin is thick enough, say 6mm (0.25in) aluminium sheet, rainscreens can be fixed directly to the sheet material rather than the frame. If a lightweight backing wall cannot accept additional loads from rainscreen cladding onto it (as with composite panels), then support rails span from floor to floor as posts.

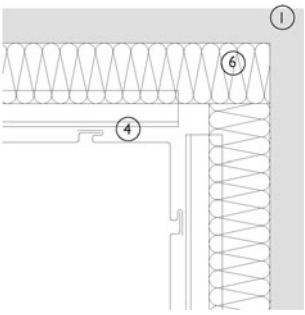
With concrete block backing walls, the thermal insulation is usually set on the outside face in order to keep the structure either warm or cool, depending on the geographical location. The waterproof layer is set directly on the outside face of the concrete. The thermal insulation used is closed cell type in order for it not to absorb water which would drastically reduce its performance. The insulation is also used to protect the waterproof membrane but this makes it necessary for support brackets to be fixed through the insulation to the supporting wall behind. Sometimes holes have to be cut in the insulation, which reduces its effectiveness, but it is always better if the fixings for sup-



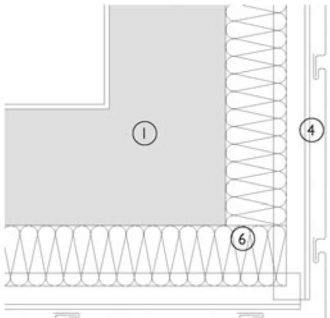
Horizontal section 1:10. Internal corner connection between metal rainscreen panels with interlocking horizontal joints and open vertical joints



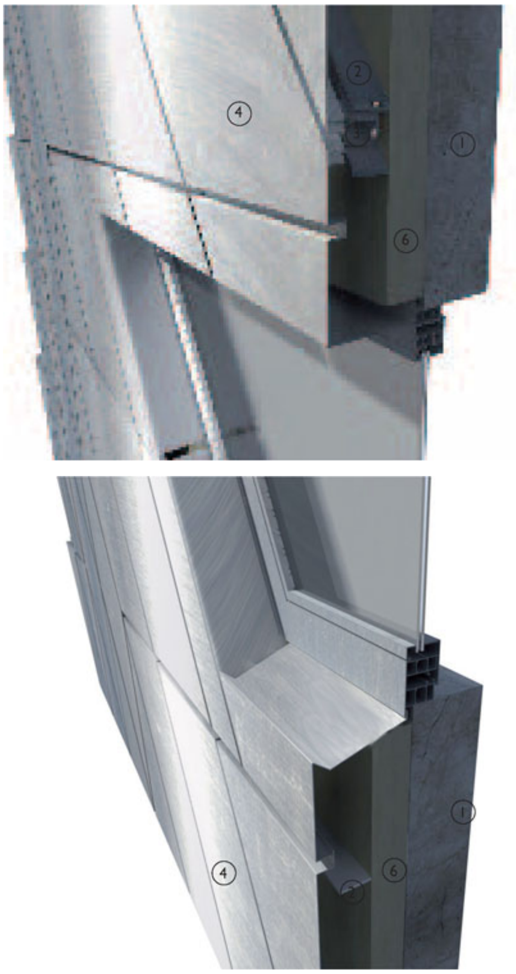
Horizontal section 1:10. External corner connection between metal rainscreen panels with interlocking horizontal joints and open vertical joints



Horizontal section 1:10. Internal corner connection between metal rainscreen panels with open horizontal joints and interlocking vertical joints

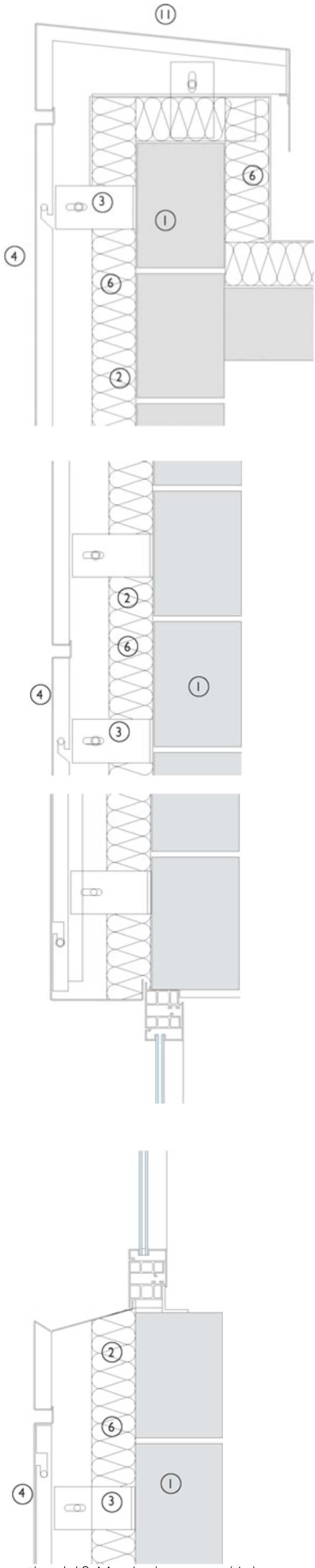


Horizontal section 1:10. External corner connection between metal rainscreen panels with open horizontal joints and interlocking vertical joints



3-D view of semi interlocking metal rainscreen with angled joints and aluminium window recessed into the facade. Type 3

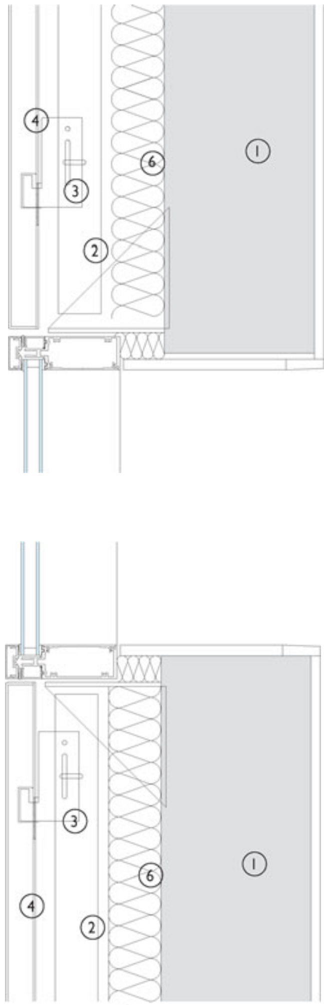
Details
1. Backing wall or structural wall supporting rainscreen
2. Supporting Frame
3. Support Bracket
4. Metal rainscreen panel
5. Open joint
6. Closed cell thermal insulation
7. Waterproof membrane
8. Internal finish
9. Supporting structure
10. Pressed metal cill
11. Pressed metal coping
12. Continuity of waterproofing layers of wall and roof



Vertical section 1:10. Metal rainscreen with interlocking horizontal joints, parapet and recessed window

Horizontal section 1:10. Connection between metal rainscreen and curtain wall type glazing with flush finish

3-D view of curtain wall type glazing set flush with metal rainscreen cladding. Type 3



Vertical section 1:10. Metal rainscreen with curtain wall type glazing set flush with face of cladding.

Details

1. Backing wall or structural wall supporting rainscreen
2. Supporting Frame
3. Support Bracket
4. Metal rainscreen panel
5. Open joint
6. Closed cell thermal insulation
7. Waterproof membrane
8. Internal finish
9. Supporting structure
10. Pressed metal cill
11. Pressed metal coping
12. Continuity of waterproofing layers of wall and roof

port rails can be fixed at the same time as the insulation in order to co-ordinate them and avoid later cutting of the insulation.

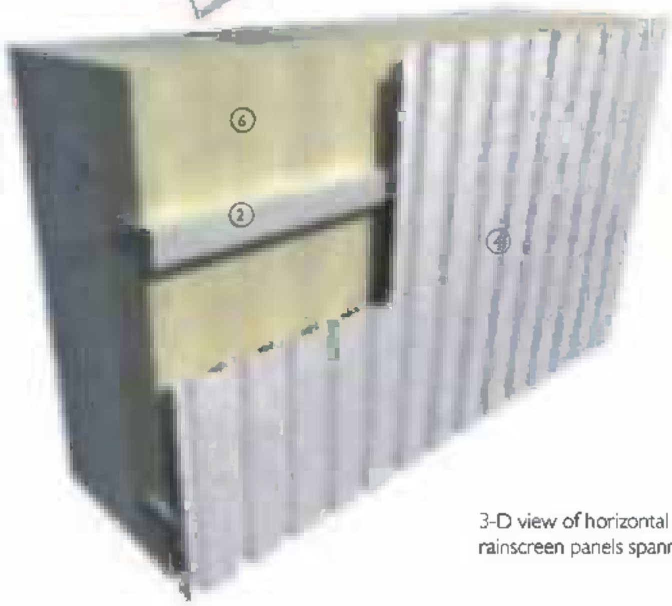
With lightweight backing walls in timber or pressed steel, thermal insulation is set within the frame. A waterproofing layer is set on the inside (warm in winter) face. An internal finish layer is then set in front of this vapour barrier. Rainscreen fixings for support rails are fixed directly to the outer waterproofing layer using sealing washers that avoid leaks through the fixing point. The framed backing wall is designed to receive fixing brackets at points which transfer loads down to the primary structure. The use of framed backing walls with rainscreens makes it necessary to co-ordinate the two elements of construction during the design rather than during the construction.

Construction sequence

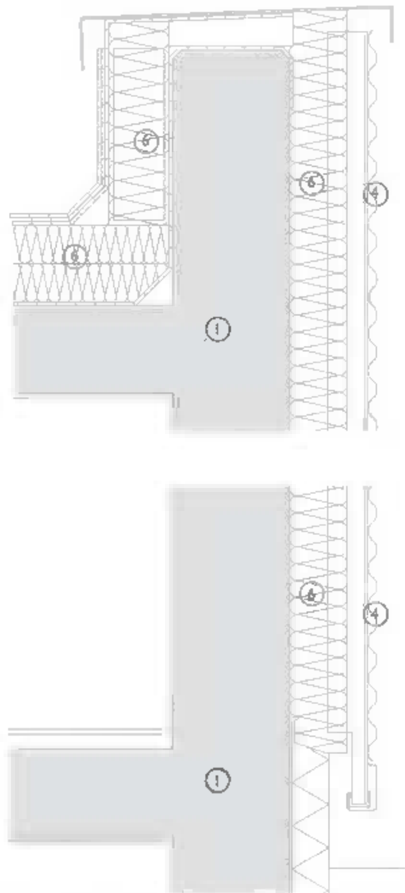
An essential aspect of rainscreen construction is the sequence in which the various elements of the backing walls, windows, thermal insulation, waterproofing layer and rainscreen panel are brought together. Although the rainscreen principle is very effective and often very economic, its effectiveness can be reduced if seals are not properly applied or insulation is damaged because elements are assembled on site in the wrong order. Typically, windows are sealed against the backing wall before the rainscreen panels are set in place. An advantage of this form of construction is that the external wall can be made waterproof before the rainscreen panels are fixed.

A typical construction sequence is to build the backing wall first and set the water-

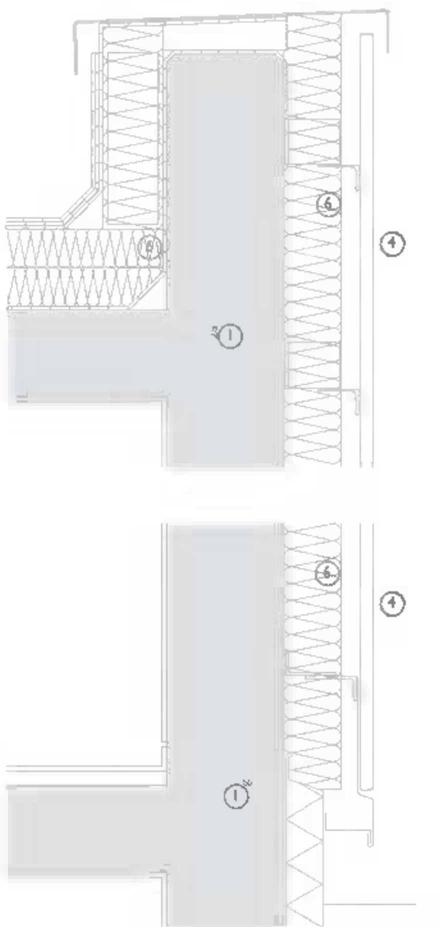
3-D view of vertical rail system with rainscreen panels spanning horizontally. Type 1



3-D view of horizontal rail system with rainscreen panels spanning vertically. Type 1



Vertical section 1:10. Horizontally spanning metal rainscreen panels with vertical rail system



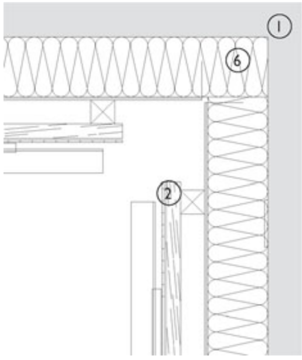
Vertical section 1:10. Vertically spanning metal rainscreen panels with horizontal rail system

proofing layer and insulation in place. Windows are then set into the backing wall and are sealed against its waterproofing layer. Thermal insulation, if set outside the line of the waterproofing layer (as in in-situ concrete, precast concrete or concrete block) makes it easier to set the thermal insulation on the backing wall after the windows and doors have been fixed. Support rails for the rainscreen panels are then fixed to the backing wall, followed by the metal panels themselves. Panels are usually fixed in horizontal rows from the bottom up so that corner panels and panels at window openings can be fixed from the outside from the top of the panel. Metal panels can then be set in a correct alignment with the windows in terms of their position and in setting the required joint width. The open jointed nature of the construction usually dictates that the rainscreen panel is set in a way that avoids a view through the joint to the backing wall beyond.

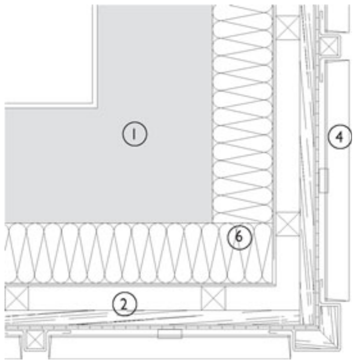
Window and door openings

Because window and door openings are usually set into an opening before the rainscreen panels are set, reveals are sealed with either individual rainscreen panels or with sheet metal trims similar to those used for sheet metal construction. Unlike sheet metal construction however, a gap is usually maintained between the trim and the window in order to maintain the joint principle. Similarly gaps between reveal trims and adjacent wall panels are also separated by an open joint. Since windows and doors are sealed against the waterproofing layer behind the rainscreen

3-D view of metal rainscreen shingles with folded metal parapet



Horizontal section 1:10. Internal corner of metal rainscreen shingles



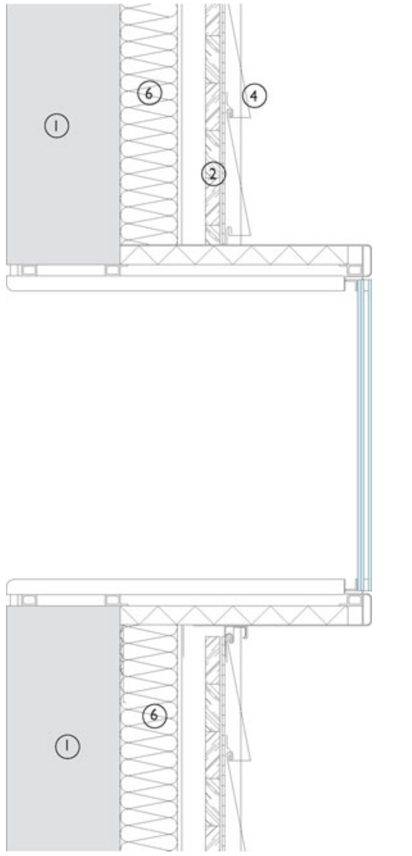
Horizontal section 1:10. External corner of metal rainscreen shingles

panel rather than to the panel itself, these separations are straightforward to achieve. These open joints around openings are made in a way that conceals the waterproof layer behind, thus protecting it from both accidental damage from building users and from the possible effects from sunlight heating up the membrane or attacking it with UV light. Windows and doors are usually provided with an additional wider frame or trim at their edges in order to allow thermal insulation in the cavity to provide continuity at the opening and allow the rainscreen panel to lap against it.

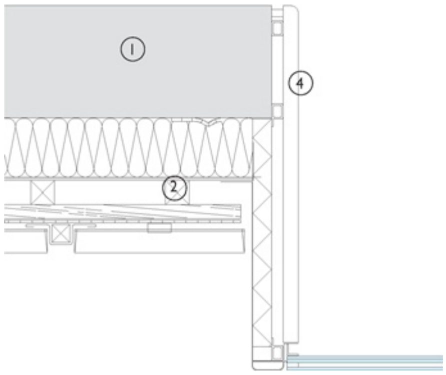
Parapets and cills

Parapets have an open joint between the parapet flashing and the panel below but horizontal joints between flashings are usually closed to protect the parapet from accidental damage to the waterproofing undercloak beneath or from the harmful effects of sunlight from above acting on its horizontal surface. Joints between flashings may be recessed to match the visual appearance of the rainscreen panels by providing a shadow or may be lapped in the manner of fully supported sheet metal cladding. The waterproofing layer will form a continuous seal with the adjacent roofing membrane. Cills at the base of the wall are detailed in a similar way with metal being continuous but with joints either recessed or lapped.

3-D views showing recessed timber window opening in metal rainscreen shingle cladding system



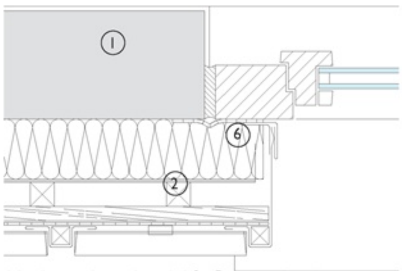
Vertical section 1:10. Connection between metal rainscreen shingles and timber window



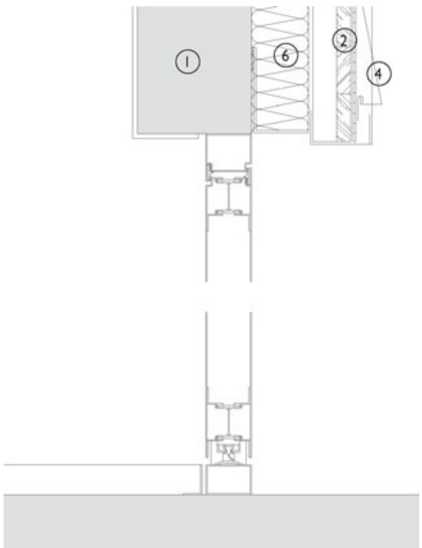
Horizontal section 1:10. Connection between metal rainscreen shingles and timber window

Details

1. Backing wall or structural wall supporting rainscreen
2. Supporting Frame
3. Support Bracket
4. Metal rainscreen panel
5. Open joint
6. Closed cell thermal insulation
7. Waterproof membrane
8. Internal finish
9. Supporting structure
10. Pressed metal cill
11. Pressed metal coping
12. Continuity of waterproofing layers of wall and roof

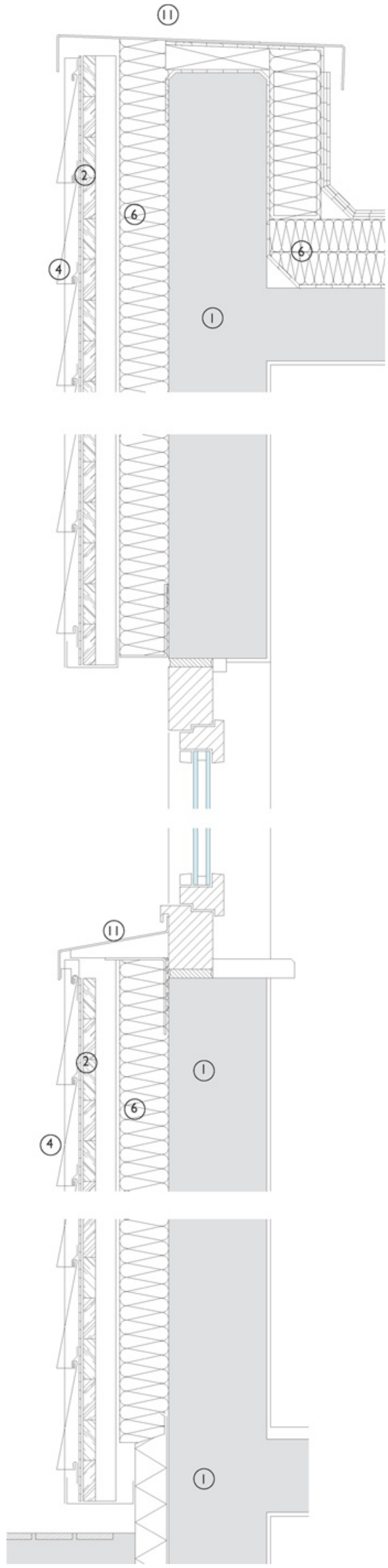


Horizontal section 1:10. Connection between metal rainscreen shingles and timber window



Vertical section 1:10. Metal door recessed into metal shingle rainscreen construction

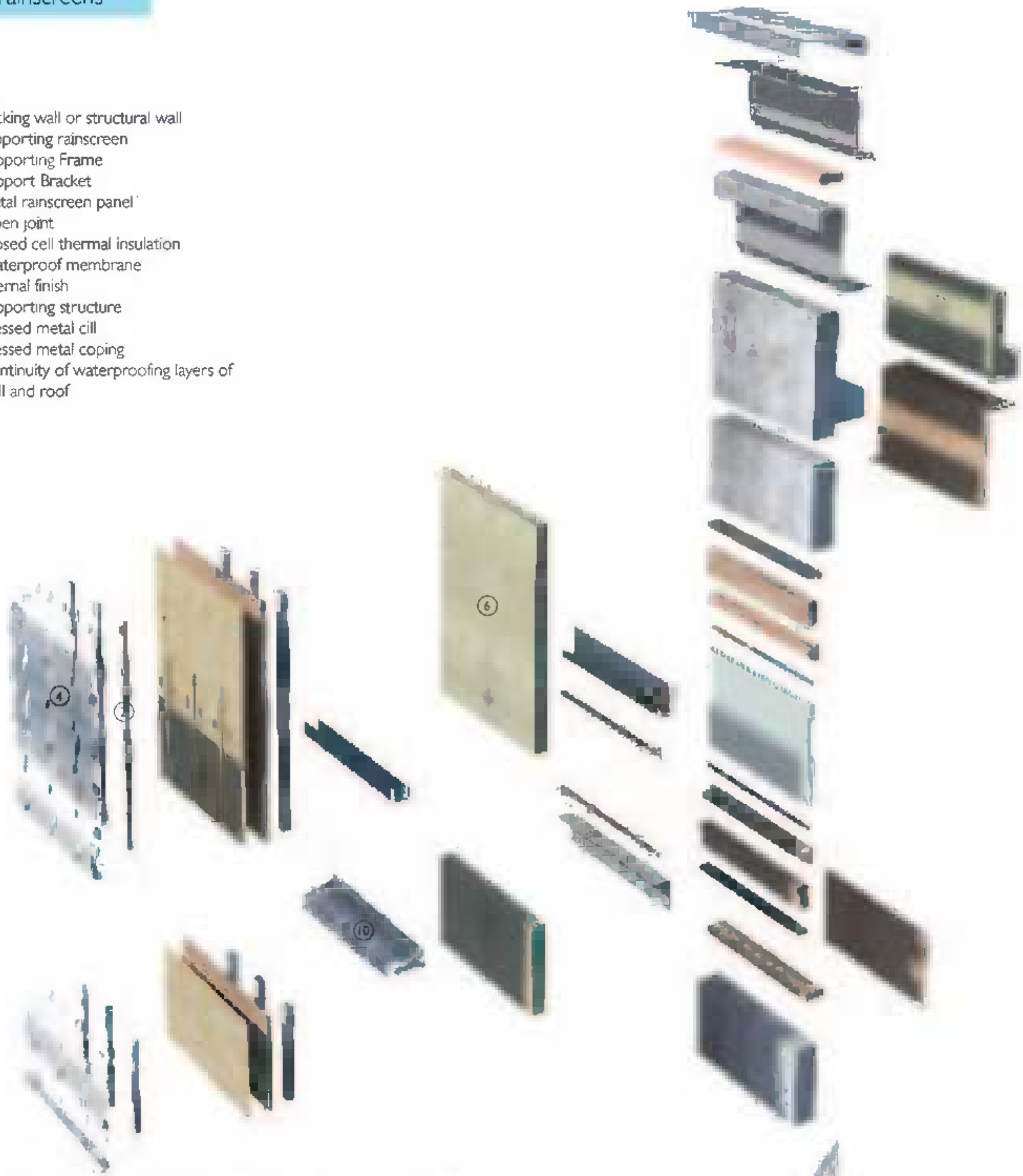
3-D view recessed timber window in metal rainscreen shingle cladding system



Vertical section 1:10. Semi-interlocking metal rainscreen shingle system with parapet, timber window and finish at ground level

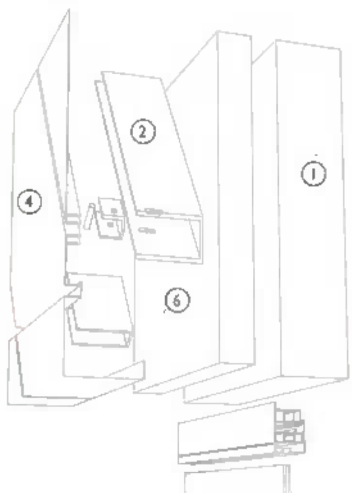
Details

1. Backing wall or structural wall supporting rainscreen
2. Supporting Frame
3. Support Bracket
4. Metal rainscreen panel
5. Open joint
6. Closed cell thermal insulation
7. Waterproof membrane
8. Internal finish
9. Supporting structure
10. Pressed metal cill
11. Pressed metal coping
12. Continuity of waterproofing layers of wall and roof

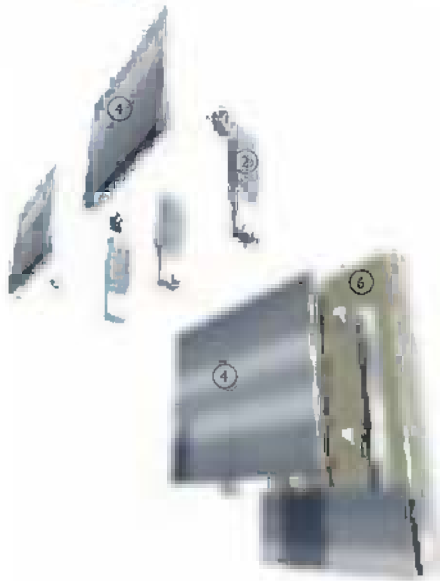


3-D exploded view of metal rainscreen panel system with overlapping tiles as panels

3-D exploded view of parapet condition

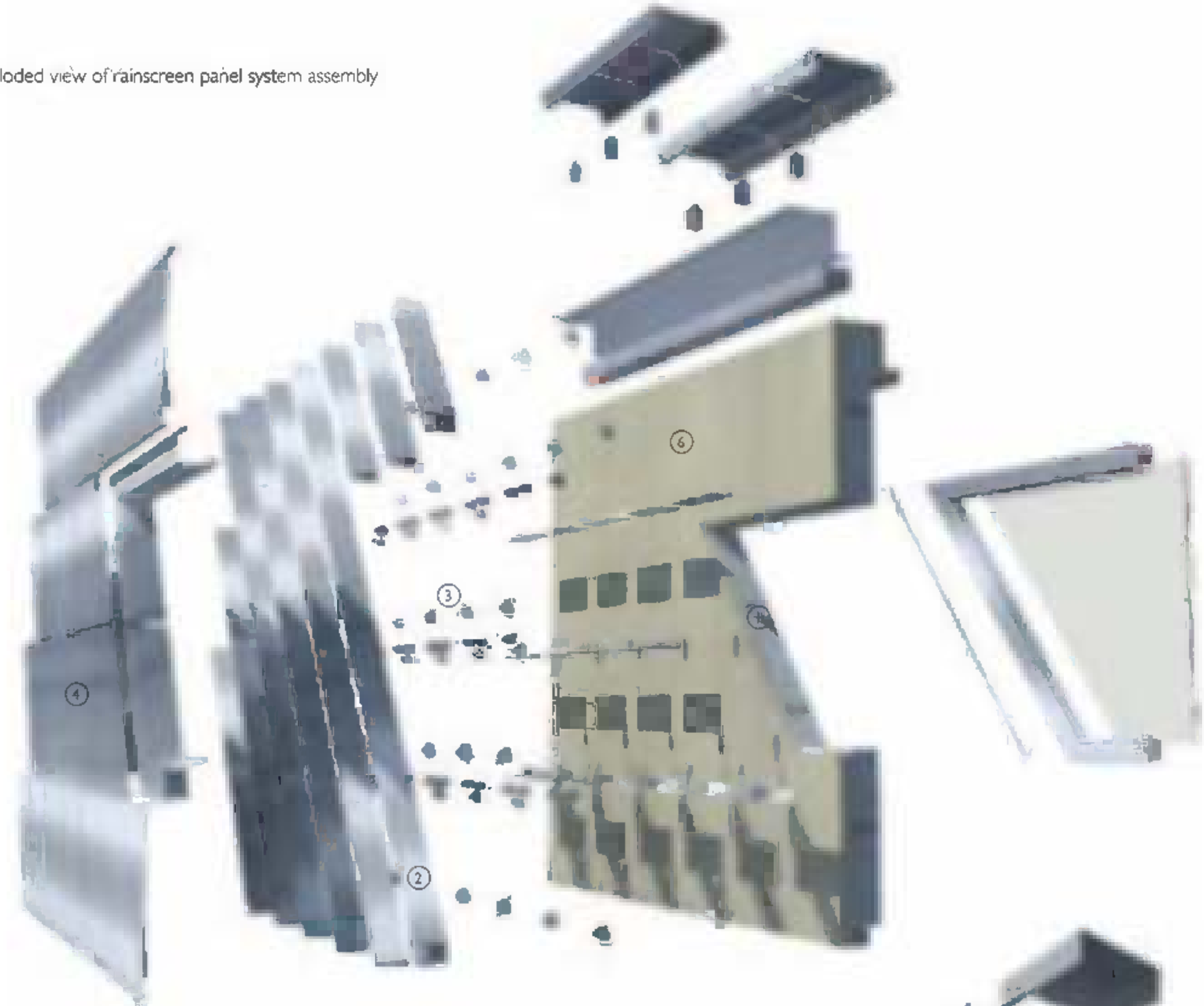


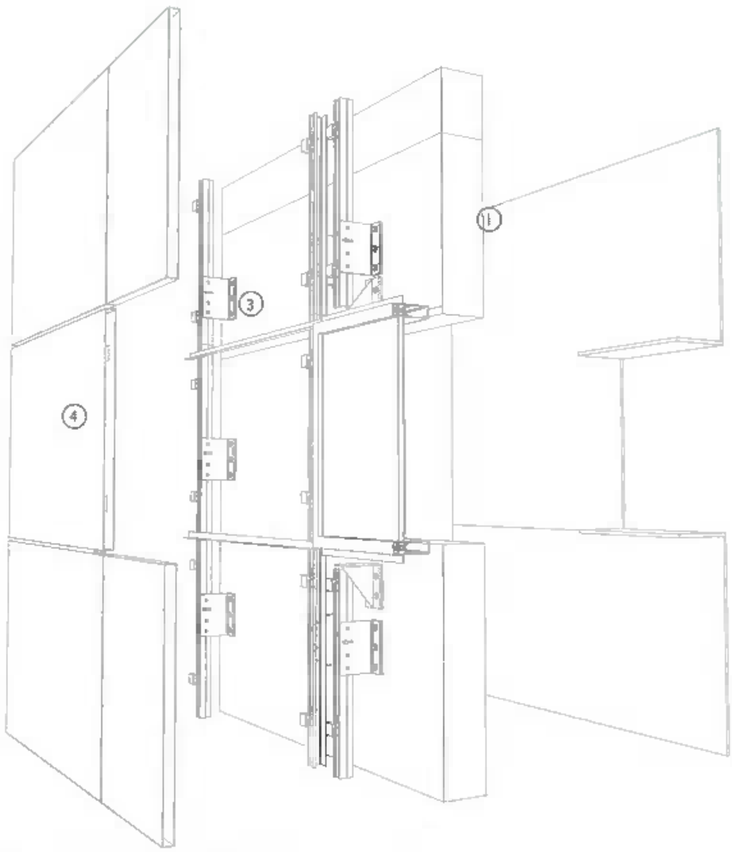
3-D exploded view of top of window opening



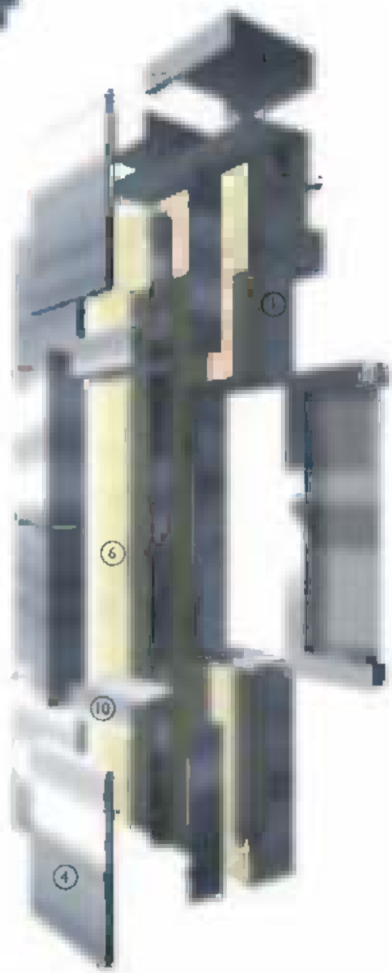
3-D exploded view of rainscreen panel system

3-D exploded view of rainscreen panel system assembly

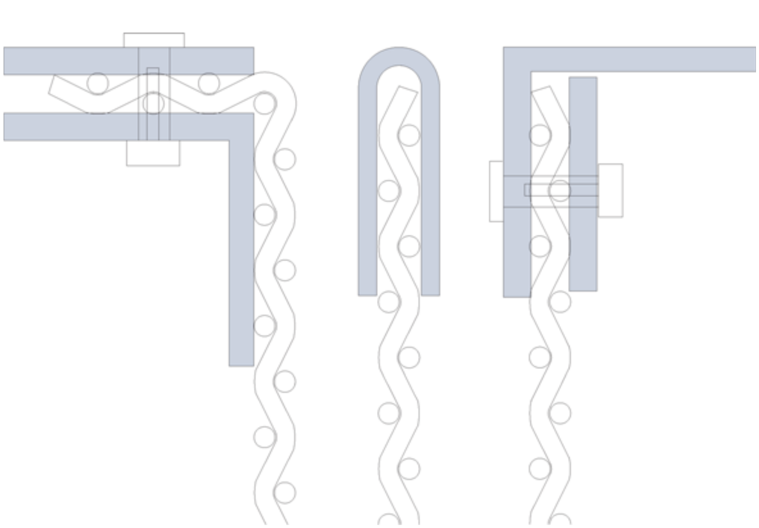




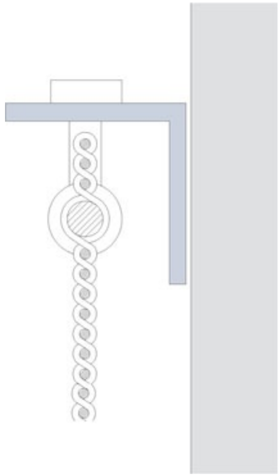
3-D exploded view of opening in rainscreen panel system



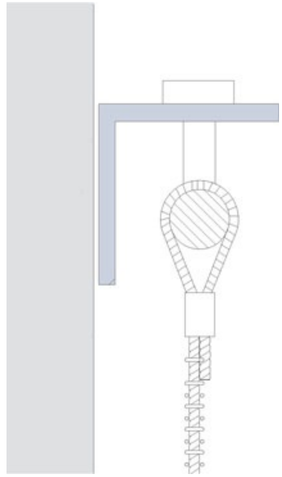
3-D exploded view of typical window opening



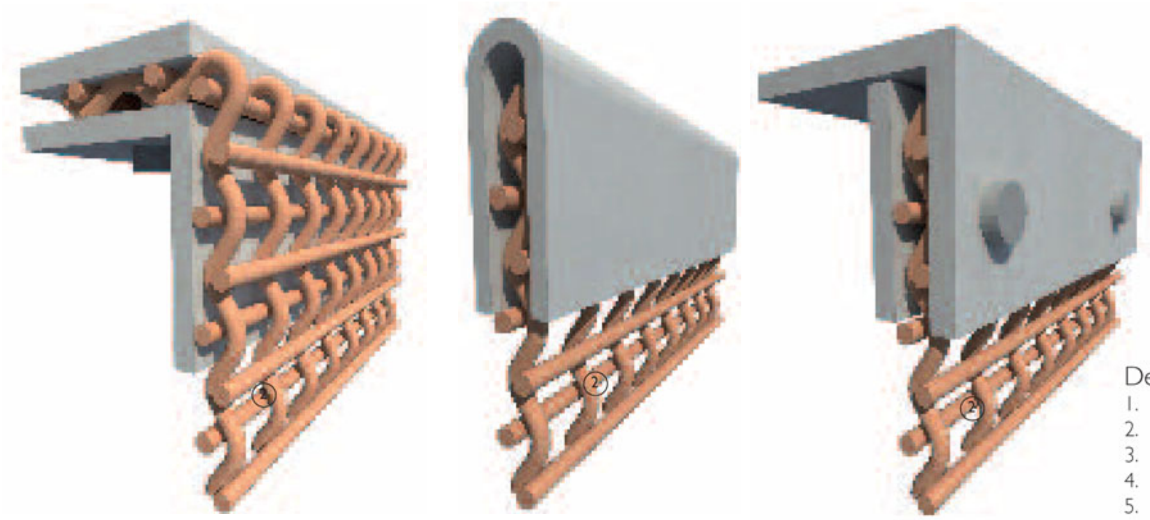
Vertical section 1:2. Edge fixing variations for rigid mesh supported on frame



Vertical section 1:2. Steel rod incorporated into mesh weave and supported from eyelets fixed to backing wall

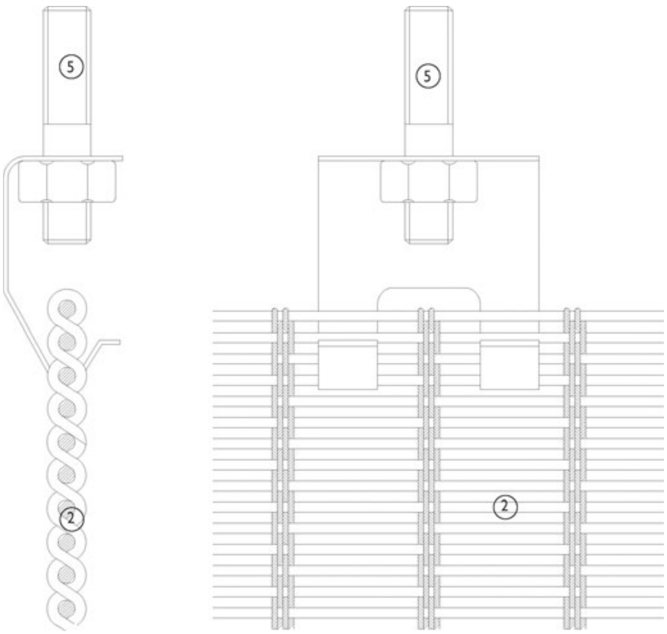


Vertical section 1:2. Mesh cable formed into eyelet and hung from metal rod

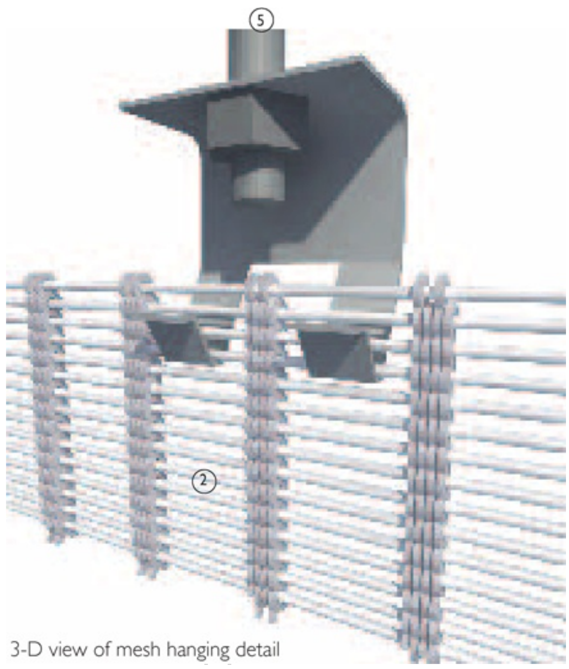


3-D views of edge fixing details for frame supported mesh

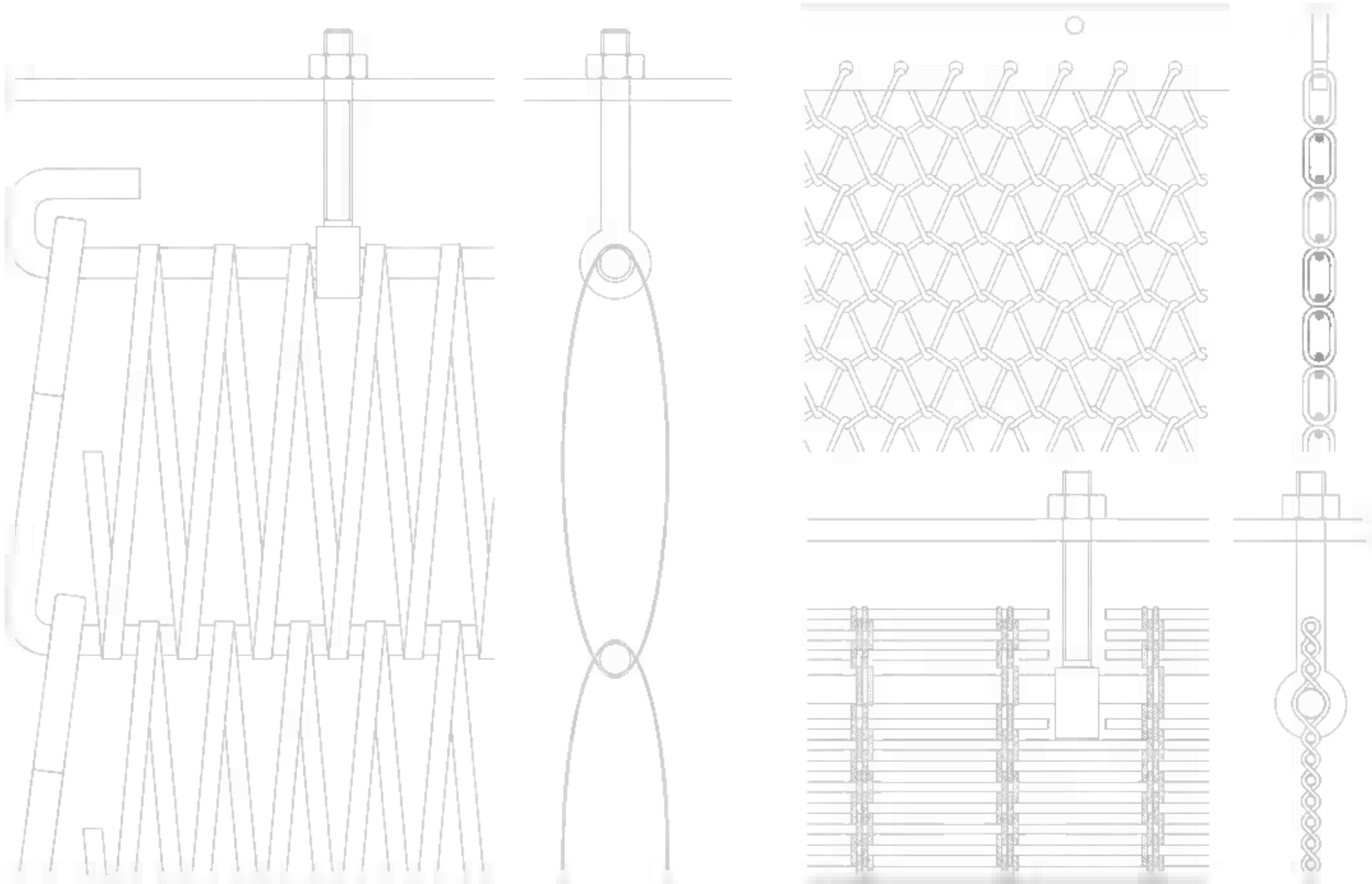
Details for mesh
1. Metal support edge frame
2. Stainless steel mesh
3. Stainless steel spring
4. Metal fixing bracket
5. Metal support rod
6. Fixing bolt to tension mesh
7. Floor slab or backing wall
8. Adjacent curtain wall



Vertical section and elevation 1:2. Mesh hung from shaped metal bracket bolted to supporting structure



3-D view of mesh hanging detail



Vertical section and elevation 1:2. Mesh weave and support variations

Stainless steel mesh screens have been introduced into mainstream building construction only in the last ten years. This metal is preferred for mesh screens due to its durability and weather resistance when used externally. Their appearance as a textile rather than as a sheet material has led to the use of mesh as 'wraps' to facades in a similar way, in visual terms, to rainscreens. Their purpose is often to provide a smooth, textile-like surface across a wall that can conceal a variety of different facade elements immediately behind it. It has also found favour in car park design, where open mesh decks are given homogeneity with a woven mesh screen. Their varying levels of translucency can be exploited both in daylight by providing depth to a facade that gives some privacy to building users, and from a night time glow across its surface generated by electrical light within the building.

Meshes are of three essential types: rigid mesh made from rod, mesh flexible in one direction made as woven wire with rods in one direction and wire in the opposite direction, and mesh that is flexible in two directions which is made from woven wire only.

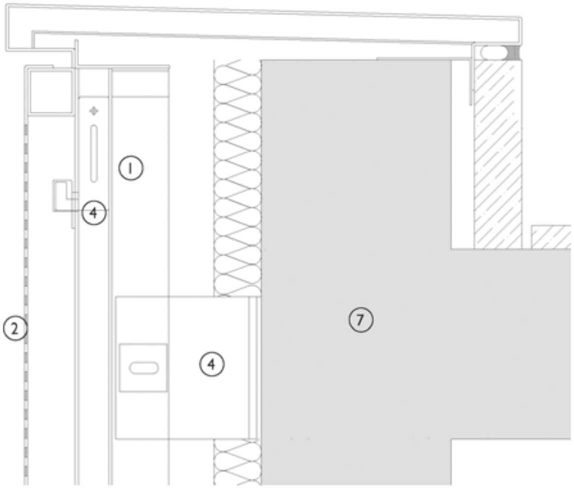
Rigid mesh

Rigid mesh is made in relatively small sheet sizes and is suitable mainly for balustrades or areas of facades where the material can be supported on a visible frame. It is also used as external solar shading where its lightness in weight allows it to be moved in a motorised system. The material is made in both mild steel and stainless steel but mild steel requires painting. Polyester powder coating is the most common finish. Rigid mesh cannot be tensioned and so it is clamped in a frame at its edges.

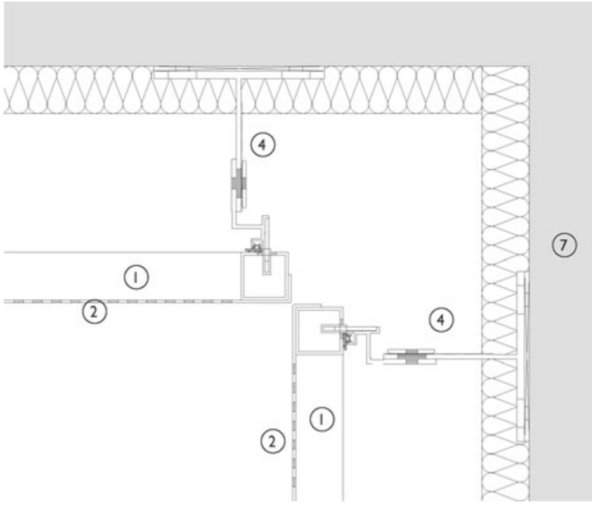
This material is usually made in relatively small panels of around 1800 x 1500mm (6ft x 5ft). Stainless steel bars are woven in two directions, giving the material a stiffness comparable to aluminium sheet but with a surface texture much more undulating than perforated metal sheet. Rigid mesh can provide up to around 50% shading. Rod thickness is typically 1.5mm (0.054in) diameter woven to form openings of around 6mm x 2mm (0.25in x 0.08in). Because they cannot be tensioned, rigid meshes are either held in a continuous edge frame or supported at points in the manner of bolt fixed glazing. They are most commonly used in balustrading where rigidity of material is an essential requirement. The economic nature of the material allows it to be used as both balustrading and full height screening as part of the same design. When used as a balustrade, the exposed edges of the material are held captive in a protective edging if not fixed into a full supporting frame. This avoids injury to building users. A folded flat sheet or a pair of flats are commonly used.

Meshes flexible in one direction

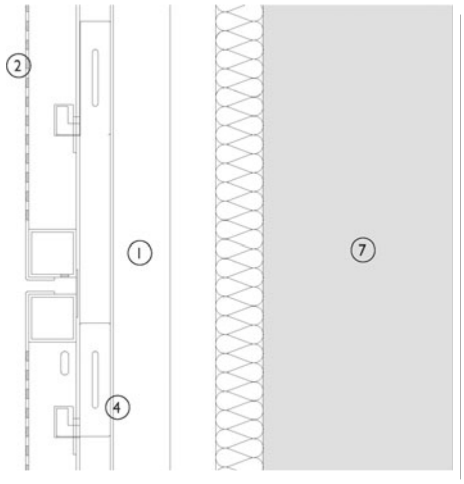
These meshes are made with rigid stainless steel rod in one direction woven and stainless steel cable in the other direction. An advantage presented by the cables is that they can be tensioned at each end to provide a large continuous flat area of translucent metal.



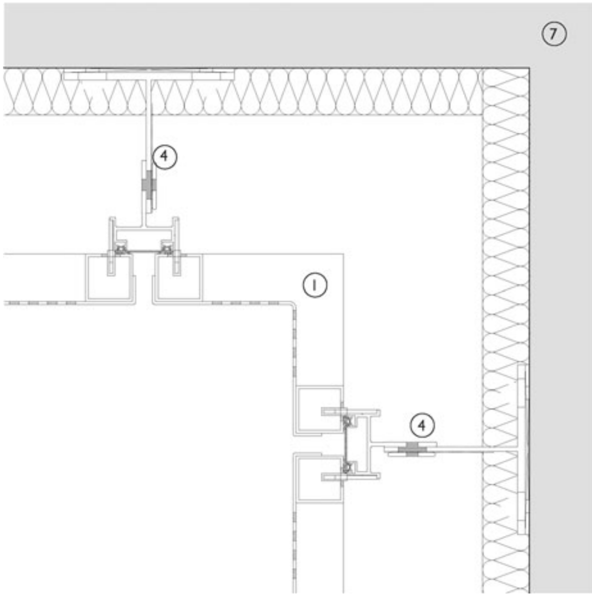
Vertical section 1:10. Parapet detail



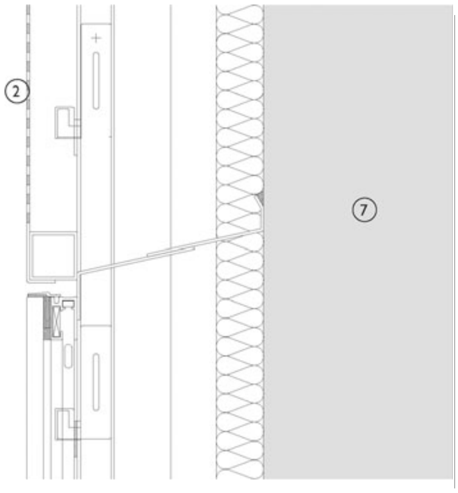
Horizontal section 1:10. Regular panels forming internal corner



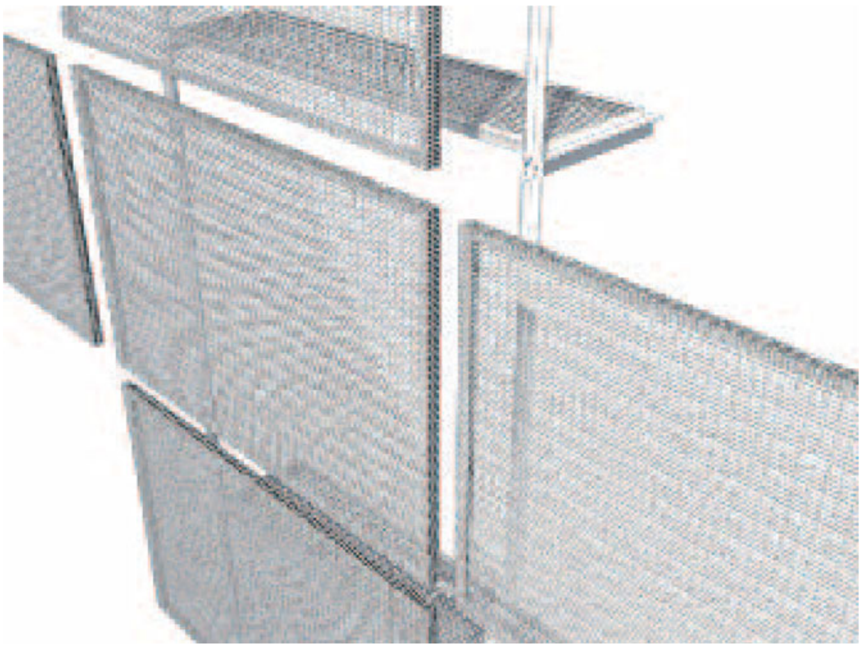
Vertical section 1:10. Panel to panel connection detail



Horizontal section 1:10. Internal corner using special corner panel



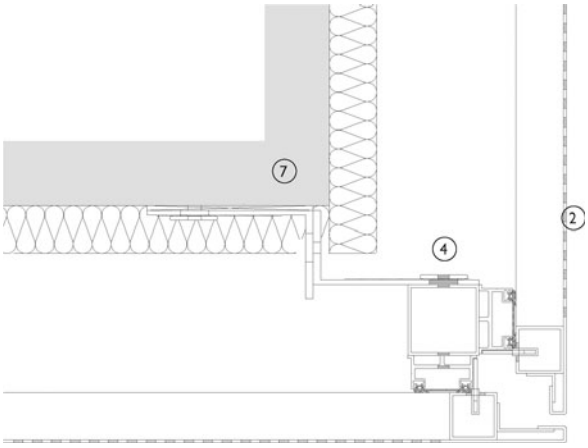
Vertical section 1:10. Panel to panel connection detail



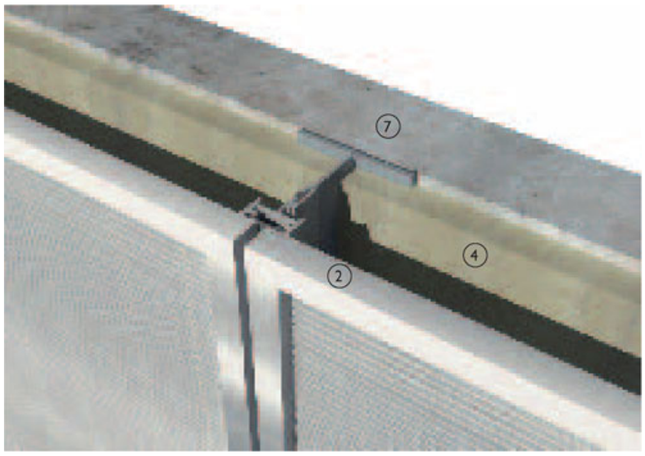
3-D exploded view of mesh panels clamped to frame and supported on steel frame

Details for mesh

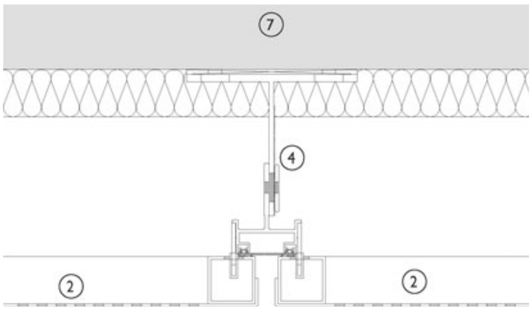
1. Metal support edge frame
2. Stainless steel mesh
3. Stainless steel spring
4. Metal fixing bracket
5. Metal support rod
6. Fixing bolt to tension mesh
7. Floor slab or backing wall
8. Adjacent curtain wall



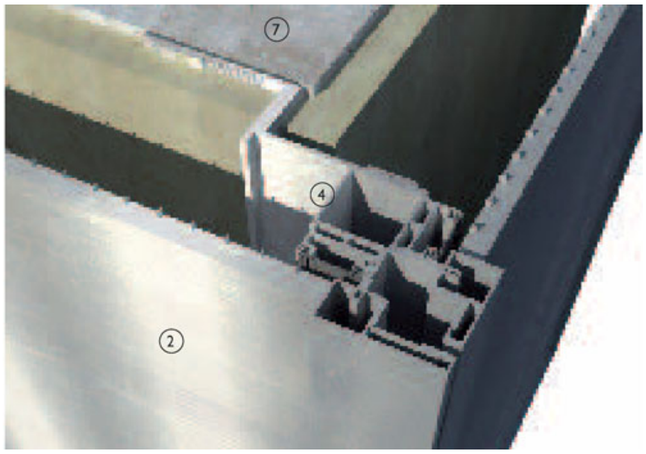
Horizontal section 1:10. External corner formed with special frame extrusion



3-D view of panel connection between mesh screens



Horizontal section 1:10. Connection between frame supported metal mesh panels



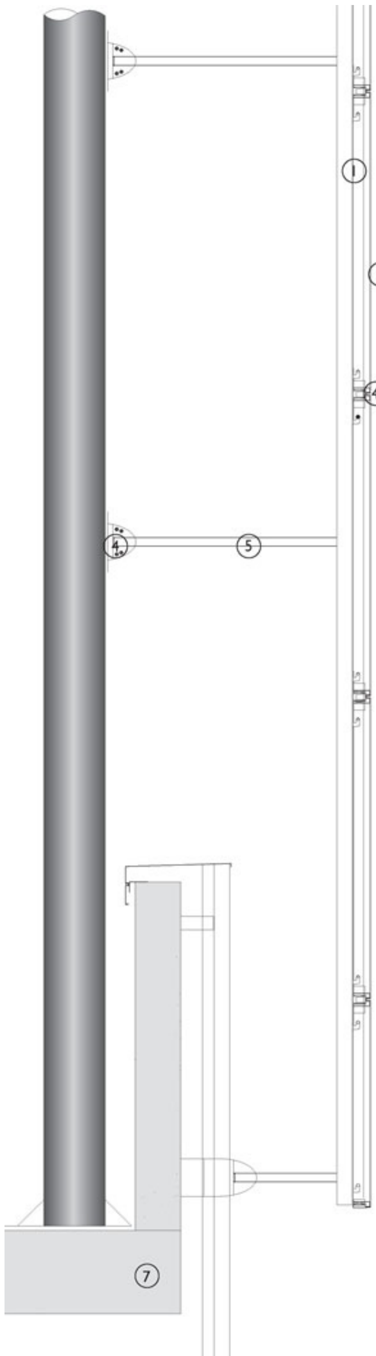
3-D view of external corner of mesh screen

Most of these meshes come in a maximum width of around 7500mm (25ft). Since the material is made as a continuous run, it can be made in very long lengths, making it ideal for use in a single run of material from top to bottom of a facade without joints. In terms of transparency, the material can vary from around 25% light transmission to 65% depending on the weave. The amount of light transmission can be varied by increasing the thickness and frequency of cables. The distance between rods cannot be varied by reducing the thickness of the cable, allowing it to be more tightly woven, but more cables are usually introduced to compensate for the loss of strength in the cable when tensioned. Cable thickness can vary from 2.0mm to 2.5mm (0.08in to 0.1in) diameter. Rod thicknesses can vary from 2.0mm (0.08in) up to 4mm (0.15in) diameter. The weave pattern can vary from 4mm x 10mm (0.18in x 0.37in) to 4mm x 100mm (0.18in x 4in), giving very different visual effects from dense to very open. In addition, varying densities can be woven into a single panel, or length, of material.

Meshes flexible in one direction are fixed by tensioning the cables at each end. The cable is usually set vertically to avoid sag associated with horizontal laying. The cables are looped in a secure loop at each end around a rod or bar. One end is fixed while the other is tensioned by springs set at intervals along the length of the horizontal bar. Springs are usually set at the bottom so that the mesh is first hung, then secured and tensioned at the bottom. Lateral stability to the mesh over a long run of the material is provided either by bars woven or fixed into the mesh, or by point fixings. The point fixings comprise discs set either side of the mesh to hold the material in place. A bolt runs through an opening in the mesh between the two discs, which is secured back to the supporting structure, typically a floor slab or backing wall. Meshes will span 2.0 to 2.5 metres (6ft 6in to 8ft) vertically between points of lateral restraint. Adjacent sheets can be fixed together by using a bracket with two bolts in the manner of bolt fixed glazing or by lapping the mesh panels and using a single bolt in the manner of a popper on textile cloths as used in denim jeans, for example. Applications of mesh using wide strips are increasingly common, in widths from 5 to 7metres, (16ft to 23ft) hung from continuous rods and restrained back to a frame at 1.0 to 1.5 metre (3ft 3in to 5ft) centres.

Fully flexible mesh

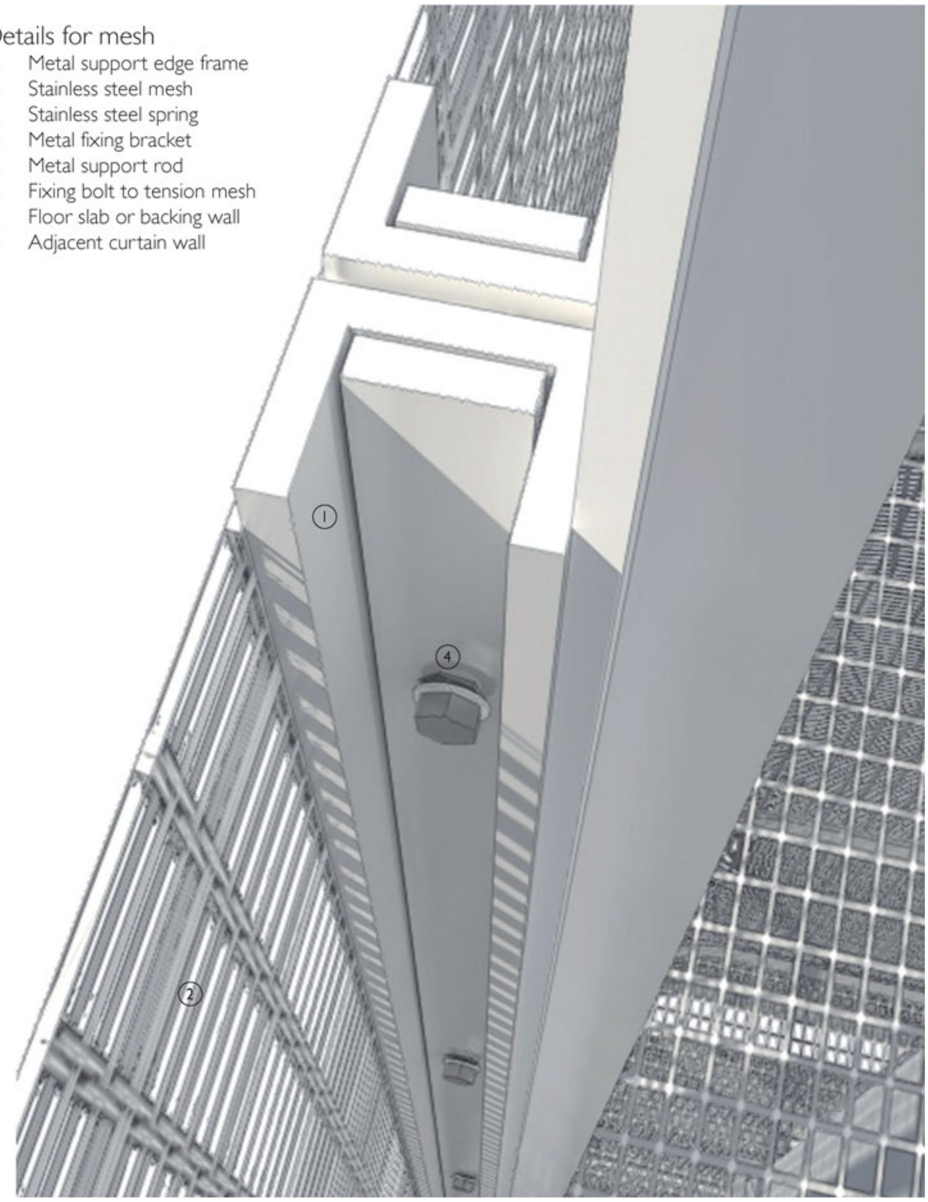
This material is made as a woven-wire cloth or as a crimped wire panel. Wires are crimped down the length of the material and straight wires across its width. The woven cloth type is manufactured primarily for small solar shading screens. It is also used for balustrades in continuous long lengths and as vertically- or horizontally-set bands of solar shading material. Large panels are not interrupted by joint lines. The material is fixed by tensioning it vertically. Closely woven meshes have a light transmission of between 1% and 5%, while crimped wire screens vary from 25% to 50%. The tightly woven types are made in widths from around 1800mm to 2400mm (6ft to 8ft) and are made in very long lengths. The more open weaves have an appearance similar to those with cables, using straight rod in one direction, weaving rod in



Vertical section 1:10. Metal mesh supported from steel structure on top of regular rainscreen clad structure

3-D view of metal mesh fixed to steel frame with maintenance deck behind

Details for mesh
1. Metal support edge frame
2. Stainless steel mesh
3. Stainless steel spring
4. Metal fixing bracket
5. Metal support rod
6. Fixing bolt to tension mesh
7. Floor slab or backing wall
8. Adjacent curtain wall



3-D view of metal mesh clamped to supporting frame

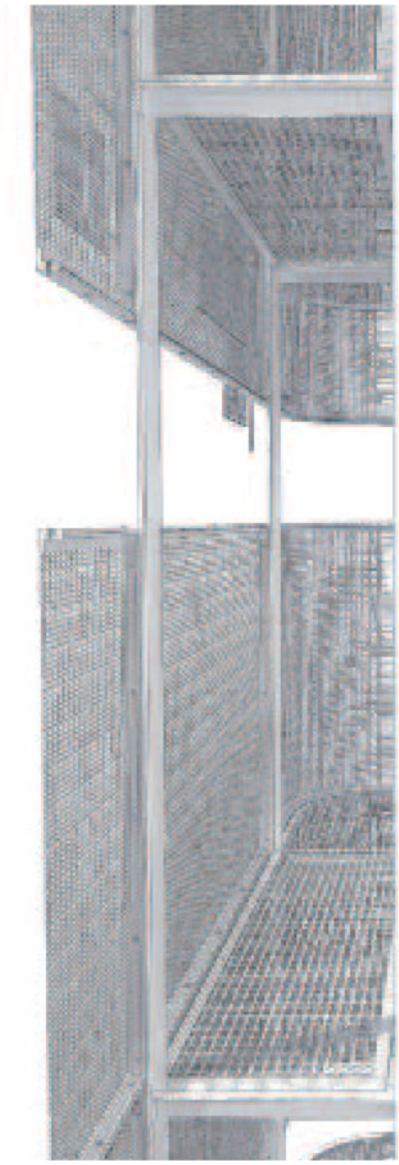
the other direction around the flat rod. These open weave types are made in widths of around 6000mm (20ft) though these sizes are difficult to use in facade panels since the support grid of around 2000mm (6ft 6in) is usually needed to restrain the material. Since the material is made from rod, metals other than stainless steel can be used, though typically copper and bronze are the most common alternatives. They are less rigid than stainless steel but can produce quite dramatic visual effects. A grid of 3mm x 1.5mm (0.125in x 0.0625in) is common in this more open weave material.

Mesh used on curves

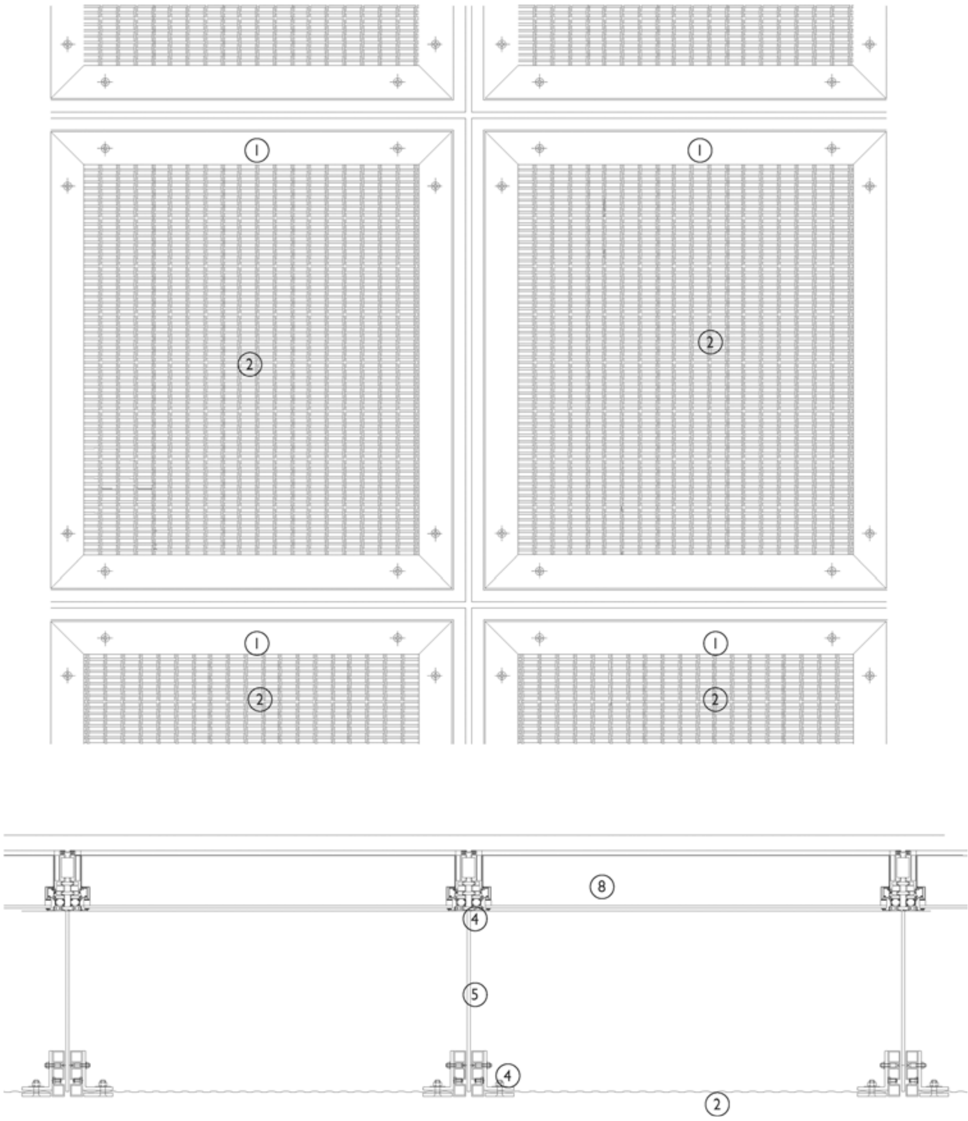
Regular mesh that is rigid in one direction is difficult to curve, as it is suited to flat, rectilinear designs. Curves can be formed over lengths of 2-3 metres (6ft 6in to 10ft) by setting out the cables on a curve top and bottom which forces the thin rods in the opposite direction to the curve. However, meshes are being developed which can take up curves more easily for complex geometries. Instead of using cables, loops of stainless steel strip are woven in loops between rows of rods. This allows the rods to be bent around a form or bowed out by brackets, while allowing the loops to be individually stretched between each row of rods. Variations on this type of mesh are set to grow over the next ten years.

Perforated metal

Non-rectilinear or irregular geometric shapes in flat or curved form can more easily be achieved in perforated metal. Although panel



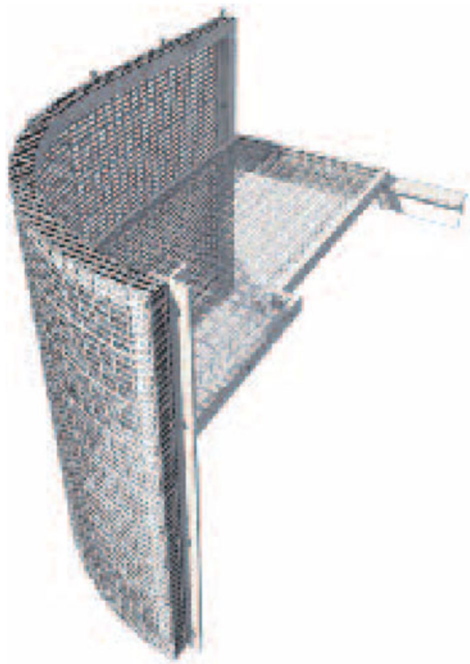
3-D view of metal mesh supported on steel framework with maintenance deck



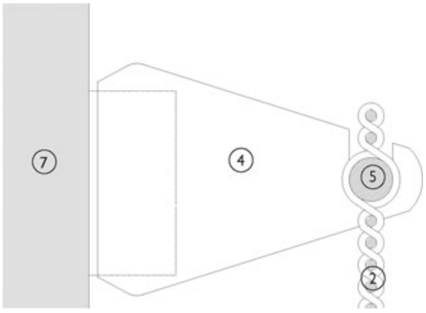
Elevation & horizontal section 1:25. Frame hung metal mesh supported from curtain wall glazing system

sizes are much smaller than tensioned mesh, a greater range of forms can currently be made more economically. Perforated metal in each mild steel (paint or polyester powder coated) and aluminium (polyester powder coated or PVDF coated) are used. Both materials are manufactured with perforations of different shapes and percentages of perforations. Circular holes are the most commonly used as they are straightforward to manufacture. They are also able to have a closely controlled percentage of perforation by varying both the size of the holes and their proximity. This makes the material very useful if a precise shading coefficient (percentage of solar shading) or light transmission is specified for a facade. By varying both the hole diameter and the centres of the holes, different visual effects of transparency can be achieved. Squares and various decorative motifs are also made but with less control on precise perforation percentages.

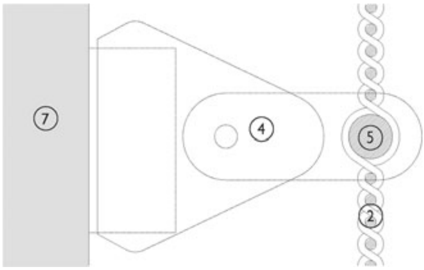
Steel and aluminium sheet are commonly available in sizes up to around 3 metres x 2.5 metres (10ft x 8ft) in 3mm (0.118mm) thick sheet allowing panels to be reasonably large, depending on wind load considerations. In general, the higher the percentage of perforation, the lower the wind load on the perforated metal panel. Perforated metal panels are usually fixed back to an edge frame made from angle or profile in the same material. The edges of the metal are usually not perforated in order to conceal the frame behind. The increased use of water jet cutting machines allows for a much greater control of the extent of pattern on a sheet. Perforated metal panels are then fixed back to the



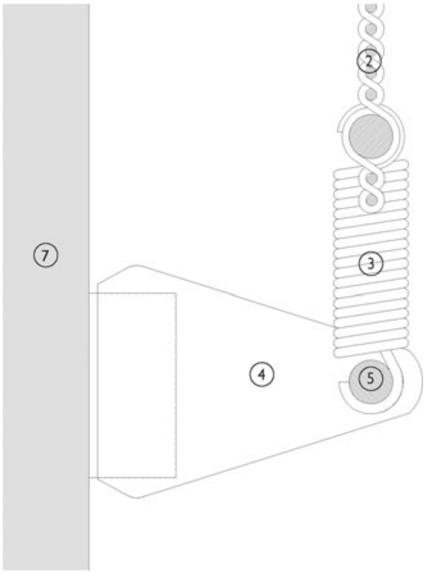
3-D view of metal mesh supported curved steel frame



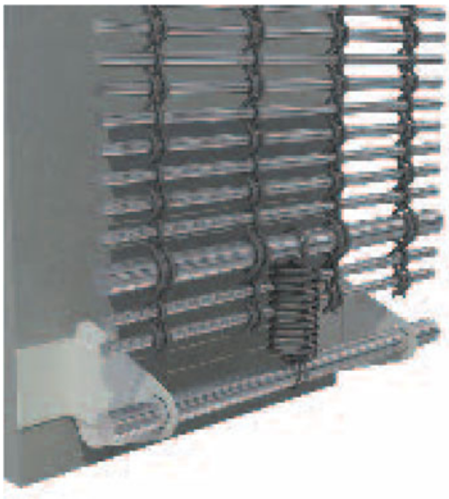
Vertical section 1:2. Flexible mesh top support



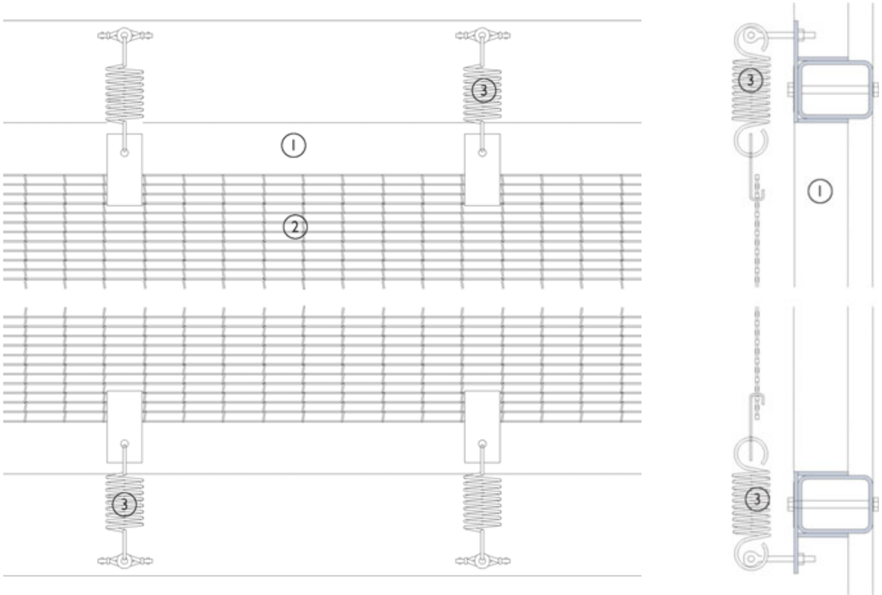
Vertical section 1:2. Flexible mesh intermediate support



Vertical section 1:2. Flexible mesh lower support with tensioning spring



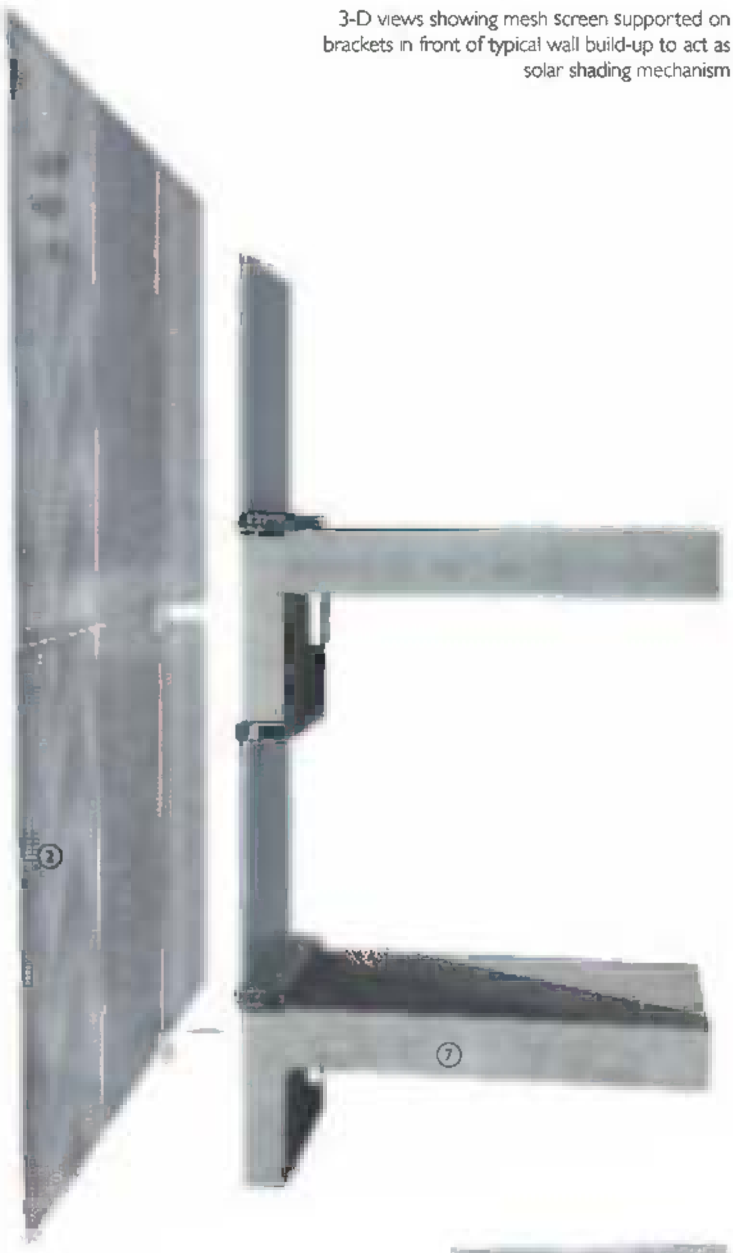
3-D view of metal mesh fixed to steel rod with tension spring



Elevation & vertical section 1:10. Flexible metal mesh supported top and bottom with tensioning springs

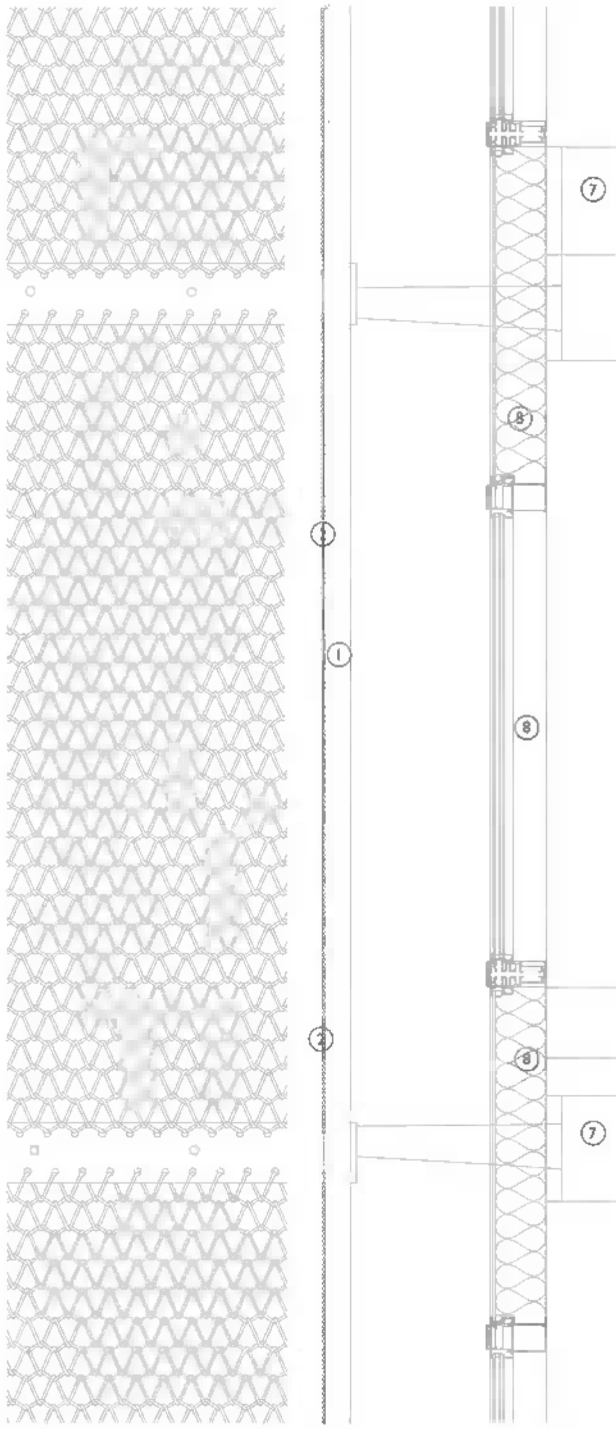
Horizontal section 1:10. Flexible metal mesh supported on vertical edges with tensioning mechanism

3-D view of metal mesh fixed in front of glazed facade to provide solar shading. A maintenance walkway occupies the space between the two systems



3-D views showing mesh screen supported on brackets in front of typical wall build-up to act as solar shading mechanism

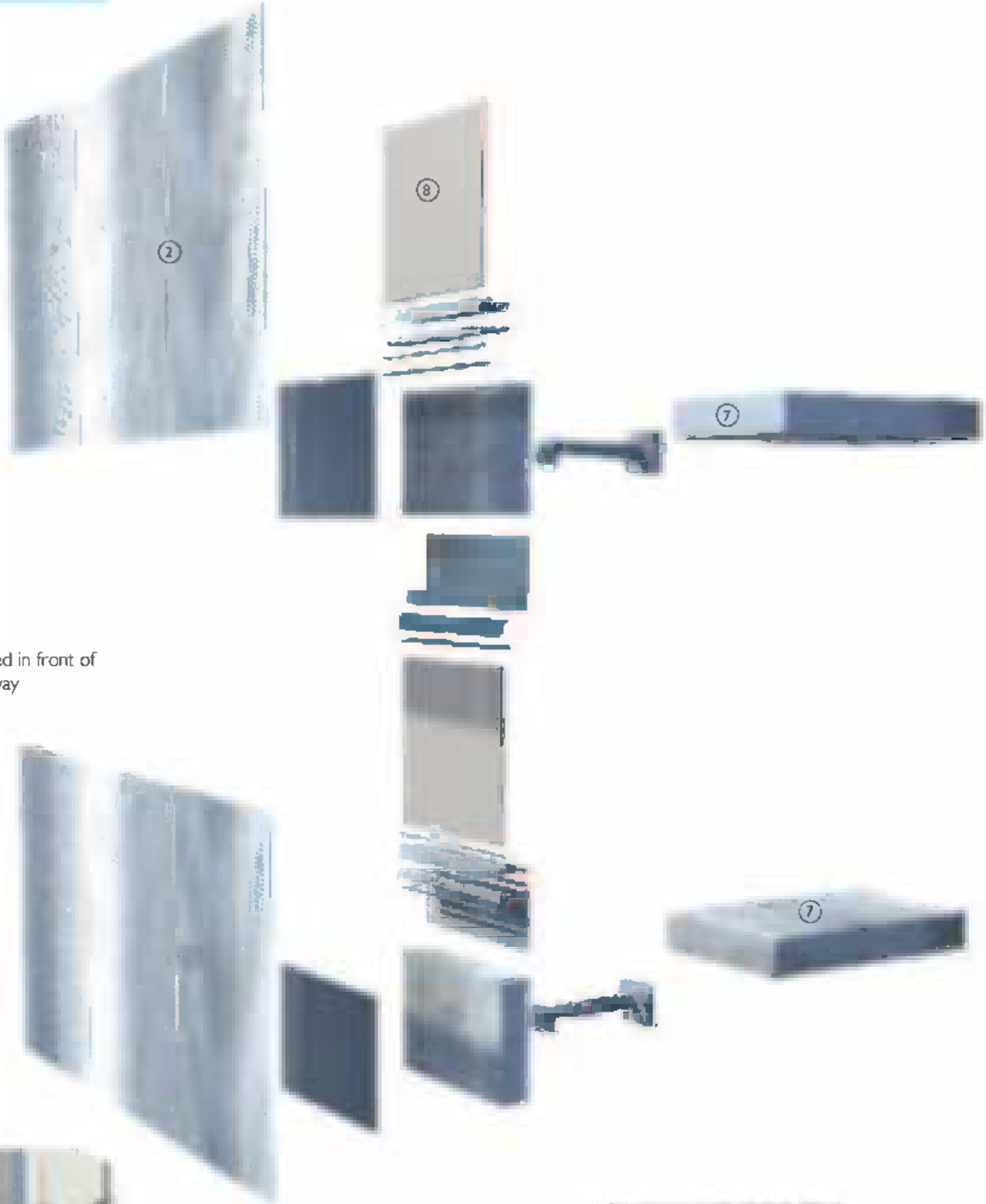
primary structure with a variety of hanging brackets, ties and struts to suit the design. The supporting structure is visually very refined if visible through the metal, particularly at night if the panel assembly is visible from lighting within the building. A series of forked pin connections or cast moment connectors are increasingly being used, with tapered tubular framing members or box sections with complex sections increasingly being the norm. Because the metal framing is exposed to the effects of weather, a high specification paint is used for steel and either polyester powder coating or PVDF coatings are used for aluminium. Anodising has become more popular in recent years but requires very close control in the factory to avoid visible colour differences between adjacent anodised panels.



Elevation and vertical section 1:10. Mesh screen supported on brackets in front of typical wall build-up to act as solar shading mechanism

Details for mesh

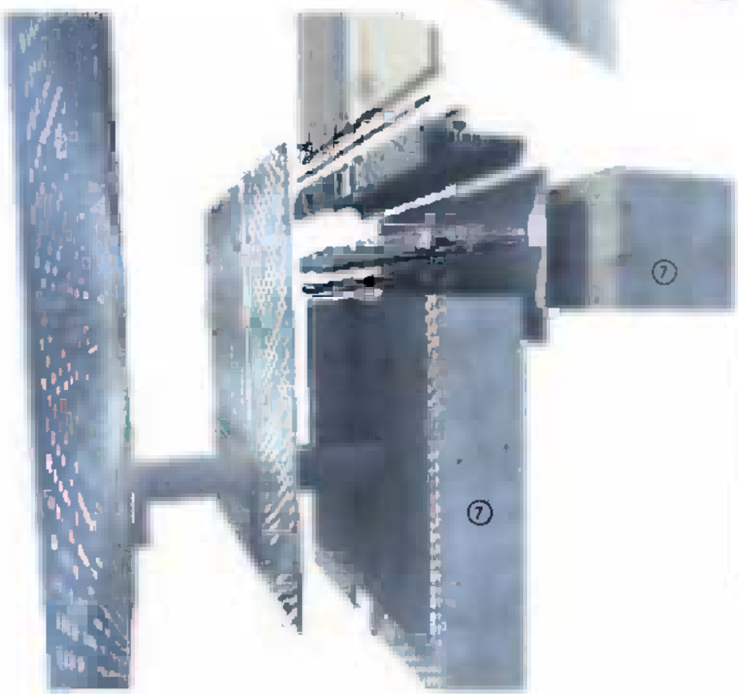
1. Metal support edge frame
2. Stainless steel mesh
3. Stainless steel spring
4. Metal fixing bracket
5. Metal support rod
6. Fixing bolt to tension mesh.
7. Floor slab or backing wall
8. Adjacent curtain wall



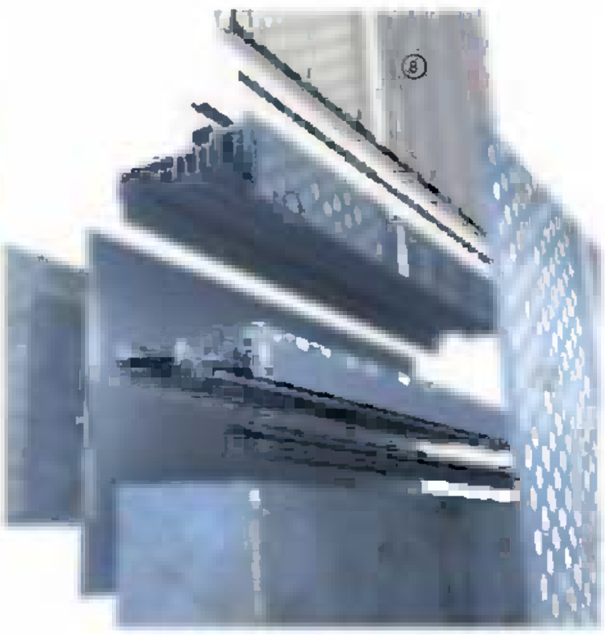
Details for mesh

1. Metal support edge frame
2. Stainless steel mesh
3. Stainless steel spring
4. Metal fixing bracket
5. Metal support rod
6. Fixing bolt to tension mesh
7. Floor slab or backing wall
8. Adjacent curtain wall

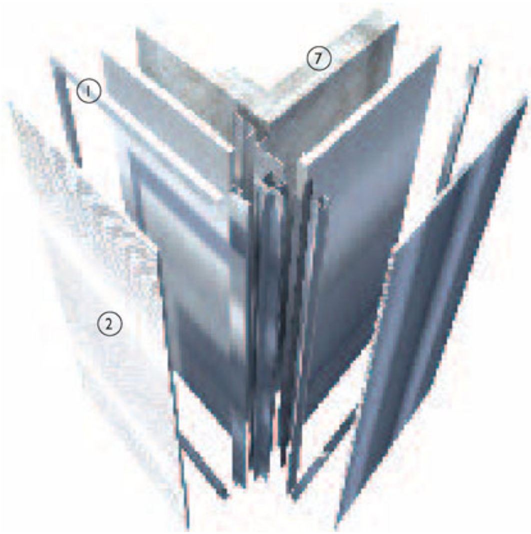
3-D exploded view of metal mesh fixed in front of glazed facade with maintenance walkway



3-D exploded detail view of metal mesh fixing method and upper floor junction



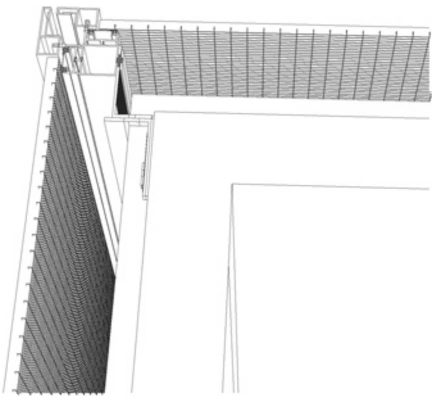
3-D exploded detail view of glazing connection in metal mesh and glazed facade



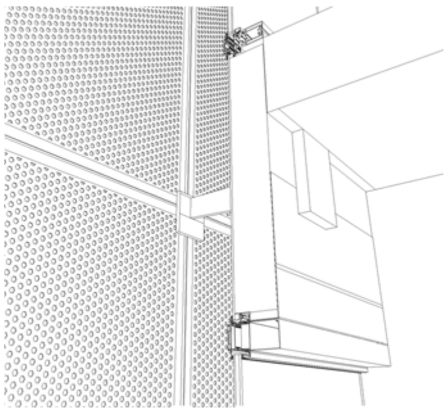
3-D exploded corner view of metal mesh panels fixed to steel supporting frame

3-D exploded view of hooked metal mesh fixing

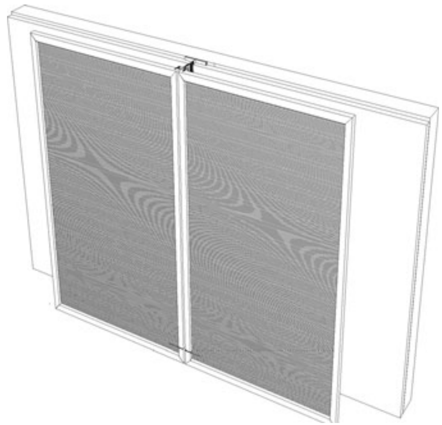
3-D exploded view of clamped metal mesh fixing



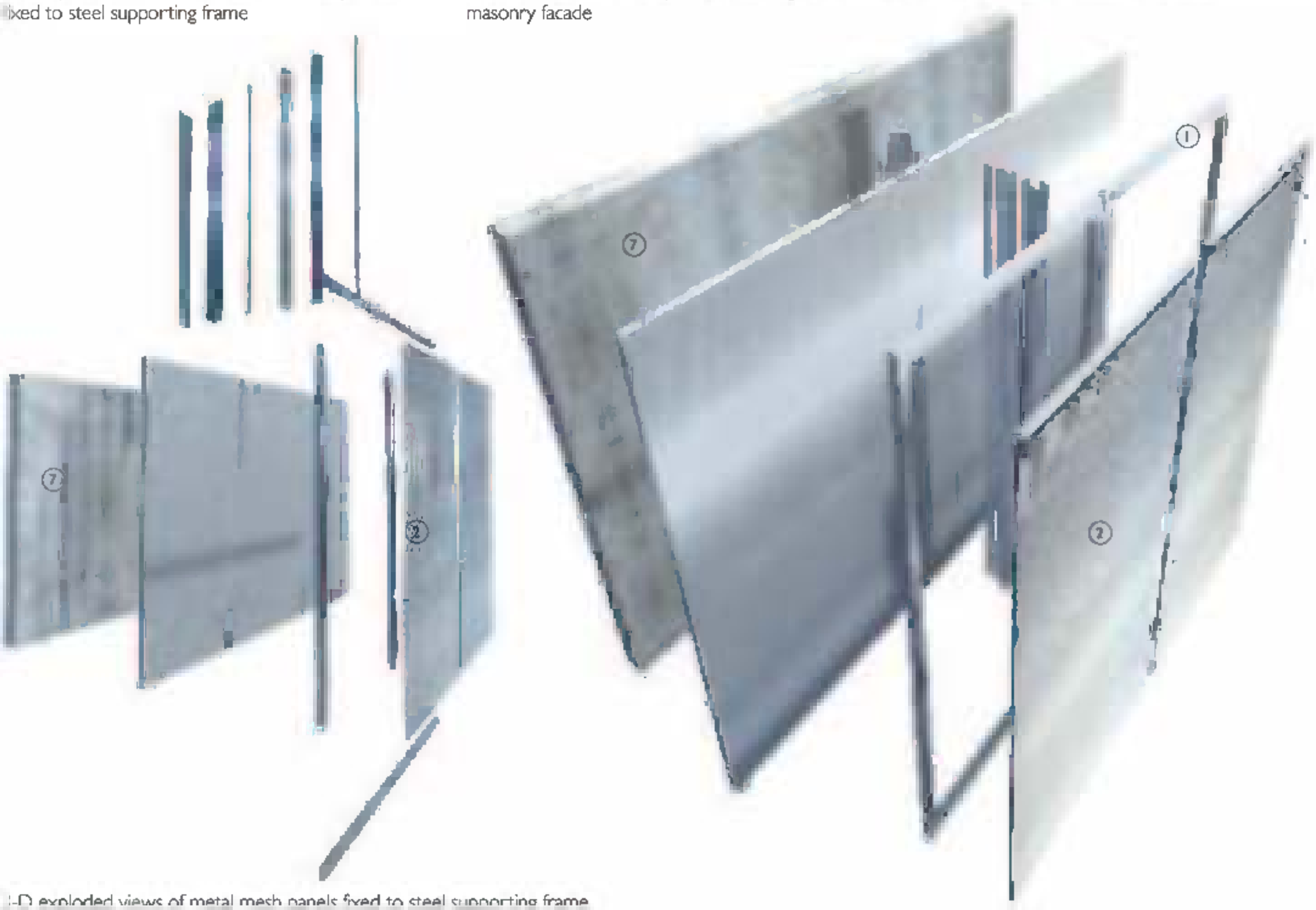
-D exploded corner view of metal mesh panels
ixed to steel supporting frame



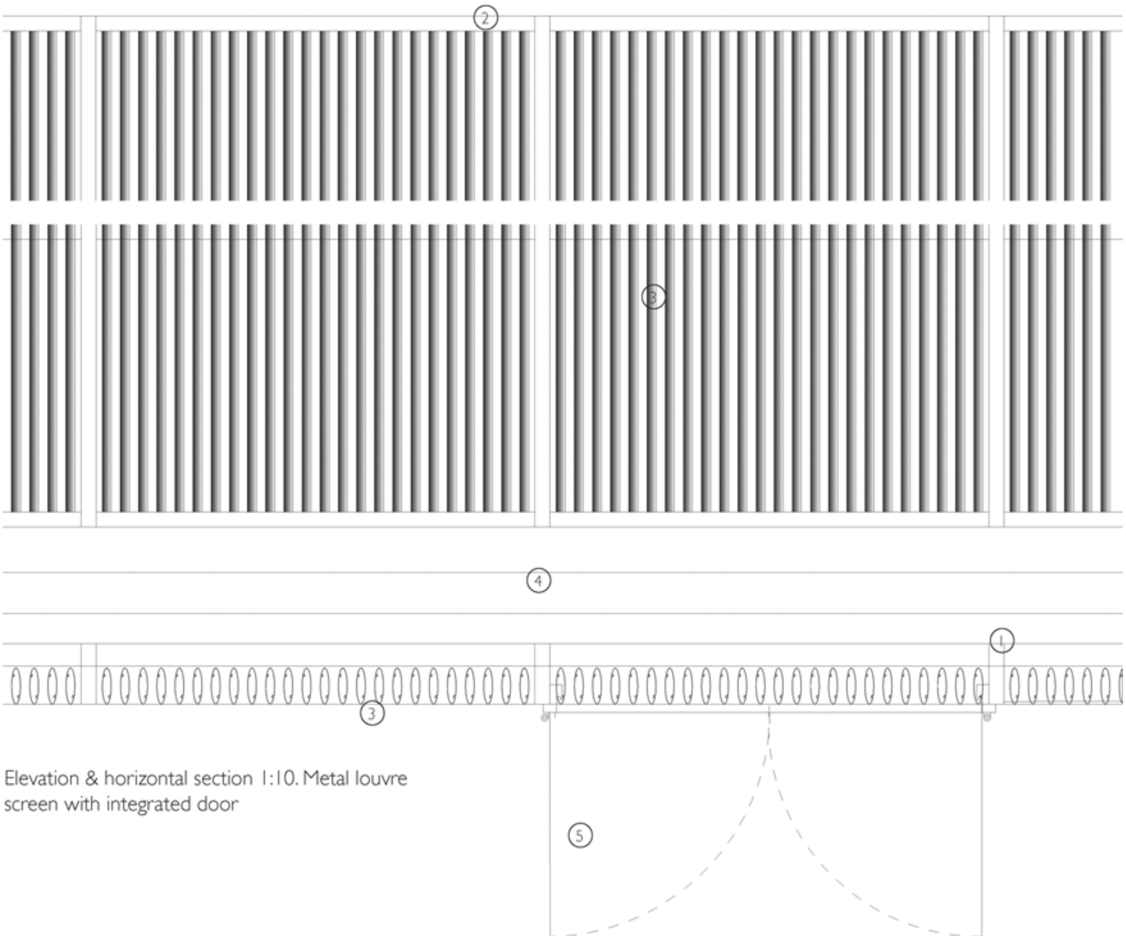
3-D view of metal mesh panels fixed to glazed masonry facade



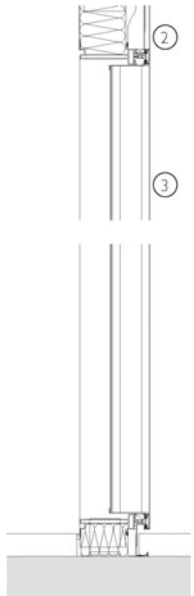
3-D view of mesh panel in isolation



-D exploded views of metal mesh panels fixed to steel supporting frame



Elevation & horizontal section 1:10. Metal louvre screen with integrated door



Vertical section 1:10. Vertically set metal louvres

Details
1. Extruded aluminium frame
2. Stick curtain walling - type carrier system
3. Extruded aluminium louvre blades
4. Backing wall
5. Louvre panel door
6. Thermal insulation

Metal louvres are typically used for two purposes: as weather-resisting screens to naturally ventilated spaces such as plant rooms, as terminations to the ends of air-handling ducts where they penetrate the external wall, or alternatively as solar shading on the outside of facades in front of glazed walls or windows. Glazed louvres are also used to provide natural ventilation to winter garden spaces where they also provide light, as in high level clerestorey glazing or in glazed walls in winter gardens in housing. Glass louvres are generally adjustable. Metal louvres are used for air handling ducts or plant rooms, and can be in single, double or triple bank depending on the amount of weather resistance required.

Metal louvres

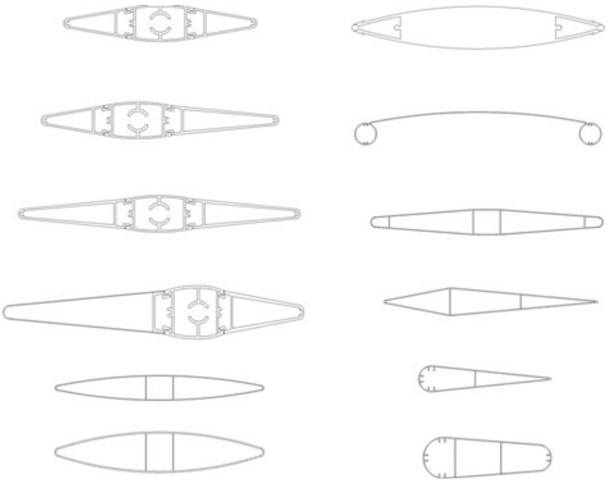
Louvre panels can be set either horizontally or vertically. Horizontal louvres have inclined blades mounted in a frame of the same material. Some louvres throw the water clear of the edge of the blade at the front. Others where more weather protection is needed, have either a drainage channel at the front, or are made as a V-shape in order to drain water away into the sides of the frame where it is ejected to the outside at the cill. Open gauge mesh is usually set at the back of the louvre panel to prevent the passage of birds. Louvres without drainage channels are used in sheltered areas and also where rain that is blown through the louvre will not damage the building fabric. Drained louvres are used where more weather protection is needed, usually where exposure to the weather is more severe and where water penetration through the panel must be reduced. These drained louvres allow a little less air movement than the standard types, and more louvre area is usually provided to compensate for this. The use of a double bank louvre ensures that water blown over the top of the outer blade will run down the face of the inner blade and be drained away. The free area from the louvres is around 50%.

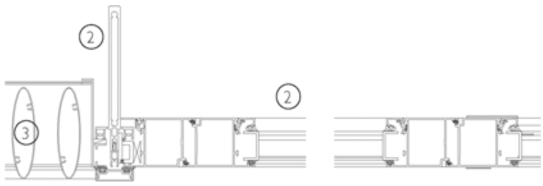
Horizontally-set blades are set 50mm apart. Stiffener bars are set at centres from 1000mm (3ft 3in) to 1500mm (3ft) vertical centres, depending on blade size and material thickness. These bars are not visible directly from the outside but can be seen from below if louvres are set at an angle that allows views through them. Louvre blades are fixed to the stiffeners with extruded aluminium clips to stiffen the blades. Corners of frames to louvre panels are mitred and screwed or welded. The edge has different profiles to suit being glazed into adjacent curtain walling, and has either recessed joints between panels, or a wide frame, to suit the type of additional support needed for the complete louvred panel width.

Vertically-set louvres have blades set at an angle (in plan) such that water drains down the face of the louvres and is drained away at the bottom of the frame. They are deeper than the simplest horizontal types and perform in a similar way to the drained horizontal types. Their depth also ensures that views through the louvre panels are severely reduced. Profiles for vertical louvres can be both V-shaped and elliptical. The free area is also around 50%. Panels are assembled in a factory for coupling together on site. Typical panel sizes are around 1.5 metres

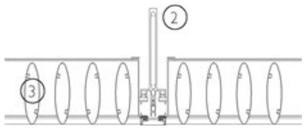
3-D detail view of metal louvres

3-D detail view of frame supported metal louvres used as a shading device in front of glazed curtain wall

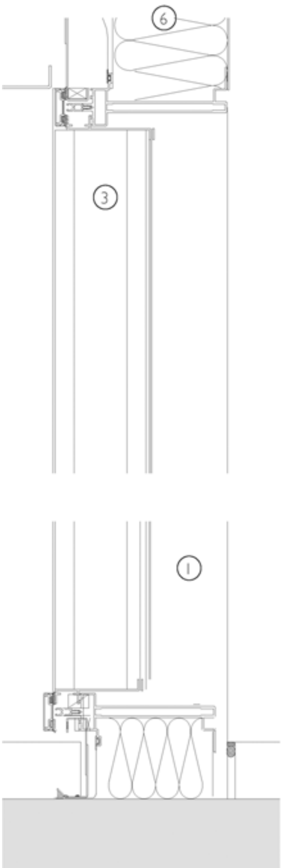

Profile options for metal louvres



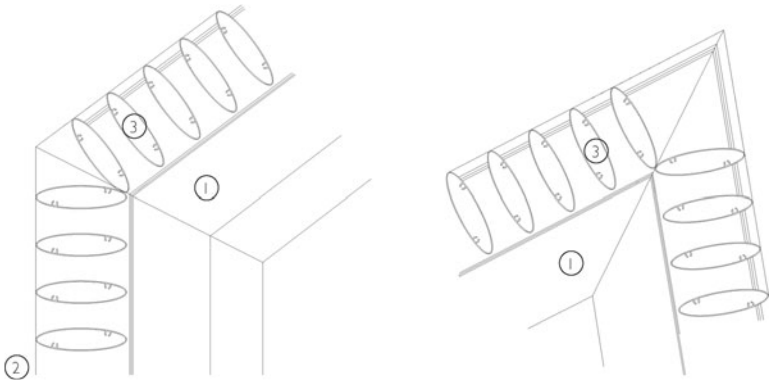
Horizontal section 1:10. Junction between vertically set metal louvre panels and metal door



Horizontal section 1:10. Junction between vertically set metal louvre panels



Vertical section 1:10. Door with vertically set metal louvres

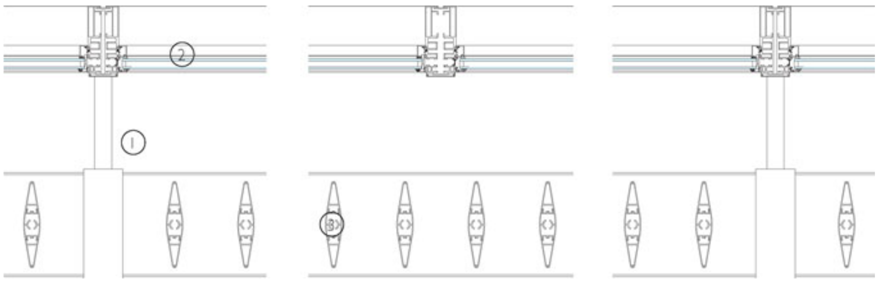


Horizontal section 1:10. Corner arrangement for vertically set metal louvre panels

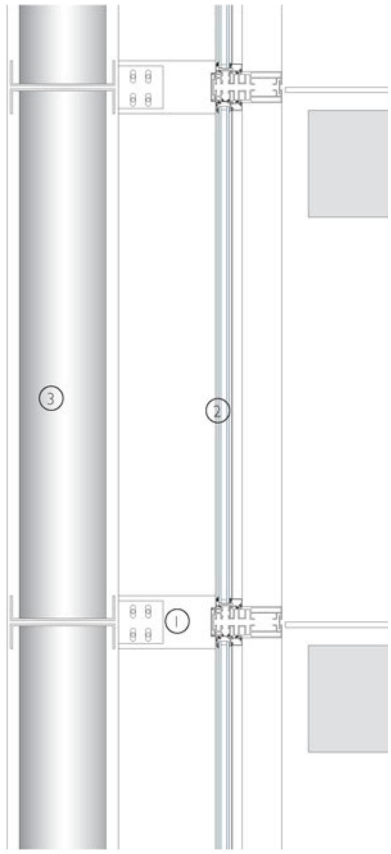
3-D view of frame supported metal louvres used as a shading device in front of glazed curtain wall

3-D view of frame supported metal louvres

3-D view of frame supported metal louvres



Horizontal section 1:10. Vertically set metal louvres used as shading device



Vertical section 1:10 .Vertically set metal louvres used as shading device

× 2.5 metres (5ft × 8ft) for both vertical and horizontally set louvres. Larger panels can be fabricated, but transportation to site becomes more difficult. Louvred panels can be arranged in heights up to around 4 metres (13ft) with extruded aluminium mullions. Above this height, additional steel posts are required behind panel joints to provide both support and lateral restraint.

Louvre panels can also be set at inclined angles but resistance to rain penetration is significantly reduced on inclined walls that can be seen from below. Louvres can be set upside down to avoid views through the screen, but they provide no weather protection. In both cases, an additional vertical louvre is set behind to exclude rain.

Banks of louvre blades can also be made to tilt to suit varying ventilation requirements, such as in buildings with a high degree of natural ventilation. Panels can open and close from rain and wind sensors forming part of the BMS (building management system). Panel sizes are similar to those of fixed panels, that is, 1.5 × 2.5 metres (5ft × 8ft). They have a single rod set into the edge frame that connects all the blades together and which is pushed up and down by a separate motor or is connected to a manual winding rod.

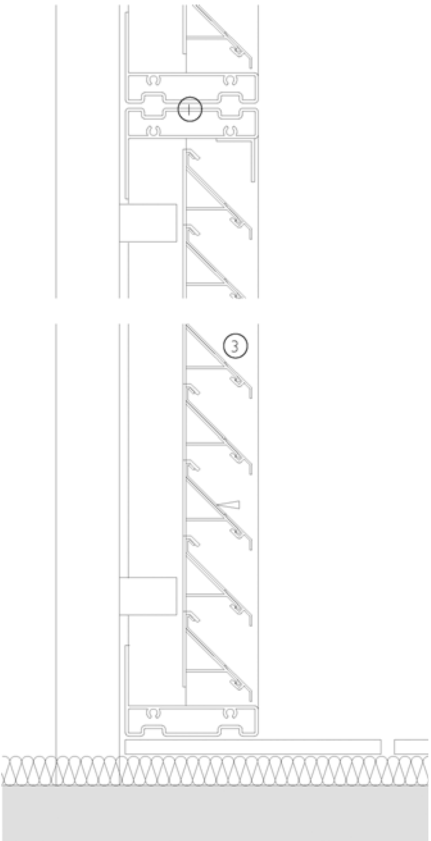
Doors are made in the same way as louvre panels but have stiffer frames to suit movement. They are designed with louvre panels and are often the same size in order to conceal their appearance.

Sandtrap louvres are designed for use in sandy and dusty conditions to prevent most airborne sand and dust from passing through the louvre. They consist of vertically-set C-shaped aluminium profiles which interlock to provide a continuous barrier. Air passing through the louvre passes round the interlocking profiles while sand is trapped by the inner profile and falls to the bottom of the frame. The cill is inclined to ensure that sand falls out of the bottom of the panel at the front. Sandtrap louvres remove most of the sand and dust particles before the air reaches the filters on mechanical ventilation equipment. Insect screen is also usually provided and this has little effect on air flow rates. Maximum sizes are similar to those of other louvre types in 1.5 × 2.0 metres (5ft × 6ft 6in), though as with all louvre types, larger panels can be specially made.

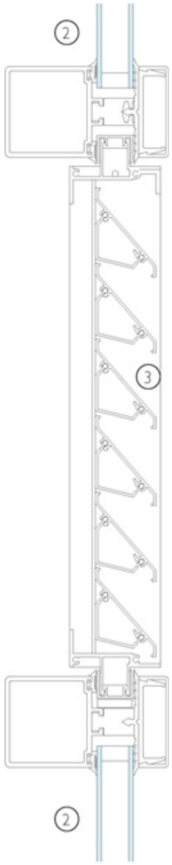
Glazed louvres

These have traditionally been poor excluders of air (high air infiltration rates) but they have improved significantly in recent years. The amount of opening can be closely controlled. They consist of glass blades held in an aluminium frame or in aluminium clips, secured on pivots into an edge frame made from extruded aluminium profiles. Some clips holding the glass in place are made from polypropylene rather than aluminium, to avoid rattling between the two components. The most recent development has been in thin aluminium clips and the use of bolt fixed glazing to hold the glass in place.

Louvre glass blades are usually made in laminated glass for safety, though float glass is sometimes used for small-scale applications. Solar control glasses are often used to match adjacent areas of glazing. Single or double glazed units are available. Glass louvre panels are either hand operated by a wire cable-type winding handle or are electrically oper-

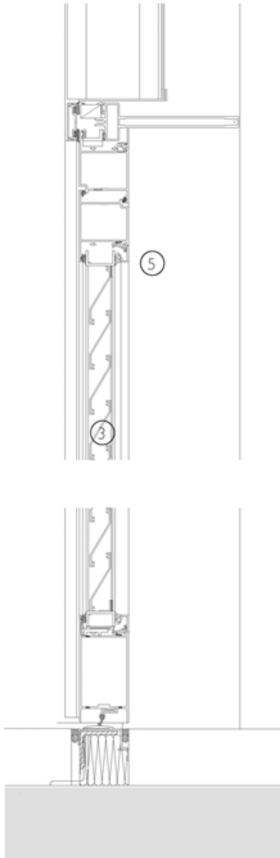


Vertical section 1:10. Frame supported metal louvre screen

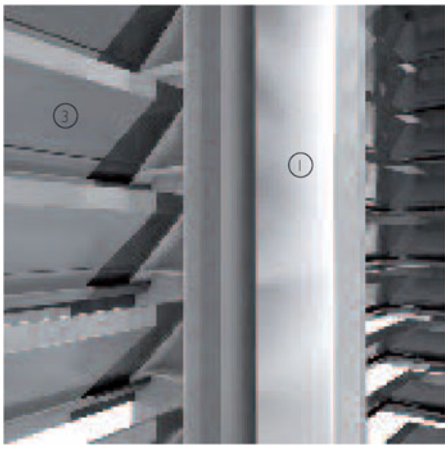


Vertical section 1:10. Metal louvre panel supported in curtain walling system

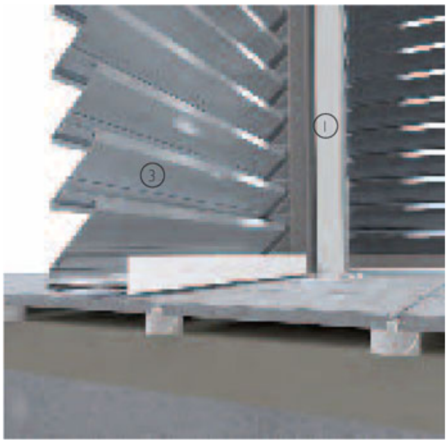
Vertical section 1:10. Metal louvre panel in rainscreen type facade



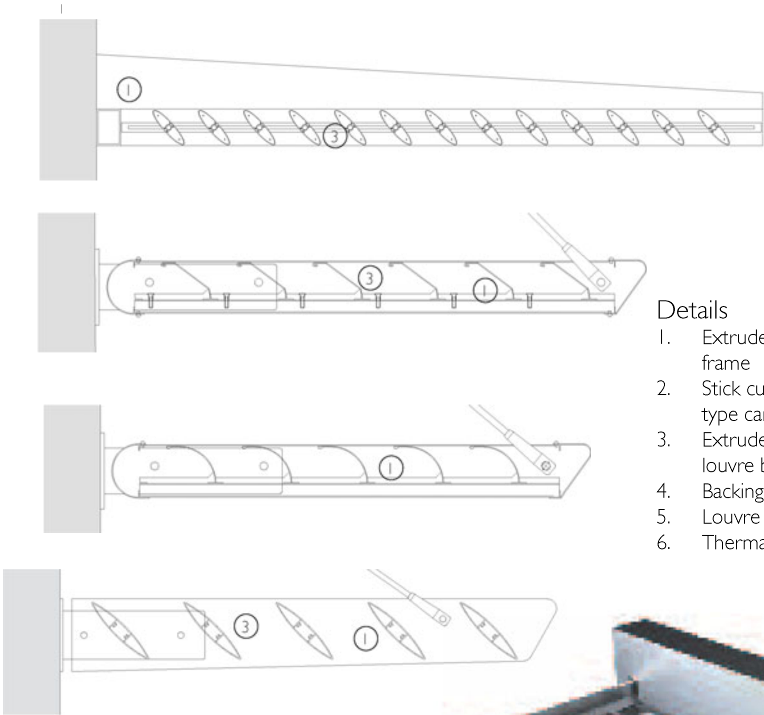
Vertical section 1:10. Door with horizontally set metal louvres



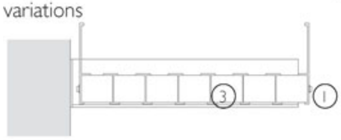
3-D view of frame supported metal louvres



3-D view of frame supported metal louvres at ground level



Vertical section 1:10. Metal louvre canopy variations



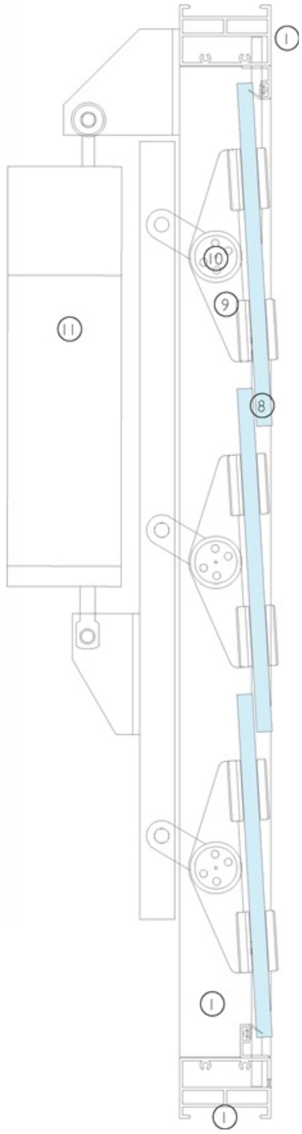
Vertical section 1:10. Walk on metal louvre canopy

Details

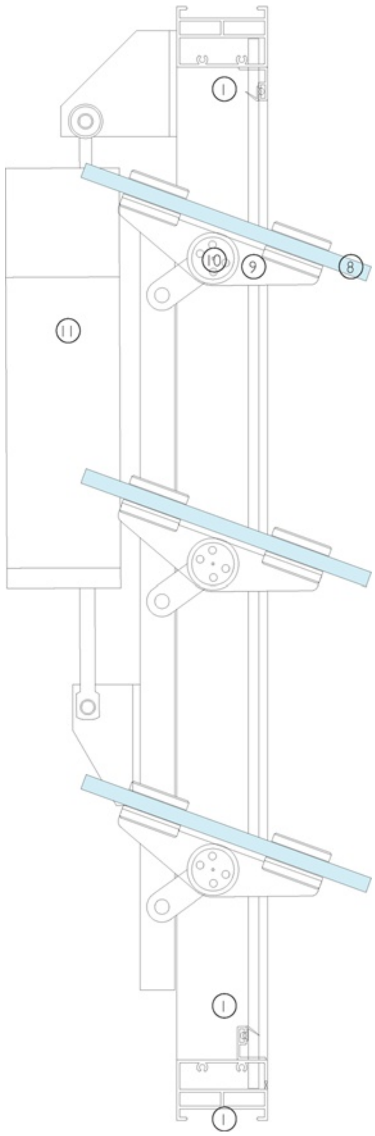
1. Extruded aluminium frame
2. Stick curtain walling - type carrier system
3. Extruded aluminium louvre blades
4. Backing wall
5. Louvre panel door
6. Thermal insulation

3-D view of metal louvre canopy

3-D view of mechanically controlled opening glass louvres in open position



Vertical section 1:10. Mechanically controlled opening glass louvres in closed position



Vertical section 1:10. Mechanically controlled opening glass louvres in open position

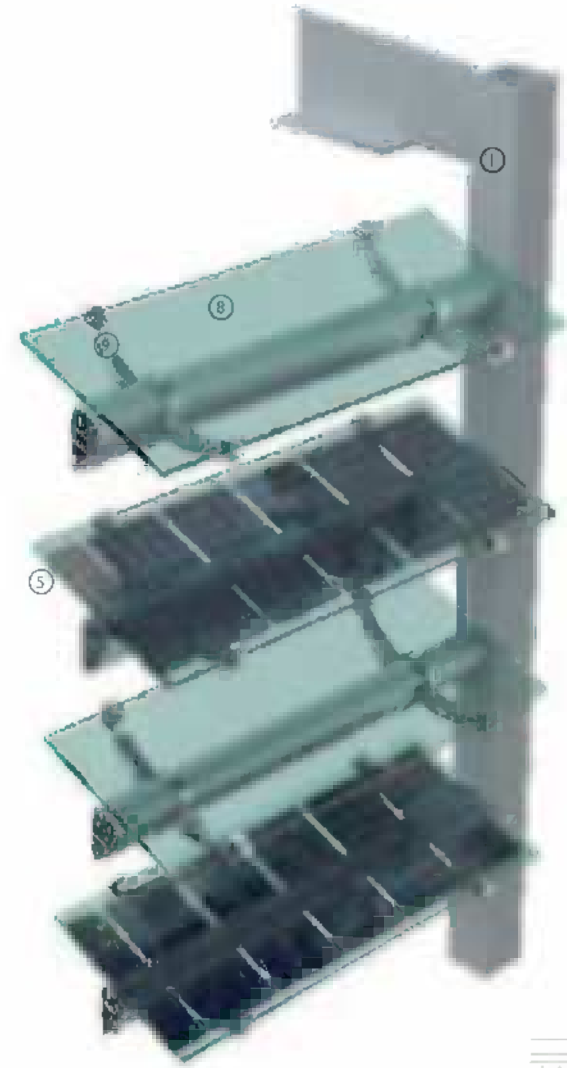
3-D view of mechanically controlled opening glass louvres in closed position

ated with rods as used in metal louvres. Electrically operated units are generally 1500mm (5ft) high to suit the length of the rods. Panels are coupled vertically or horizontally to form a large-scale screen of panels. They can also be glazed into curtain walling systems. Maximum sizes are bigger than metal louvres in 2400mm x 2400mm (8ft x 8ft) approximately, but maximum length of ventilator unit is around 1200mm (4ft). Automatic opening types are used as smoke vents in the event of fire. They provide around 70% free area when fully open.

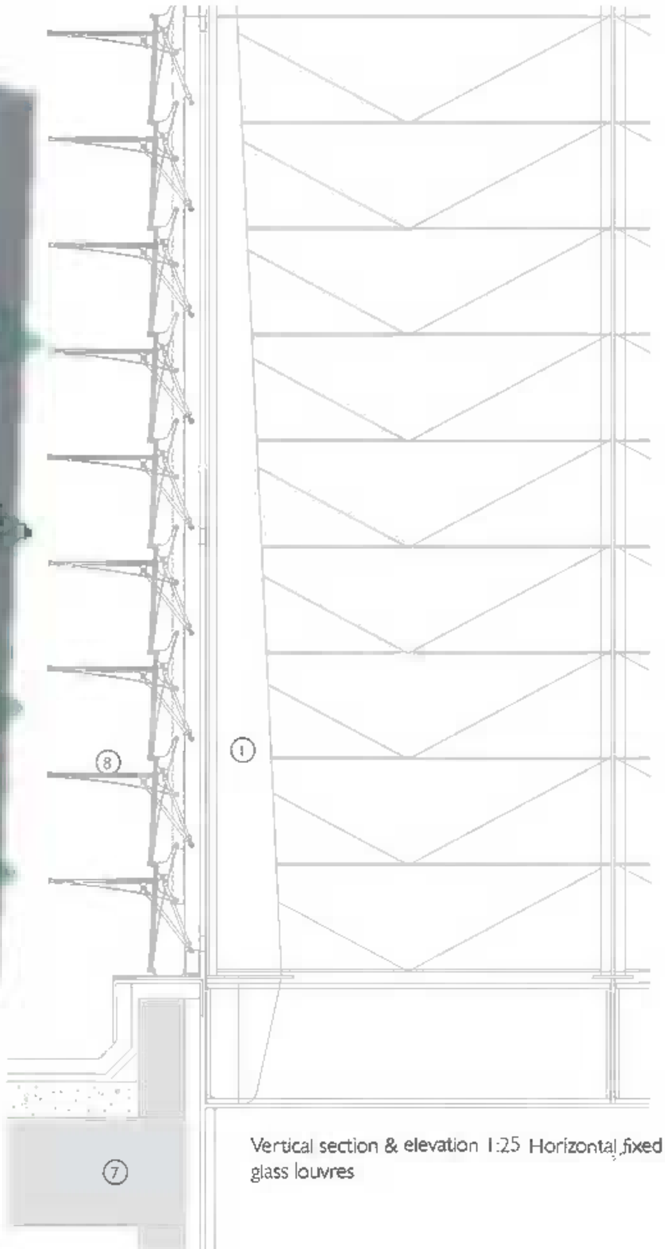
Where double glazed units are used, they are typically in 24mm thick overall units of 4/16/4 (glass/cavity/glass). The outer 4mm is slightly thicker if a laminated glass is used for safety. Like single glazed louvres, the maximum length of a panel is 1200mm (4ft), but two are commonly joined to provide an overall maximum panel length of 2400mm (8ft). The thicker frames give less free area for ventilation of around 50%. Although the glass is insulated for reasons of energy conservation, frames are not yet thermally broken. Condensation risk when windows are closed is assessed for each application.

Solar shading

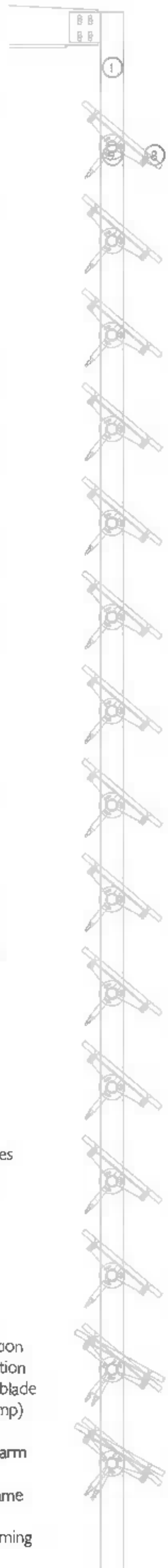
Metal louvres are also used as solar shading on glazed facades. Louvres are located either in panels set away from the external wall or horizontally projecting from the facade as cantilevered panels. Louvres are set either horizontally or vertically to suit the protection needed from varying sun angles. Vertical-



3-D view of fixed glass louvres with option of integrated photo-voltaic cells



Vertical section & elevation 1:25 Horizontal fixed glass louvres



ly-set louvres are positioned forward of the glass, usually a minimum of 600mm (2ft) to allow a person to pass between the external wall and louvres for maintenance access and cleaning. The shading devices are fixed to vertical posts or mullions which usually coincide with the module of the glazing behind. Horizontally-set panels consist of fixed louvres, usually inclined at 45° to the vertical in order to maximise the shading effect. The louvres are fixed to mild steel channels or T-sections which are in turn fixed to support brackets projecting through the external wall. Where glazed curtain walling is used, the support bracket goes through the mullion (vertical member) where it can be properly sealed against water penetration. Louvres for both vertical and horizontal shading usually span much further than those used in 1200mm (4ft) wide opening louvre panels, and need to be more rigid as a result. Panels project a maximum of around 1000mm (3ft 3in) without additional diagonal tie rods to prop the panels. Most proprietary systems can reach 2000mm (6ft 6in) with an additional diagonal brace.

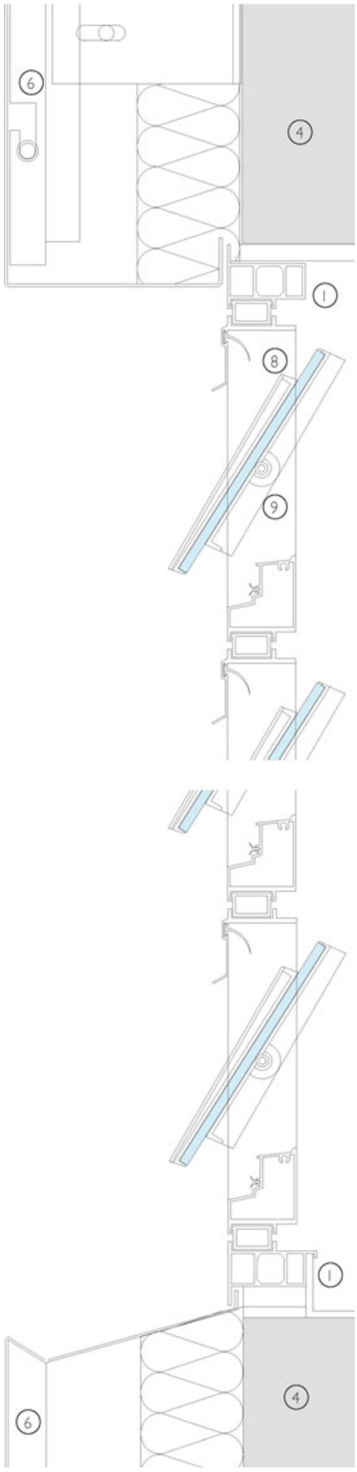
Elliptical and aerofoil-shaped aluminium profiles are most commonly used since their shape is seen outside the building and from inside. More traditional Z-shaped louvre profiles are also used. An advantage of horizontally-set louvres over projecting canopies is that they do not require rainwater drainage that is needed for a continuous horizontal surface. Small louvre blades are made as a single extrusion, but larger louvres, up to

Details

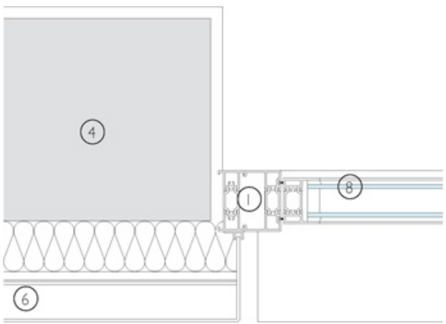
1. Extruded aluminium frame supporting louvres
2. Stick curtain walling - type carrier system to louvre panels
3. Extruded aluminium louvre blade
4. Backing wall providing support
5. Photovoltaic panel
6. Adjacent wall construction
7. Adjacent roof construction
8. Laminated glass louvre blade
9. Point fixing (bolt or clamp)
10. Hinge
11. Hydraulically operated arm to operate louvres
12. Extruded aluminium frame to glass louvre
13. Double glazed unit forming louvre

Vertical Section 1:25. Glass louvres fixed to steel supporting frame

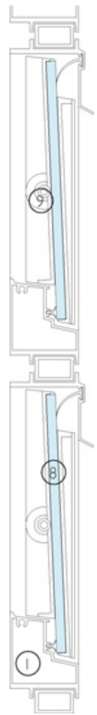
Details
1. Extruded aluminium frame supporting louvres
2. Stick curtain walling - type carrier system to louvre panels
3. Extruded aluminium louvre blade
4. Backing wall providing support
5. Photovoltaic panel
6. Adjacent wall construction
7. Adjacent roof construction
8. Laminated glass louvre blade
9. Point fixing (bolt or clamp)
10. Hinge
11. Hydraulically operated arm to operate louvres
12. Extruded aluminium frame to glass louvre
13. Double glazed unit forming louvre



Vertical section 1:10. Single glazed louvre window panels set into metal raincreen facade



Horizontal section 1:10. Single glazed louvre window panels set into metal raincreen facade



Vertical section 1:10. Single glazed louvre window panels in closed position

3-D view of single glazed louvre window system in open position

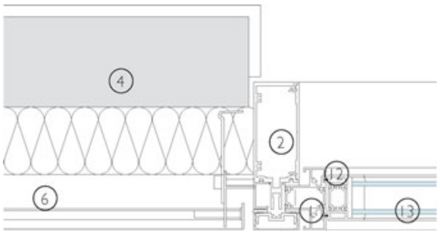
around 500mm (1ft 8in) in width are made from an extruded aluminium core to which curved or flat aluminium sections, usually 3mm (0.118mm) thick, are fixed. The ends of profiles are fitted with extruded aluminium end caps both for visual reasons and to protect the inside surfaces from corrosion. Aluminium louvres are finished in either PVDF or polyester powder coating. Blades are usually fixed at their ends from the centre of the extrusion at a single point at each end.

Where louvres are motorised, they are fixed at single pivot points to vertical posts. Link rods are set into the support post joining each blade in order to operate a set of louvres from a single motor. Pivots have nylon bushes fitted to avoid long term rattle and noise from the moving parts.

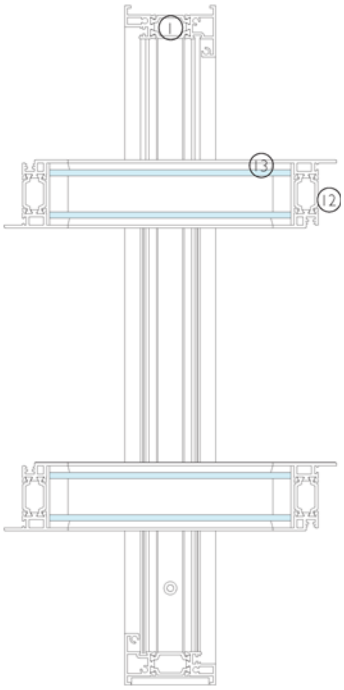
Vertically-set louvres use the same variety of section profiles and are set on transom (horizontal) sections that are connected back to mullions or directly back to the external wall. Vertical louvre sections using an elliptical or aerofoil profile can span up to around 3000mm (10ft) vertically without need for additional stiffeners.

Walkways

Horizontally-set louvres can also be used as maintenance walkways if they are made sufficiently rigid. T-section aluminium profiles are used, and have a serrated top to provide an anti-slip surface. A fall arrest system is used to secure maintenance personnel to the walkway. This consists of a continuous cable or tube fixed to a convenient point along the walkway. A maintenance person in a harness is then linked to the continuous cable or tube



Horizontal section 1:10. Double glazed louvre window system set flush with metal rainscreen cladding

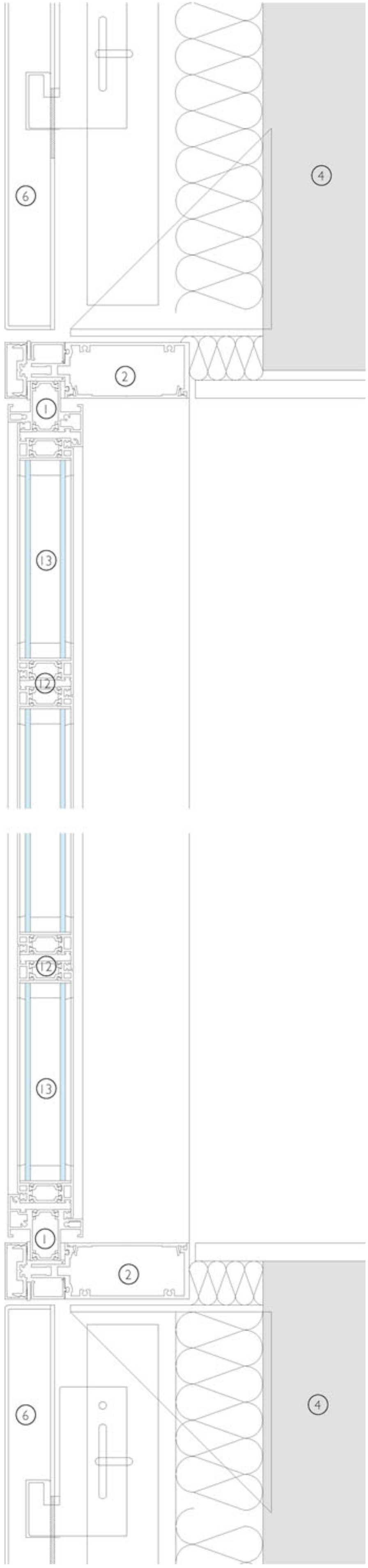


Vertical section 1:10. Double glazed louvre window system in open position

3-D view of double glazed louvre window system in open position

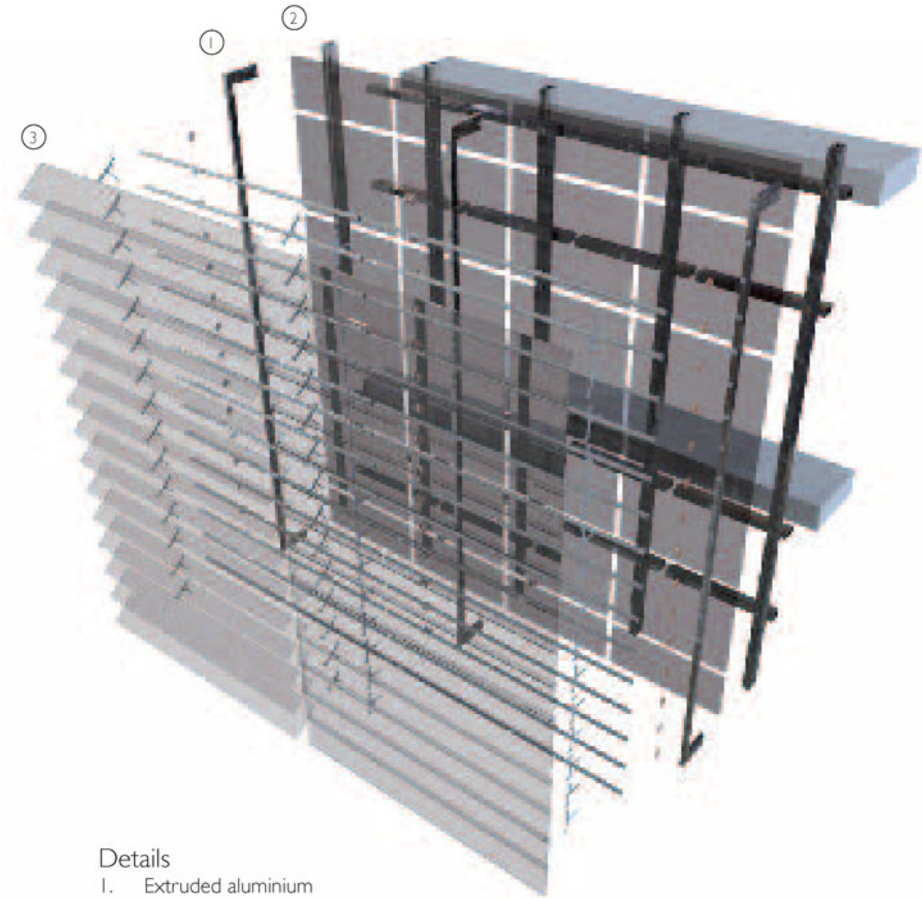
by a secure line. The aluminium T-sections are fixed to steel I-sections or channels which span between column supports adjacent to the external wall, typically at around 7500mm (24ft 6in) centres. The main sections supporting the T-sections are fixed to stainless steel or aluminium brackets that project through the external wall from the edge of the floor slab.

A recent development in metal louvre design is in movable types. Louvres are set on a moving rack which allows them to be moved from open to closed, using perforated aluminium sheet to form louvres. When closed, the louvres create a translucent screen with 20% to 50% light transmission (depending on the degree of perforation in the steel) to 100% light transmission when open. This allows a glazed wall to deal with changing sun angles at different times of day and different times of year through a change in the angle of the blade only. This system is used on both vertical and horizontal planes, for example on large glass facades as well as projecting areas of horizontal glazing within the facade. The use of more complex metal profiles where blades interlock, together with different perforated metals and their connection to a BMS (building management system) is sure to make significant developments over the next ten years. Such controls can reduce energy consumption within a building by reducing the amount of mechanical cooling needed as well as control glare from direct sunlight.



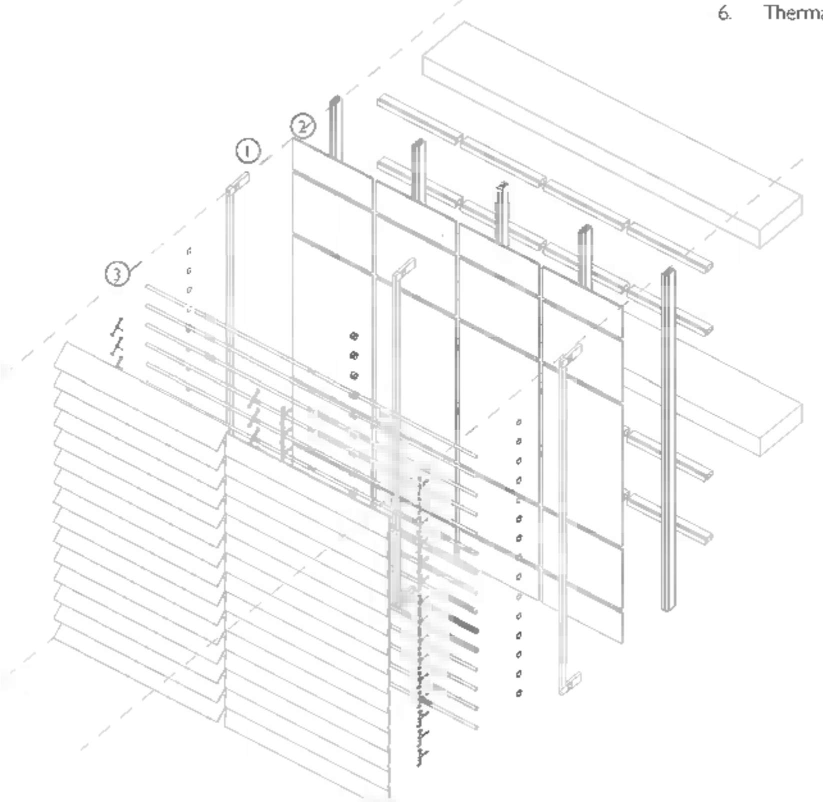
Vertical section 1:10. Double glazed louvre window system in closed position set flush with metal rainscreen cladding

3-D detailed views of frame supported solar control glass louvres used as a shading device in front of glazed curtain wall



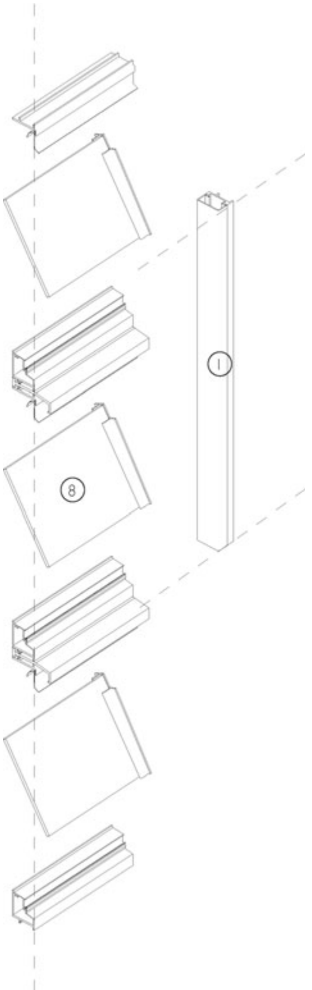
Details
1. Extruded aluminium frame
2. Stick curtain walling - type carrier system
3. Solar control glass louvre blade
4. Backing wall
5. Louvre panel door
6. Thermal insulation

3-D exploded view of frame supported solar control glass louvres used as a shading device in front of glazed curtain wall

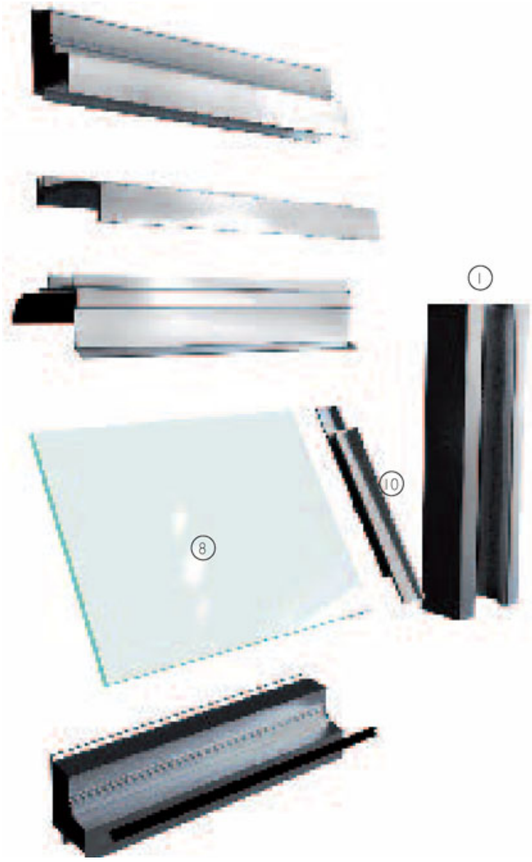


Exploded axonometric view of frame supported solar control glass louvres used as a shading device in front of glazed curtain wall

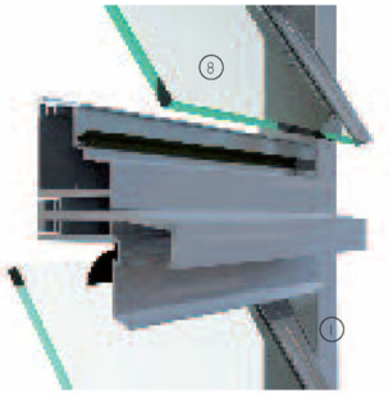
3-D exploded view of frame supported solar control glass louvres used as a shading device in front of glazed curtain wall

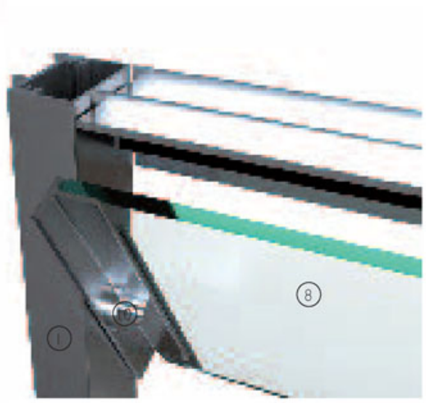


Exploded axonometric of single glazed louvre window system



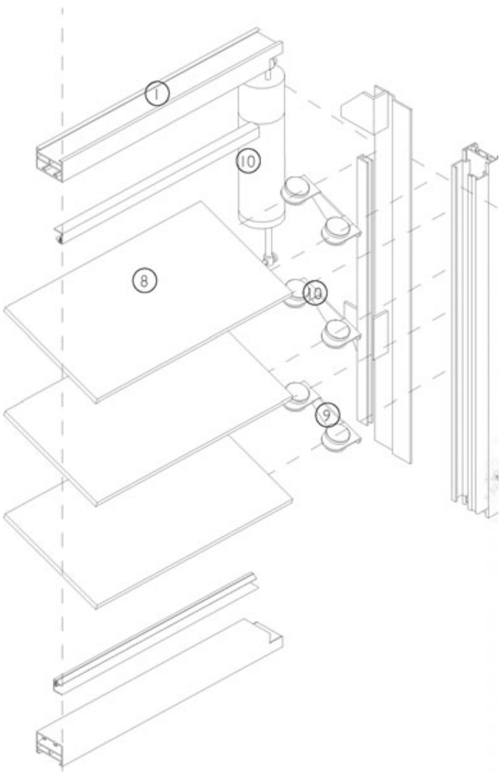
3-D exploded view of single glazed louvre window system





Detailed views of the system

Details
1. Extruded aluminium frame supporting louvres
2. Stick curtain walling - type carrier system to louvre panels
3. Extruded aluminium louvre blade
4. Backing wall providing support
5. Photovoltaic panel
6. Adjacent wall construction
7. Adjacent roof construction
8. Laminated glass louvre blade
9. Point fixing (bolt or clamp)
10. Hinge
11. Hydraulically operated arm to operate louvres
12. Extruded aluminium frame to glass louvre
13. Double glazed unit forming louvre



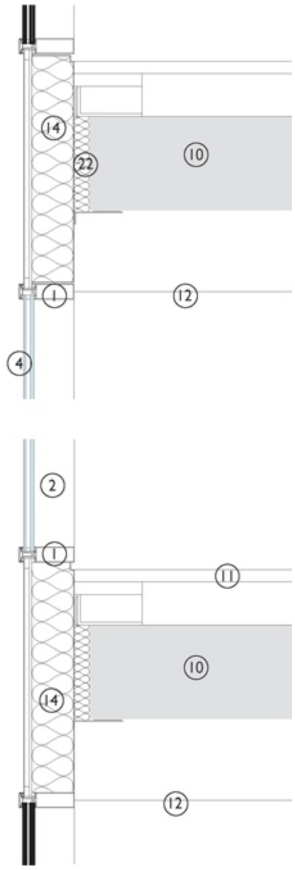
Exploded axonometric of mechanically controlled opening glass louvres

3-D exploded view of mechanically controlled opening glass louvres

Detailed views of the system

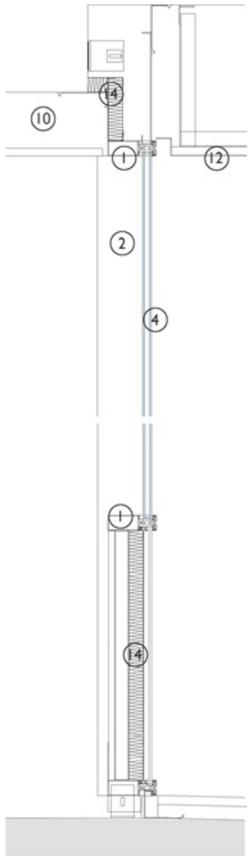
2

GLASS WALLS



Vertical section 1:25. Stick curtain wall with opaque glass spandrel panel

3-D view of curtain wall with opaque glass spandrel panel



Vertical section 1:25. Floor to ceiling glazing with insulated panel at ground level

Comparison with unitised glazing

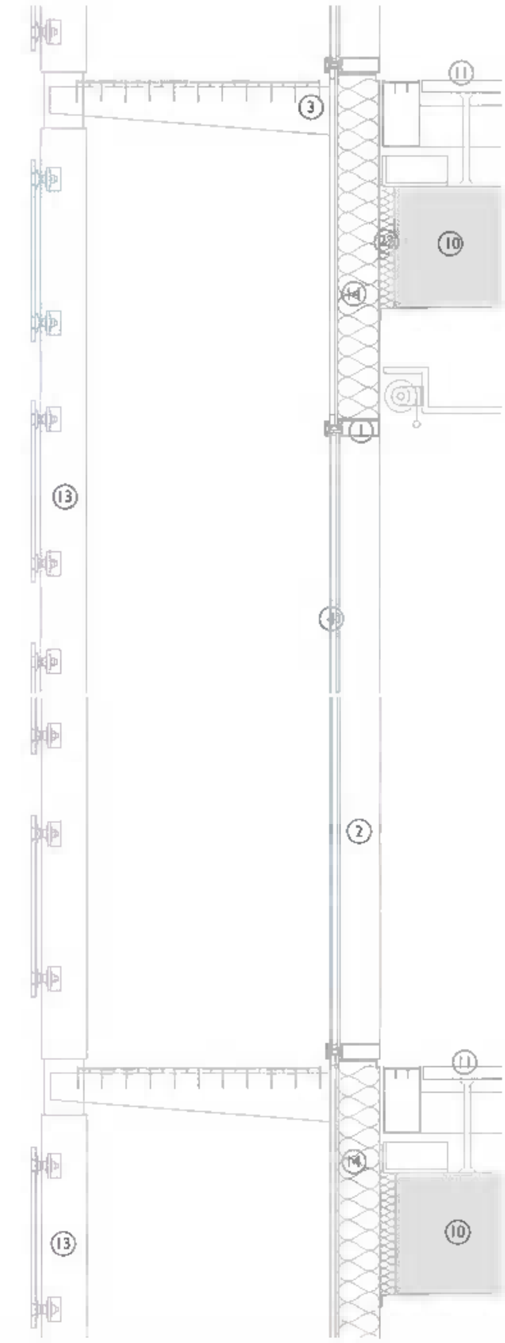
Framed glazing systems are of two types: stick and unitised. Stick systems are assembled mainly on site, while unitised systems are assembled in a factory. Stick systems are well adapted for non-modular construction. While unitised systems require a repetition in panel sizes in order to keep the types to a small number in order to remain economic, stick systems allow a high degree of freedom in module size and in facade design. Mullions and transoms do not need to be continuous; glazing bars can set out in staggered grids and can be changed easily from smaller grid sizes to larger ones. Complex geometries can be taken up much more easily by stick systems than by unitised systems. Stick systems are often preferred for low-rise building, where scaffolding is used, but the increased use of mast climbers (moving platforms) is making stick systems viable for taller buildings (10 to 20 storeys) where unitised glazing would otherwise have been used. The increased dependence on mast climbers is in part due to the need to be independent of site cranes, which are increasingly needed to service the construction of the primary structure often being built at the same time, though usually several floors higher or several bays away from the glazed walling.

For low rise building, or where there is a high degree of variation in the facade module, stick glazing is often preferred, since the wall is assembled in place on site rather than in a workshop, making it very economic when compared to unitised glazing. Although off-site fabrication saves time and can be of higher quality, it is often more expensive. Sometimes mullions and transoms are pre-assembled into carrier frames that are lifted in place and fixed without glass. This 'semi-unitised' approach can save time on construction where there is some degree of repetition.

A criticism of stick systems has traditionally been of their poorer quality of assembly when compared to unitised glazing, but this is much less the case today. However, bringing all the components together at the site, of double- or single glazed units, aluminium profiles, rubber-based gaskets and seals, folded metal flashings and copings, involves a much higher dependence on site-based work to achieve the quality of construction of the factory-based unitised systems.

System assembly

An essential aspect of stick systems is that they should be drained and ventilated in order to avoid water being drawn through the rubber-based seals into the building. Rainwater penetrating the outer seal is drained away in a ventilated zone that provides pressure equalisation between outside and inside the system. Pressure equalisation avoids water being drawn into the system by a pressure difference between two chambers, resulting in water being drawn through a joint. Any rainwater entering this zone is drained away to the outside forward of the inner seal forming a second line of defence against air and water infiltration. Most stick systems now provide a full thermal break through the aluminium profiles rather than the partial thermal breaks provided on previous systems. This reduces condensation risk on the inside face of the framing in temperate climates. In hot and humid climates, the

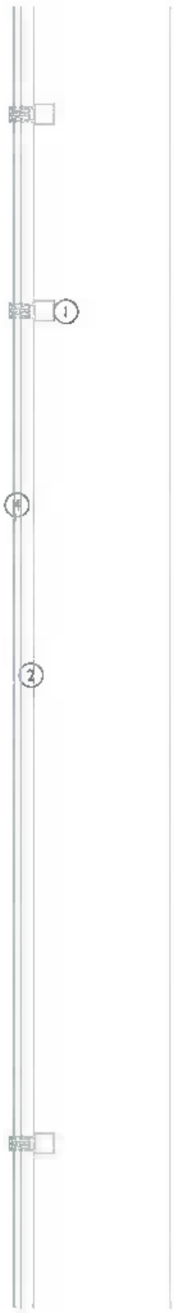


Vertical section 1:25 Glazed curtain wall with maintenance walkway and glazed solar shading panels in front

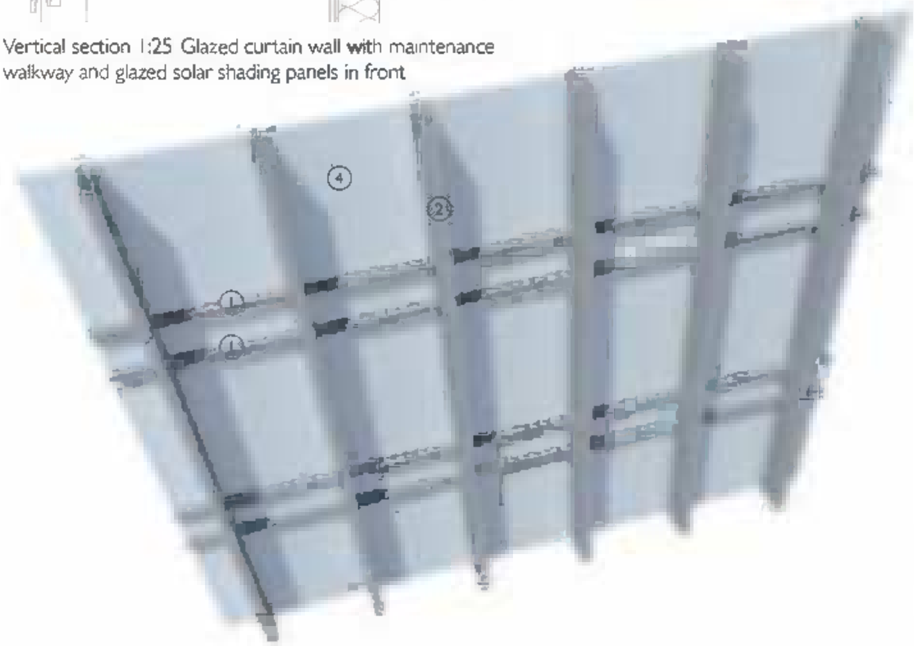
3-D view of glazed curtain wall with maintenance walkway and glazed solar shading panels in front

Details

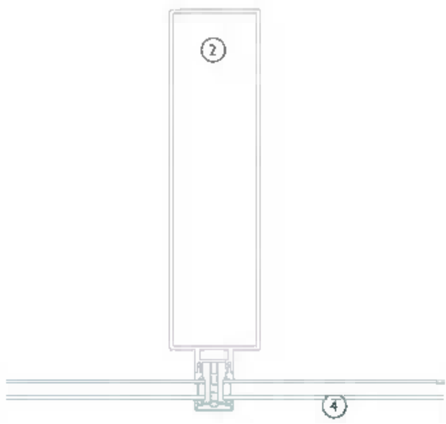
1. Extruded aluminium transom
2. Extruded aluminium mullion
3. Fixing bracket
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal-faced or opaque glass-faced insulated panel
9. Cover cap
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer glazed screen providing solar shading
14. Thermal insulation
15. Metal sheet seal
16. Maintenance access deck
17. Window glazed in curtain walling
18. Metal honeycomb panel
19. Slot in mullion to receive fixing bracelet for external screens, etc
20. Steel hollow section
21. Adjacent wall. Metal rain screen shown
22. Smoke seal



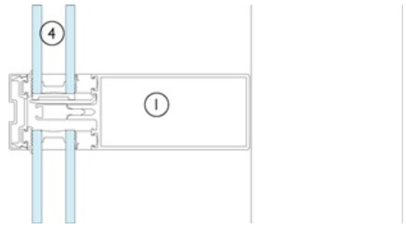
Vertical section 1:25 Curtain wall glazing on steel carrier frame



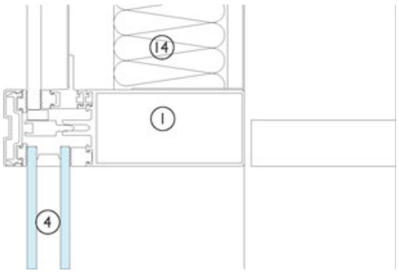
3-D view of curtain wall glazing on steel carrier frame



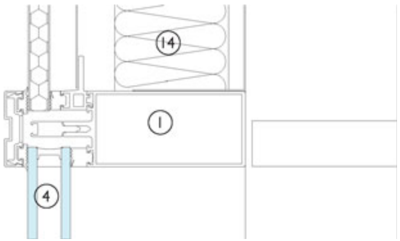
Horizontal section 1:5. Curtain wall glazing on steel carrier frame



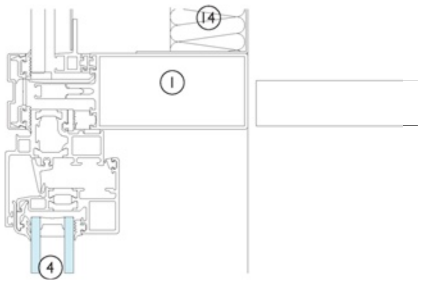
Section 1:5. Junction between double glazed units



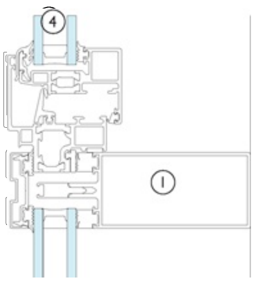
Section 1:5. Junction between double glazed unit and glass spandrel panel



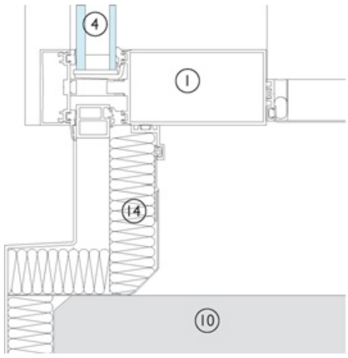
Section 1:5. Junction between double glazed unit and metal honeycomb panel



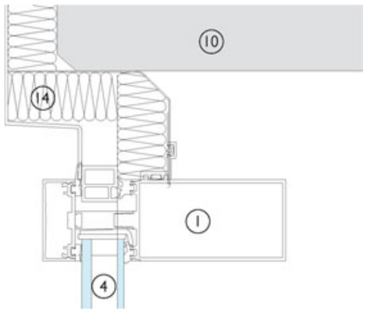
Vertical Section 1:5. Junction between double glazed unit and top of inward opening window



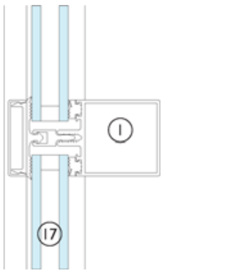
Section 1:5. Junction between double glazed unit and bottom of inward opening window



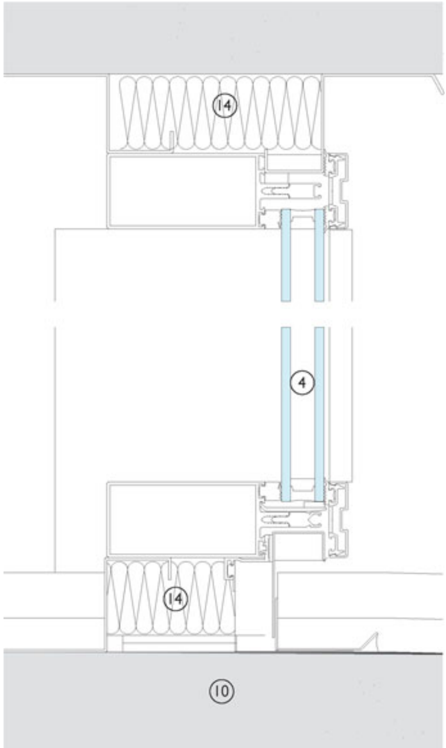
Vertical section 1:5. Top of slab connection with insulated slab capping



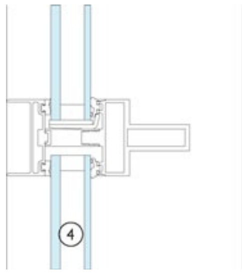
Vertical section 1:5. Underside of slab connection with insulated slab capping



Section 1:5. Junction between double glazed units using reduced frame size



Vertical section 1:5. Junction with top and bottom of slab



Section 1:5. Junction between double glazed units using slim frame profile

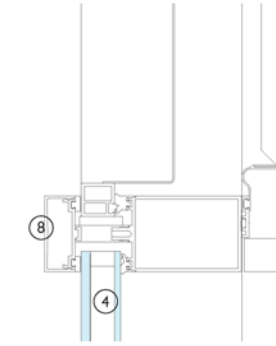
condensation will occur harmlessly on the outside face of the framing if the interior is cooled by mechanical ventilation. In all climates, a thermal break improves the U-value of the glazed wall, thus reducing energy consumption within the building for either heating or cooling.

Stick glazing is assembled mainly on site. Mullions (verticals) are fixed to floor slabs with transoms (horizontals) spanning between the mullions to which they are fixed. These framing members can be pre-assembled into 'ladders' on the ground and lifted into place by crane in order to reduce time on site. The glass is set in place and pressure plates fixed through thermal breaks back to the carrier frame of mullions and transoms. Decorative cappings are usually applied to the pressure plates to conceal the pressure plates as well as the self tapping screws holding the glass in place. Sometimes the cappings are omitted but care must be taken to ensure that the screws are properly aligned and that the pressure plates are continuous and jointed carefully.

Stick systems are fixed from floor to floor at either side of the floor slab or on top. The design of the connection is dependent mainly on the method of forming the edge of the floor construction on floor depths or uses of the adjacent floor zone, and any additional elements such as brackets for solar shading or maintenance walkways which penetrate the stick glazing. The glazing is either hung from each floor level or sits on each floor level. Hanging is usually preferred but con-

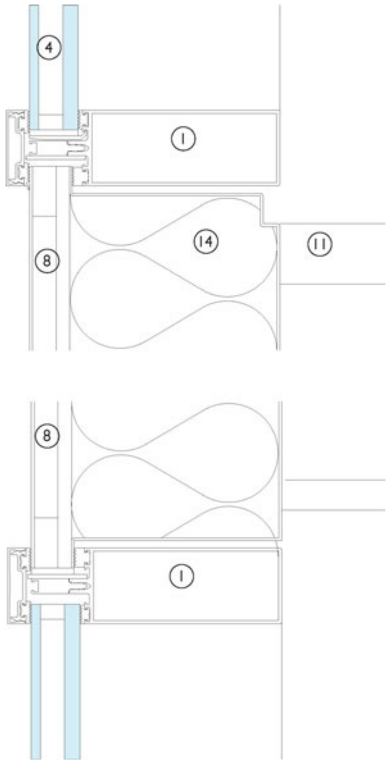
Details

1. Extruded aluminium transom
2. Extruded aluminium mullion
3. Fixing bracket
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal-faced or opaque glass-faced insulated panel
9. Cover cap
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer glazed screen providing solar shading
14. Thermal insulation
15. Metal sheet seal
16. Maintenance access deck
17. Window glazed in curtain walling
18. Metal honeycomb panel
19. Slot in mullion to receive fixing bracelet for external screens, etc.
20. Steel hollow section
21. Adjacent wall. Metal rainscreen shown
22. Smoke seal

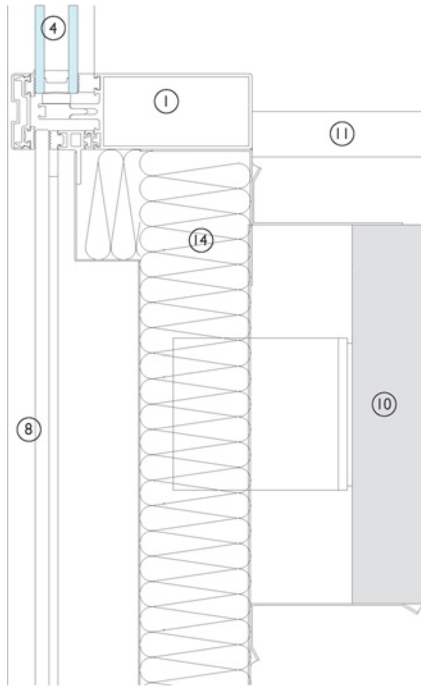


Horizontal section 1:5. Junction between double glazed unit and insulated metal panel

3-D view of glazed curtain wall with cut glazing caps



Vertical section 1:5. Junction with double glazed unit and opaque glazed panel with bonded insulation



Vertical section 1:5. Opaque glass spandrel panel with ventilated spandrel zone

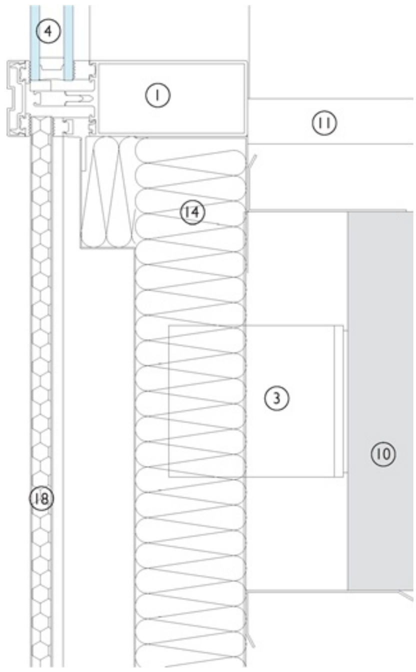
straints imposed by the structure of the building may require the glazing to be supported at the base of each mullion. Mullions are linked by spigots so that the restrained end of one mullion fits into the supported end of the other mullion.

Because glazed walling is set forward of the edge of the slab, the gap between the two is closed with a floor finish. Seals between adjacent floors are designed as either smoke seals or as flame barriers. Smoke seals comprise a mineral wool or glass wool barrier, held in place and sealed with galvanised steel sheet above and below. Flame barriers, usually of one hour or 90 minute rating are provided by a specially protected spandrel panel at the level of the floor zone. The spandrel panel forming the barrier is fixed directly to the floor slab as well as forming part of the curtain wall system. This ensures that the spandrel remains in place long after the adjacent curtain walling has collapsed during a fire. The spandrel panel itself is usually protected with a fire resistant board as part of the barrier.

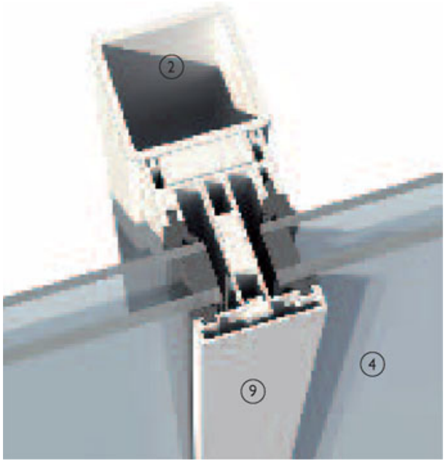
Where glazing is inclined significantly from the vertical, two-edge glazing is used to allow the water to run down unimpeded with transoms. This is a standard method for glazed roofs, where mullions are capped, but transoms running across the width of the slope are sealed with a flush silicone joint.

Framing profiles

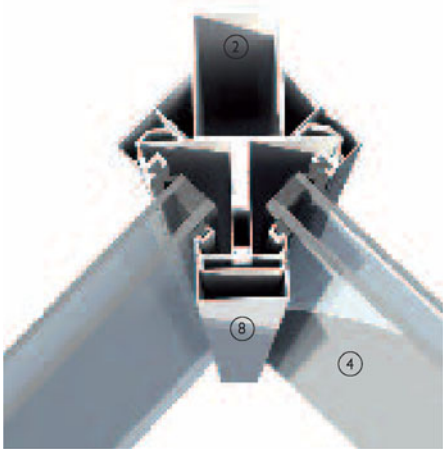
Carrier frames are made from a wide variety of sections. The shape can usually be adapted



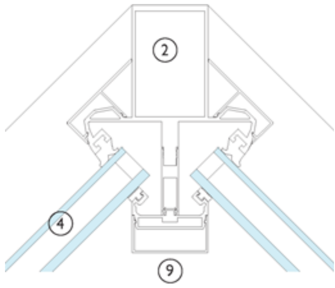
Vertical section 1:5. Metal honeycomb spandrel panel with ventilated spandrel zone



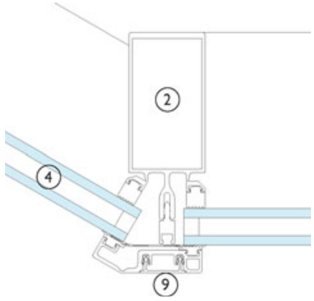
3-D view of connection between double glazed units



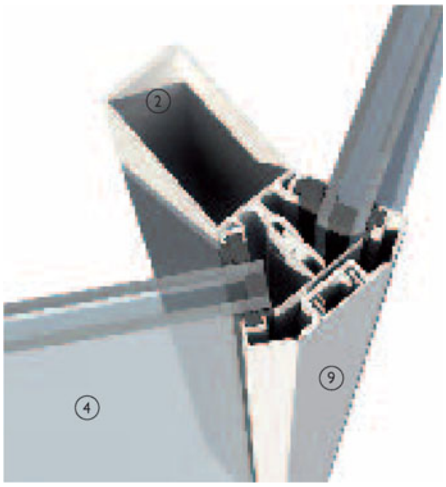
3-D view of framed internal corner connection between double glazed units

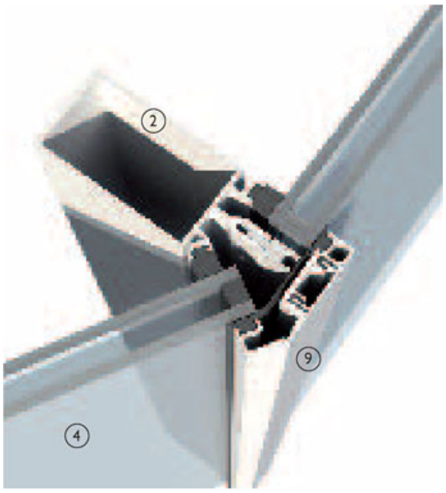


Horizontal section 1:5. Internal corner connection between double glazed units

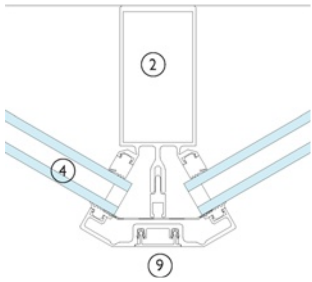


Horizontal section 1:5. External corner connection between double glazed units





3-D views of framed external corner connection between double glazed units



Horizontal section 1:5. External corner connection between double glazed units

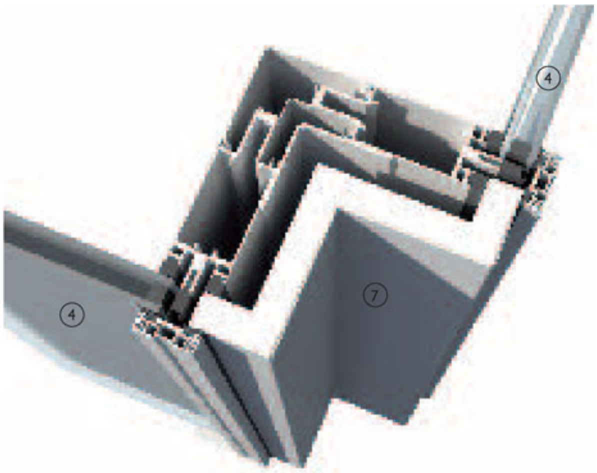
Details
1. Extruded aluminium transom
2. Extruded aluminium mullion
3. Fixing bracket
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal-faced or opaque glass-faced insulated panel
9. Cover cap
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer glazed screen providing solar shading
14. Thermal insulation
15. Metal sheet seal
16. Maintenance access deck
17. Window glazed in curtain walling
18. Metal honeycomb panel
19. Slot in mullion to receive fixing bracelet for external screens, etc.
20. Steel hollow section
21. Adjacent wall. Metal rainscreen shown
22. Smoke seal

for a specific project. The most common types are rectangular box sections that use the full width of the joint, and narrower T-shaped and I-shaped sections that are narrower than the joint width. Although the depth of the profile is determined by structural requirements, the overall shape can be adapted to suit other needs, such as incorporating roller blind guides into the sides of the vertical profiles. Mullions and transoms are often not of the same depth, for structural reasons, but can be made so if required to support blinds, for example, or for visual reasons.

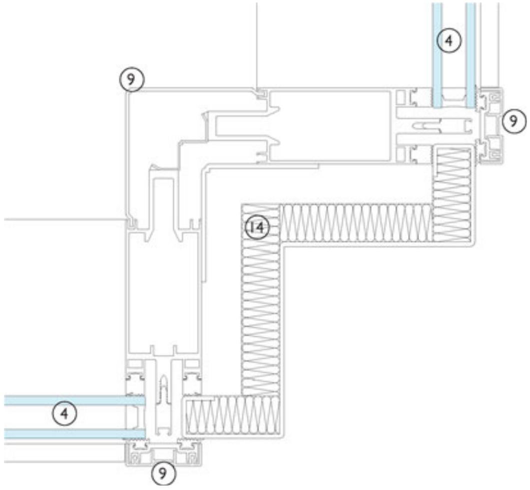
Where framing members have long vertical or horizontal spans, mild steel sections are sometimes used instead of a rectangular box section in aluminium, particularly if the equivalent aluminium section would be visually too deep or if the glazing system is fixed back to a steel frame forming part of the primary structure. The front part of the extrusion containing the seals is fixed directly to a mild steel box or T-section. The glazing is then fixed to this extrusion in the conventional way. If the steel frame has variable or complex curves then the rubber-based seals are set onto the steel frame without an extrusion with a technique commonly used in glazed roof structures. The glass is fixed with pressure plates directly to the steelwork with a rubber-based profile set between the glass and supporting steel.

Opening lights

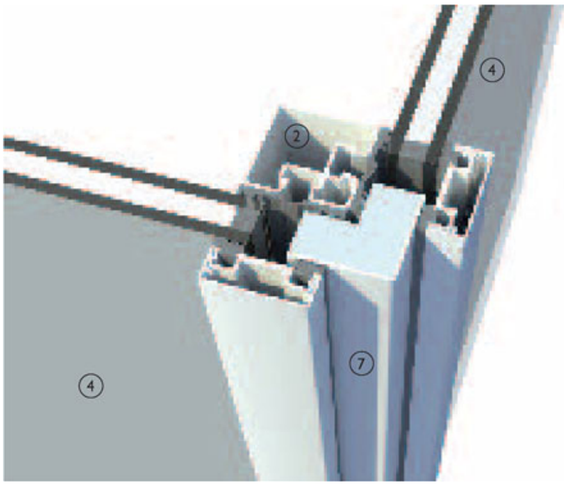
Windows, doors and smoke vents are fixed into stick glazing as items with their own frame rather than using the curtain wall fram-



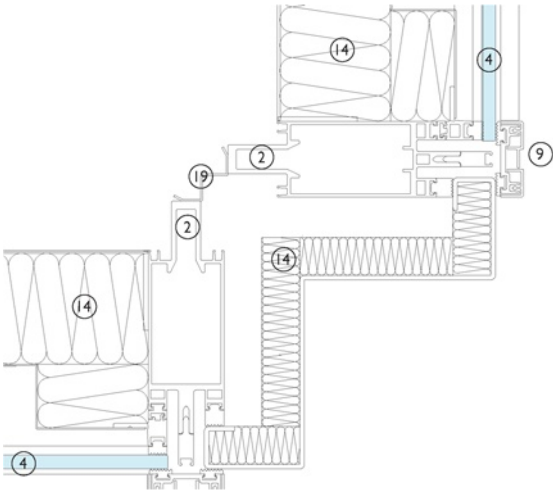
3-D view of junction between double glazed unit and insulated external corner panel



Horizontal section 1:5. Junction between double glazed unit and insulated external corner panel



3-D view of external corner connection between double glazed units

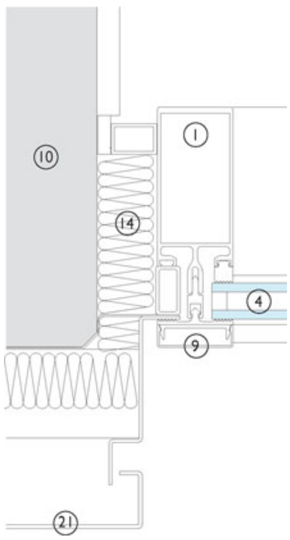


Horizontal section 1:5. External corner at spandrel level with opaque glass panels and ventilated spandrel zone

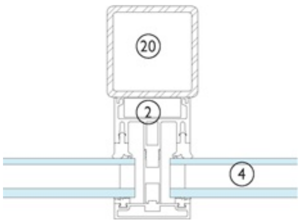
ing directly. This is because the opening light usually needs its own drainage and weather-proofing profiles and seals. This gives the appearance of a thicker frame around opening lights than around the adjacent fixed lights. Drips and seals form a part of the secondary frame in the same way as if the light were glazed into any other form of construction such as an opening in a masonry wall. The opening light is glazed into curtain walling around its edge with a thinner frame that corresponds to the thickness of the glazed units, allowing it to be fixed in place with the same technique as if it were a double glazed unit. These edge nibs are positioned on the frame to the opening light in a way that ensures that the glass of the opening light is in the same plane as the adjacent glass.

Parapets, cills and penetrations

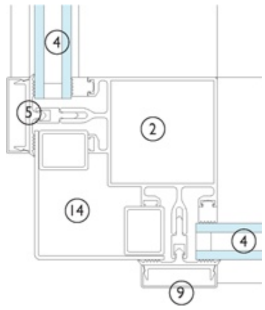
Parapet copings are glazed into the curtain walling with a pressure plate in the same way as adjacent glazing. Copings usually project to align with the face of the cappings on the pressure plates or slightly forward of them to protect the glazing beneath from the vertical movement of maintenance cradles. Copings slope inwards towards a gutter rather than sloping forwards to avoid dirt accumulating on the top of coping being washed down the facade by rain. This also avoids the need for the coping to project beyond the face of the glazing and form a drip. It should be noted that projecting drips on copings are still good practice in masonry construction, where an impervious coping washes rainwater onto a permeable masonry material beneath, causing staining. Cills at the base of stick glazing



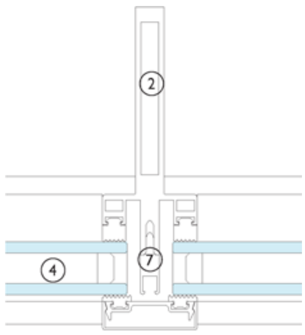
Horizontal section 1:5. Junction between curtain wall glazing and rainscreen cladding system



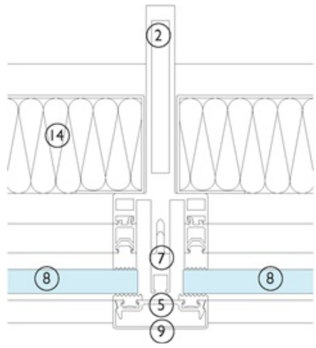
Horizontal section 1:5. Glazing frame supported directly on steel structure



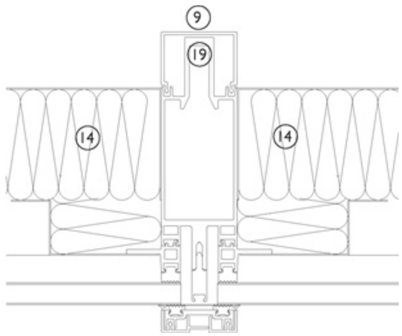
Horizontal section 1:5. Framed external corner



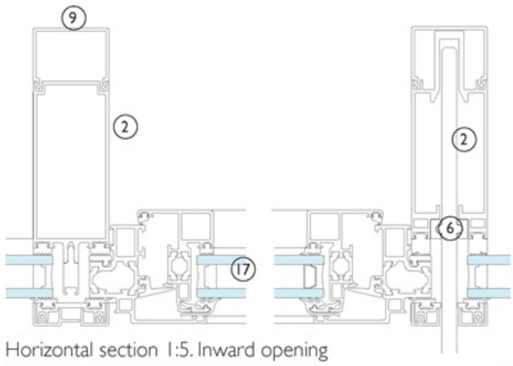
Horizontal section 1:5. Glazing frame with thin frame

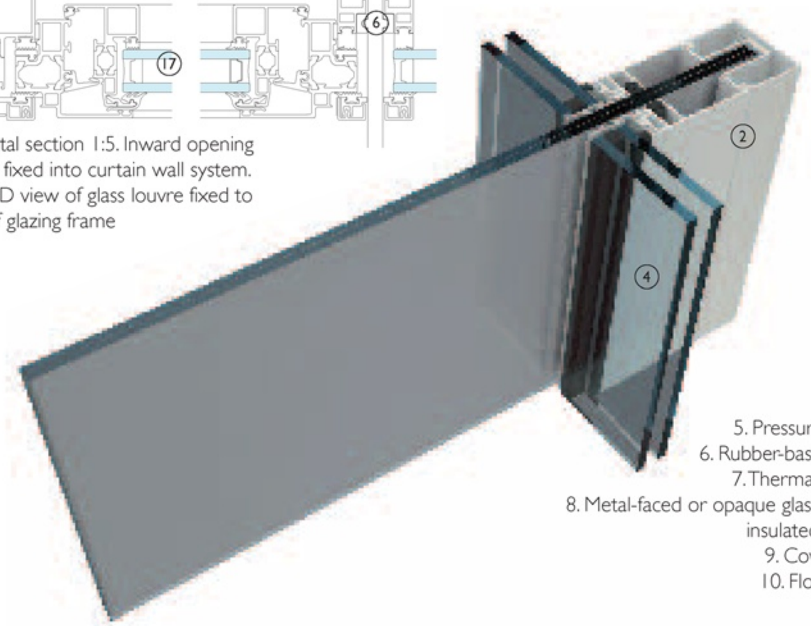


Horizontal section 1:5. Glazing frame at spandrel level with thin frame



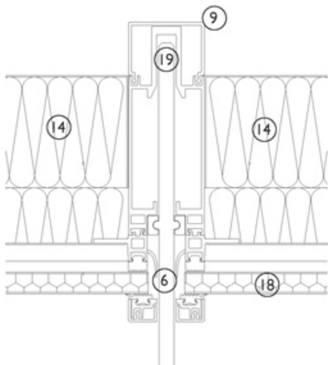
Horizontal section 1:5. Junction between insulated metal spandrel panels

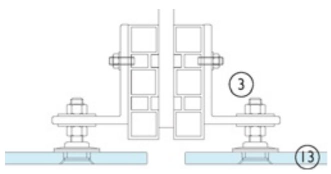




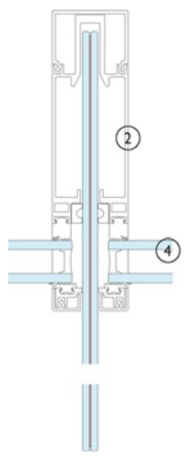
Horizontal section 1:5. Inward opening window fixed into curtain wall system. Right: 3-D view of glass louvre fixed to inside of glazing frame

Details
1. Extruded aluminium transom
2. Extruded aluminium mullion
3. Fixing bracket
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal-faced or opaque glass-faced insulated panel
9. Cover cap
10. Floor slab





Horizontal section 1:5. Glass rainscreen supported from bracket fixed to inside of glazing frame



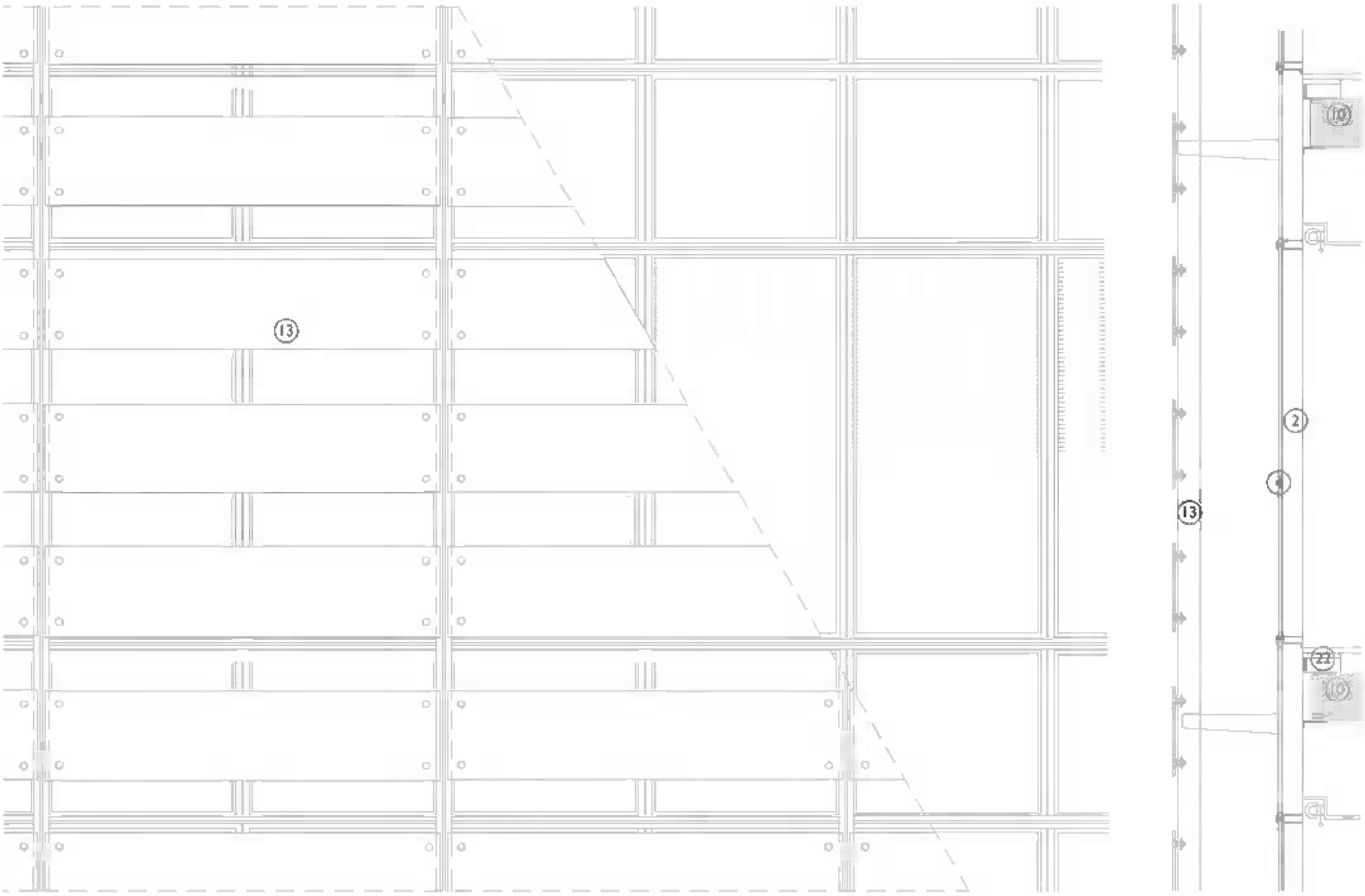
Horizontal section 1:5. Glass louvre fixed to inside of glazing frame

are formed with a pressed aluminium profile with a clip at the bottom which provides a clean line at the bottom of the wall, and provides rigidity to the profile. Where cill drips can be seen from below, the folded edge provides a smooth painted edge which is also protected from weather corrosion.

Where stick glazing abuts an adjacent area of wall in a different material, a blocking profile is glazed into the edge of the glazing profile, faced with an EPDM foil. The foil is then bonded to the adjacent wall. Where glazing abuts metal rainscreens, which is a common combination, the edge of the metal return to the rainscreen can also be glazed into the edge mullion or transom. Where a projecting cill is required at the base of the wall, for example, a projecting aluminium cill is glazed into the curtain walling at the top end, and projects down over the adjacent wall in a manner to suit the detailing of the wall beneath.

Corners

Both internal and external corners are formed by glazing in a folded aluminium strip into the mullion on each side of the corner. Alternatively, a mullion set at 45° is used to give a thin edge to the facade, with a joint width similar to that of joints elsewhere on the facade. Some manufacturers provide interlocking mullions for use at corners to allow varying angles at corners on a single building with a constant abutting of mullions on the inside face.



Elevation, vertical & horizontal 1:50. Curtain wall glazing with glass solar shading panels in front.

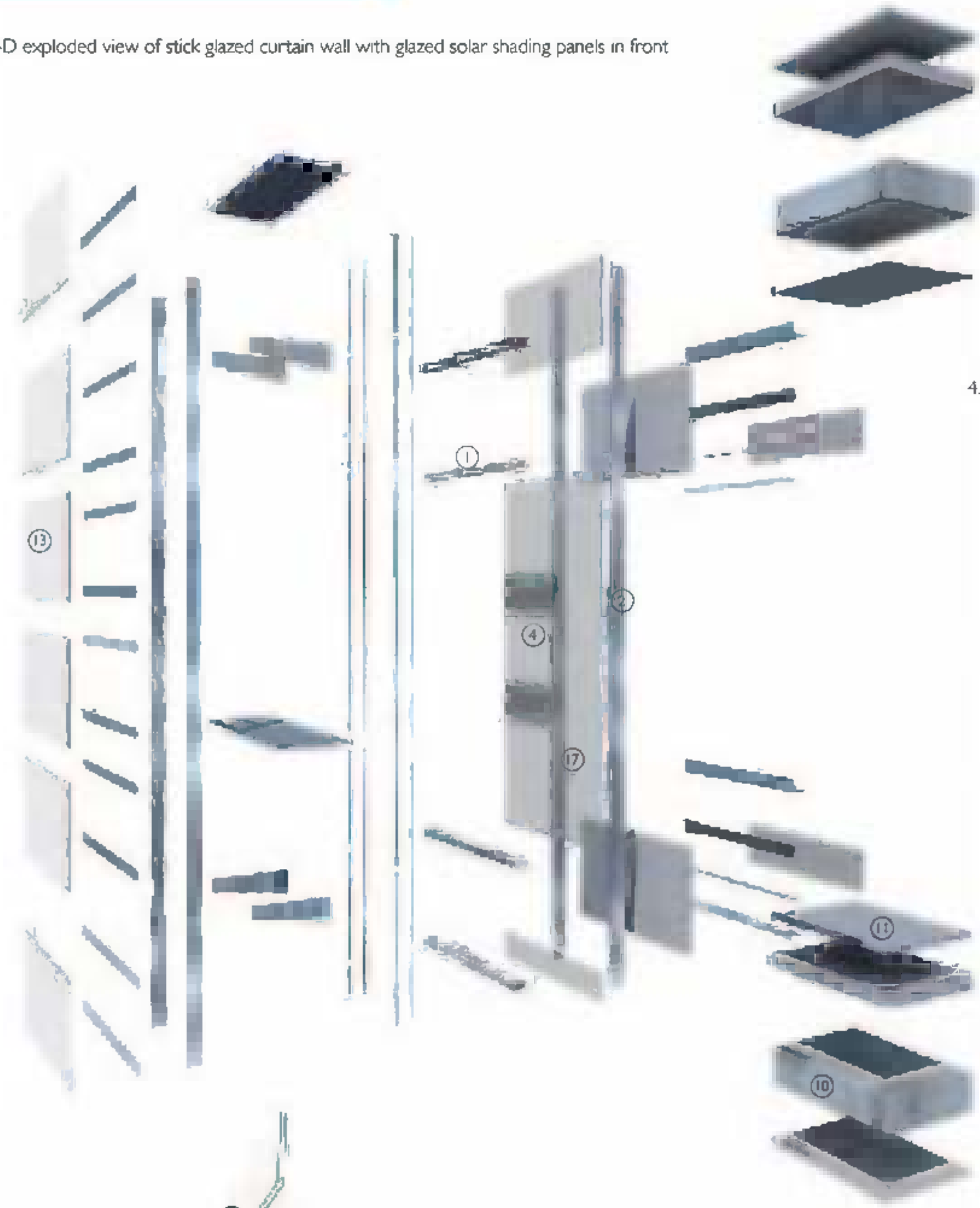
11. Floor finish
12. Ceiling finish
13. Outer glazed screen providing solar shading
14. Thermal insulation
15. Metal sheet seal
16. Maintenance access deck
17. Window glazed in curtain walling
18. Metal honeycomb panel
19. Slot in mullion to receive fixing bracelet for external screens, etc
20. Steel hollow section
21. Adjacent wall. Metal rainscreen shown
22. Smoke seal

Spandrel panels

Spandrel panels are made either as a continuous sealed panel, draining in the same way as the glass panels, or as a ventilated box. Where metal is used, spandrels can be formed as trays glazed into the framing with insulation between. Glazed spandrels are made either with rigid insulation bonded to the back of laminated glass or on a sheet of laminated glass with a ventilated void behind both to cool the glass and avoid either a visual read-through of the insulation from the outside or risk of the insulation delaminating from the glass. When glass is used it is made opaque (with either method) by screen printing, etching or a combination of both.

3-D view showing curtain wall glazing with glass solar shading panels in front at upper floor junction

3-D exploded view of stick glazed curtain wall with glazed solar shading panels in front



Details

1. Extruded aluminium transom
2. Extruded aluminium mullion
3. Fixing bracket
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal-faced or opaque glass-faced insulated panel
9. Cover cap
10. Floor slab
11. Floor finish
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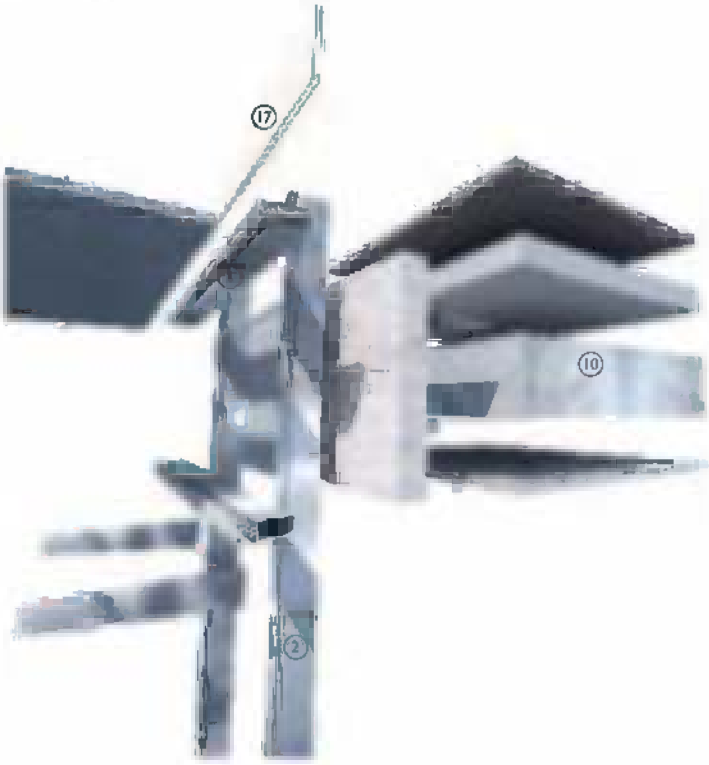
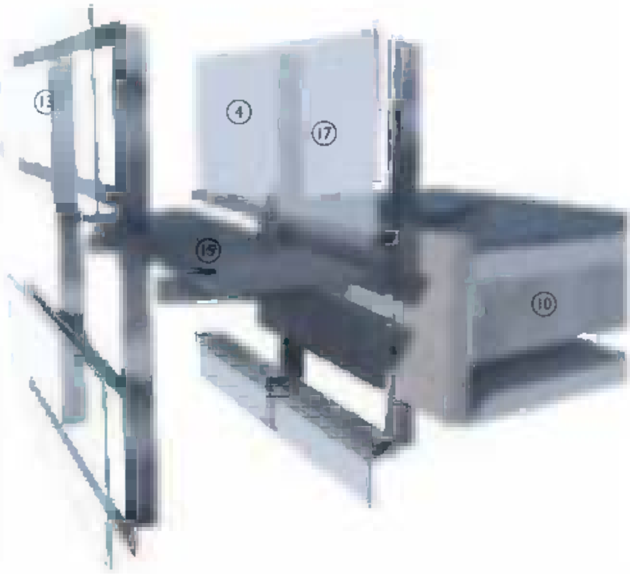
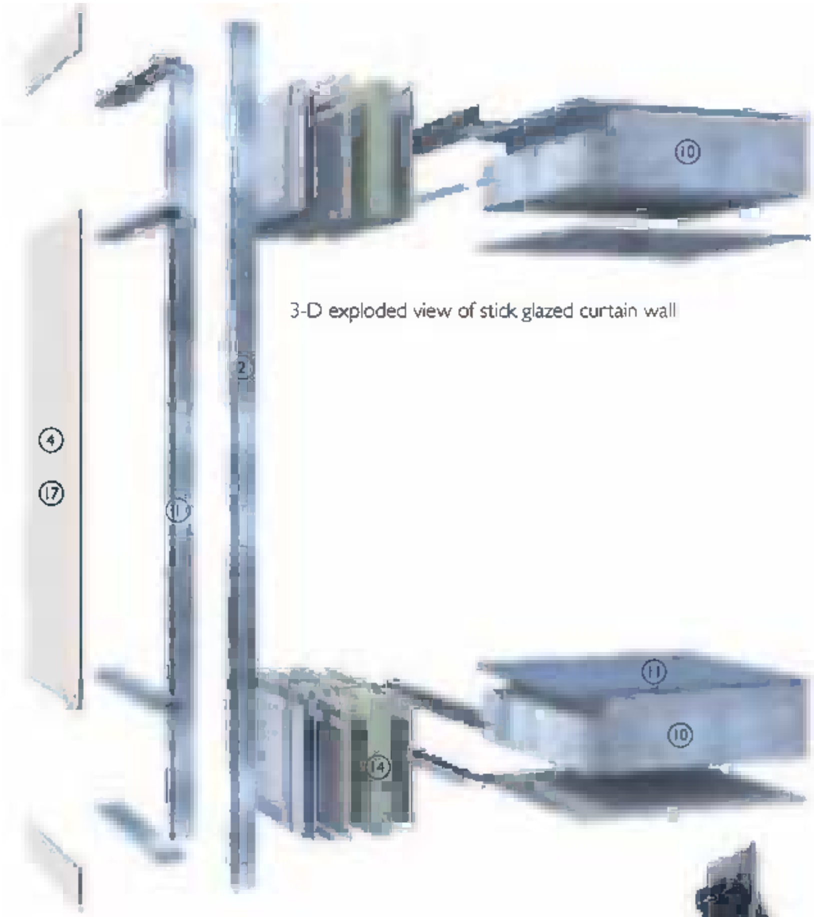
18. Metal honeycomb panel
19. Slot in mullion to receive fixing bracelet for external screens, etc
20. Steel hollow section
21. Adjacent wall. Metal rainscreen shown
22. Smoke seal



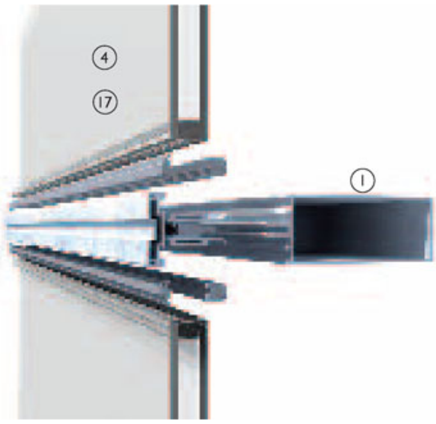
3-D exploded view of stick glazed curtain wall at floor junction



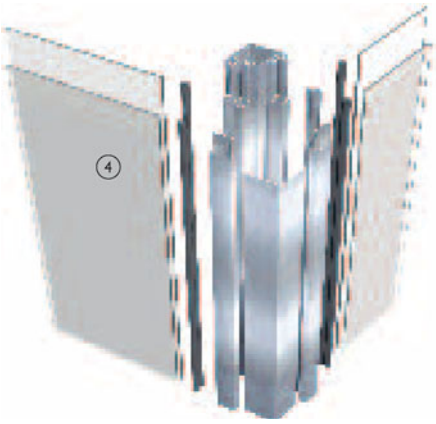
3-D exploded view of solar shading panels in front of stick glazed curtain walling



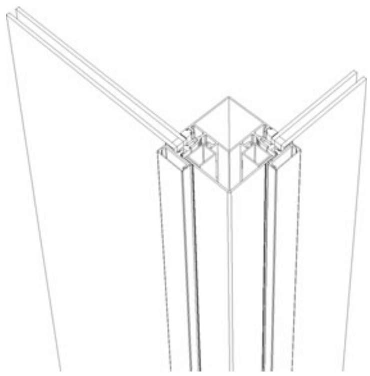
3-D exploded view of stick glazed curtain wall

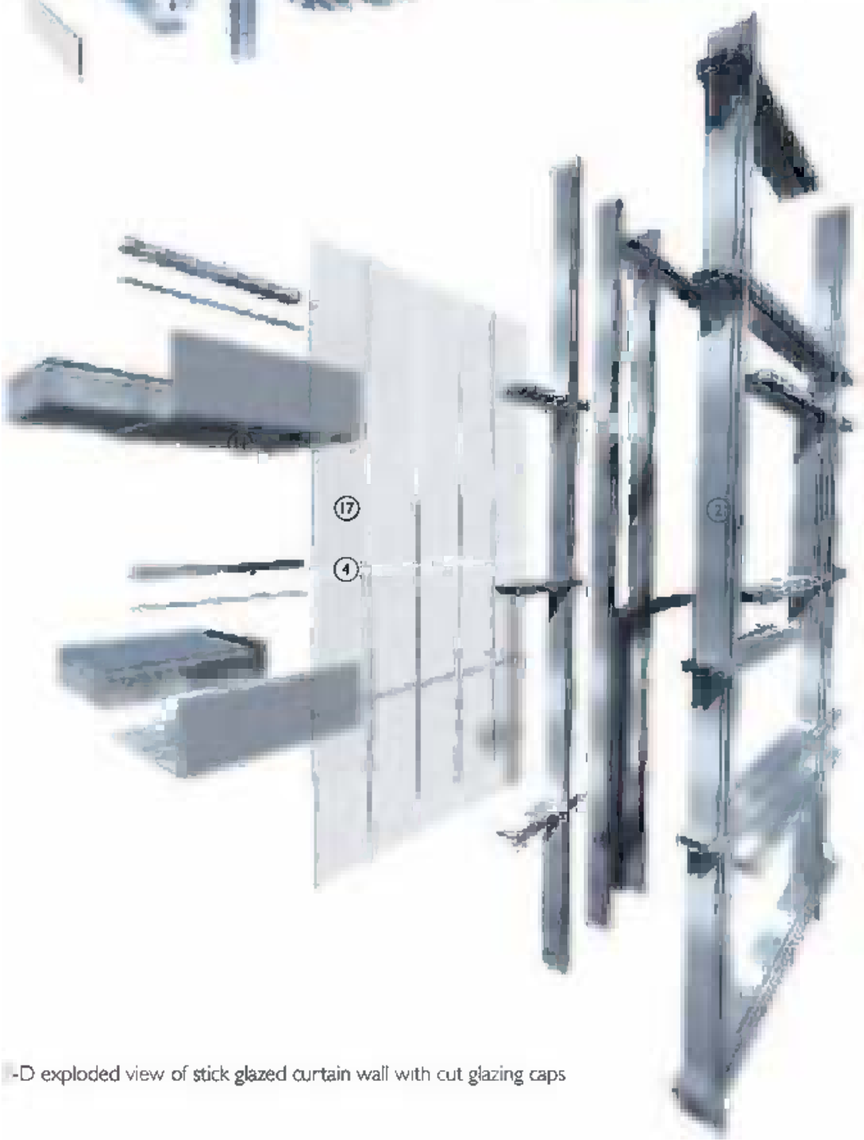


3-D exploded view of stick glazed curtain wall with glazed solar panels at floor junction

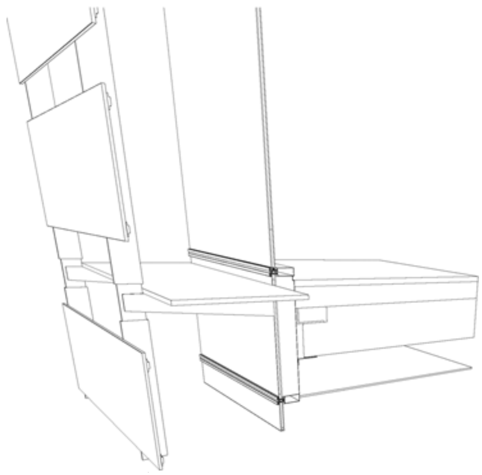


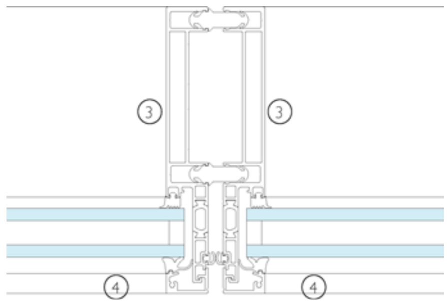
3-D exploded view of corner junction between double glazed units


3-D view of corner junction between double glazed units

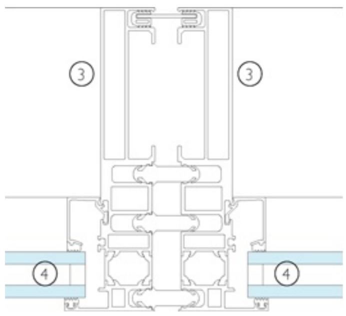


-D exploded view of stick glazed curtain wall with cut glazing caps

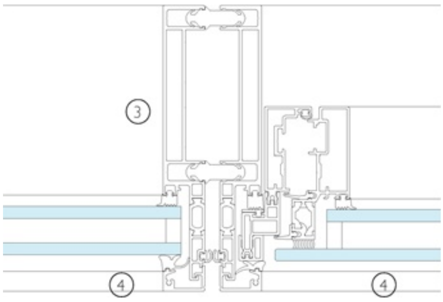

3-D view of stick glazed curtain wall with glazed solar panels at floor junction



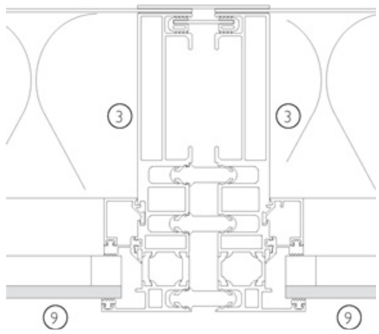
Horizontal section 1:5. Connection between unitised double glazed units with glazing fixed from outside



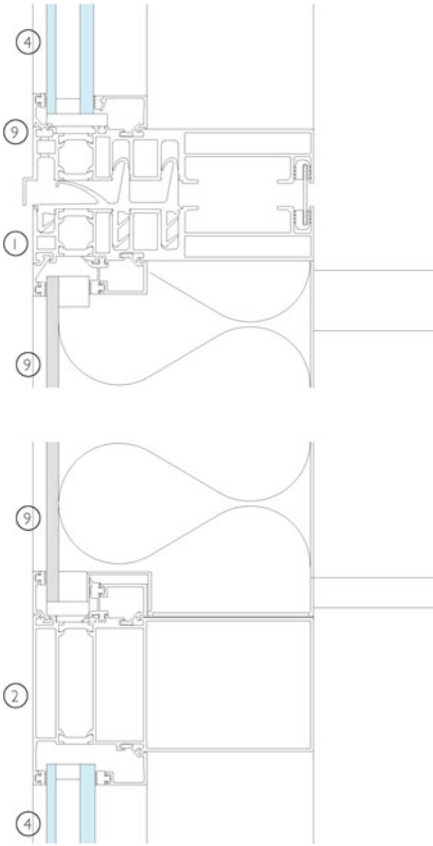
Horizontal section 1:5. Connection between unitised double glazed units with glazing fixed internally



Horizontal section 1:5. Outward opening window glazed into unitised panel



Horizontal section 1:5. Connection between unitised panels with insulated metal panels fixed from inside



Vertical section 1:5. Connection between externally glazed unitised panels with double glazed units and inulated metal panels

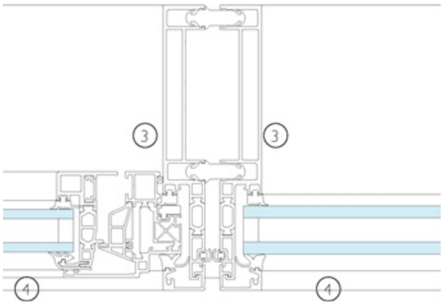
The main advantages of unitised glazing in construction are of speed of installation on site and of quality control of assembly workshop conditions over those on site. For taller buildings, for those over five or six storeys, scaffolding becomes much less practical, and so working from inside the building on a floor slab is a safer and faster method. Unitised panels are assembled and glazed in the factory. On site they are secured by brackets fixed to the floor slab and set side by side, then rising floor by floor, usually from the bottom of the building upwards. Panels are made either as panels set side by side, so that they can be replaced as complete panels if accidentally damaged, or be semi-interlocking where the glass is replaced without moving the panel. The fully unitised type has wider site lines (overall frame width) at around 80mm (3in), than the semi-interlocking type at around 65mm (2.5in). A comparable stick system would have a joint width of around 50mm 2in). From the visual point of view, the wider site lines of unitised glazing over stick glazing is the main disadvantage of this system.

Unitised glazing is much less suited to tall glazed walls, visually, that have heights greater than around four metres between floor slabs, that is, greater than a single panel height. The framing can appear to be visually very strong, and instead frameless construction is often preferred as either bolt fixed or clamped glazing. Its most common use is in modules of 1200mm or 1500mm wide (4ft or 5ft) where it suits the internal planning of office buildings, but storey height panels 3 metres wide are used. Because of the cost of setting up jigs and tools in the factory, unitised glazing is suited to use with a small number of panel types to create a high level of repetition. This suits very modular facades with relatively few panel types. Glazed units are fixed either with pressure plates, or are silicone-bonded to a light frame around the edge and then mechanically fixed to the frame of the panel.

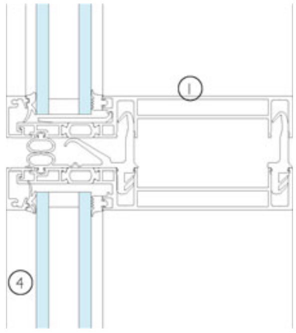
Glazed units are fitted either externally or internally depending on the glass replacement method. When glazed externally, mullions and transoms are adapted to have a clip on the outside to form a pressure plate. Where glazed units are internally glazed, clips are used which project from the sides of the mullion/transom section. This results in internally glazed sections usually being wider than those glazed externally. When glazed externally, a maintenance cradle is used with the capacity to lift glass and allow the panel to be lifted in place. This method allows glass to be replaced where it is either impractical to carry the glass through the building or where glass sizes are too large to enter stairwells or lifts. When internally glazed, glass units are carried up either in a lift or by stairs and are installed entirely from the floor plate.

Jointing panels

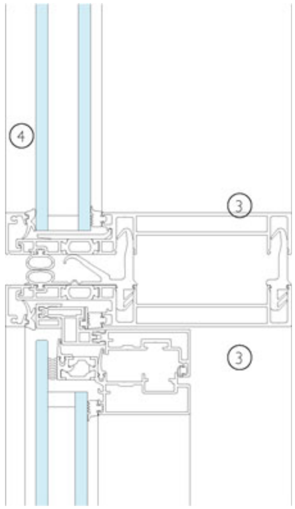
Most panels are made one storey-height, but larger panels are made to span two floors and one bay wide or one storey high and several bays wide. Those larger panels are usually done where installation time is critical. Like stick glazing, panels are either hung from the top or are supported at the bottom. Instead of a straightforward spigot between storey height lengths of mullion, panels are tied together with a 'stack' joint, so-named from the concept of panels being stacked

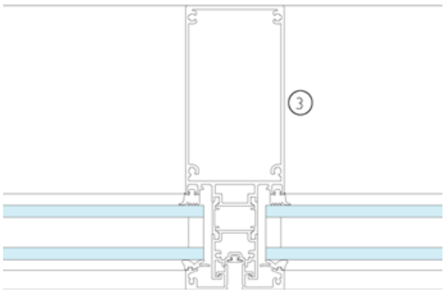


Horizontal section 1:5. Outward opening window glazed into unitised panel

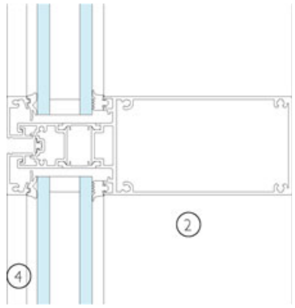


Vertical section 1:5. Connection between unitsed double glazed panels with externally fixed glass

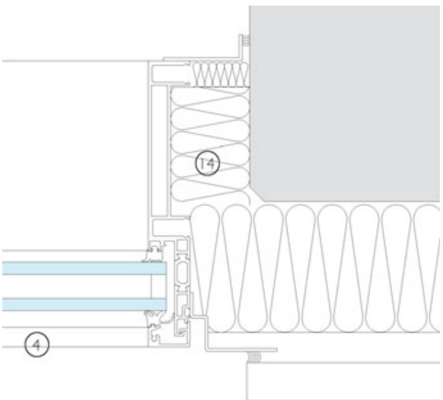




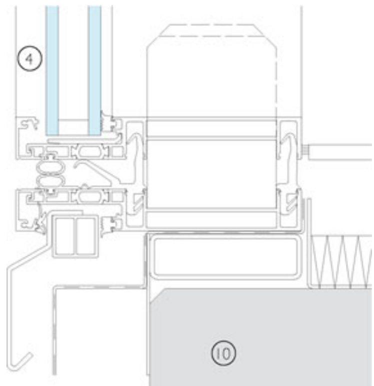
Horizontal section 1:5. Stick mullion in unitised panel



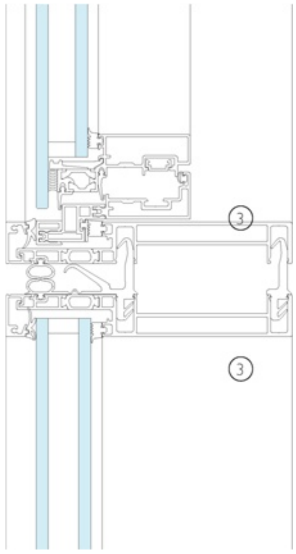
Vertical section 1:5. Stick transom in unitised panel



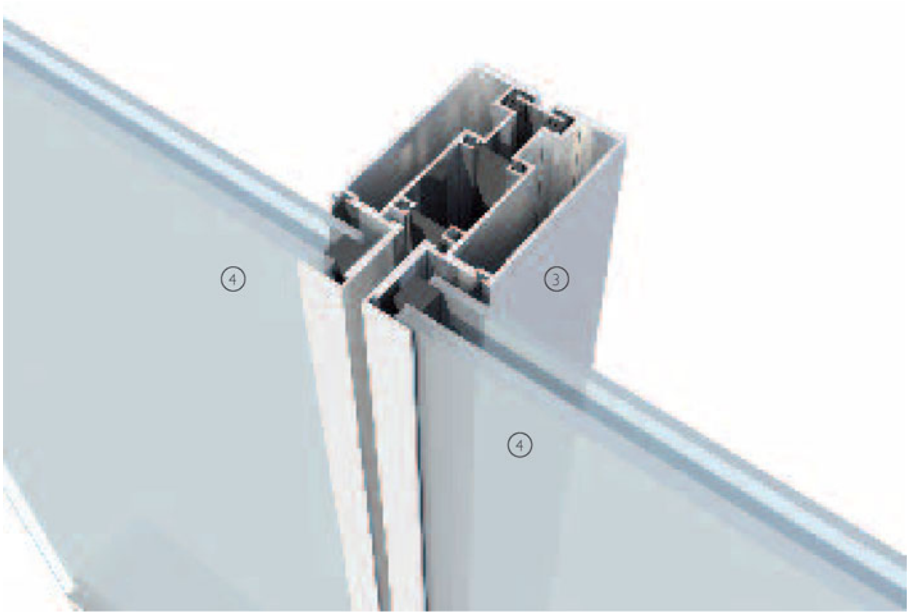
Horizontal section 1:5. Connection between unitised panel and structure



Vertical section 1:5. Unitised panel connection at ground level



Vertical section 1:5. Outward opening window glazed into unitised panel

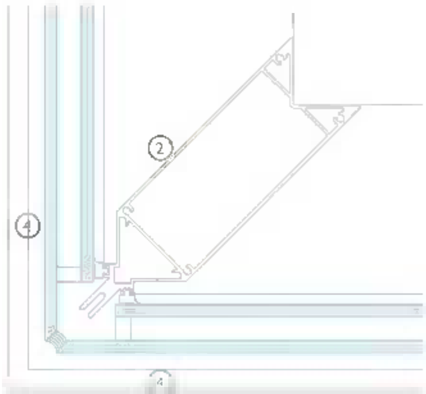


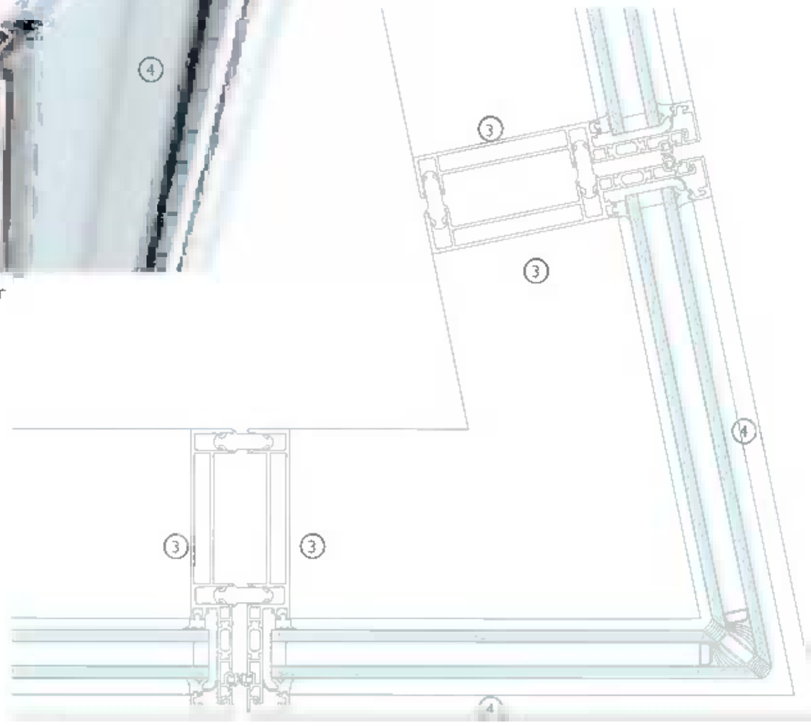
3-D view connection between unitised double glazed panels

Details

1. Interlocking transom
2. Plain transom
3. Interlocking mullion
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal parapet coping
9. Metal-faced or opaque glass-faced insulated panels
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer screen providing solar shading
14. Thermal insulation
15. Sheet metal seal
16. Cover cap
17. Smoke seal
18. Support bracket

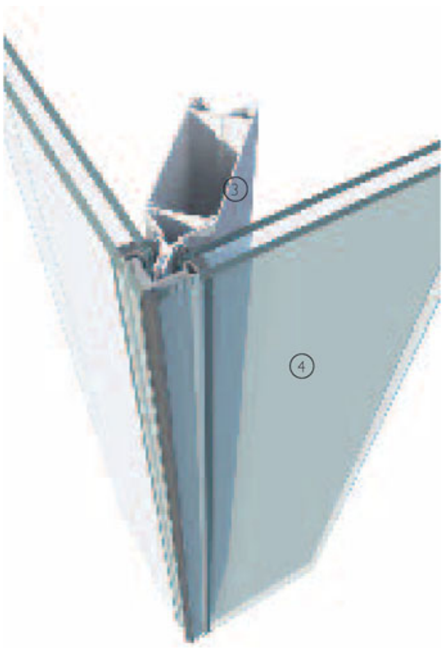
3-D view of frameless glass corner





Horizontal section 1:5. Framed glass connection within unitised external corner panel

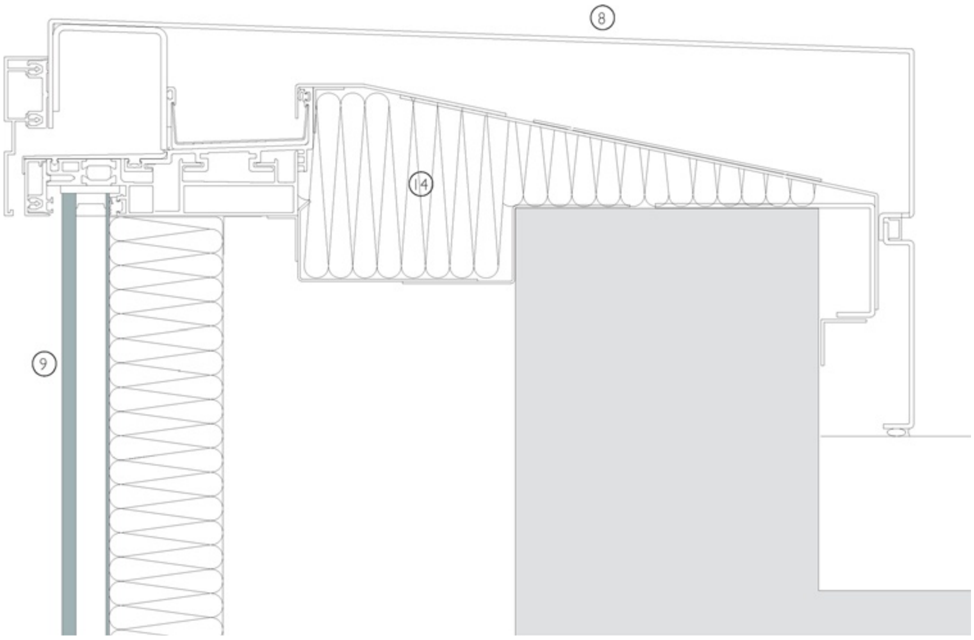
Horizontal section 1:5. Frameless external glass corner in externally glazed unitised panel



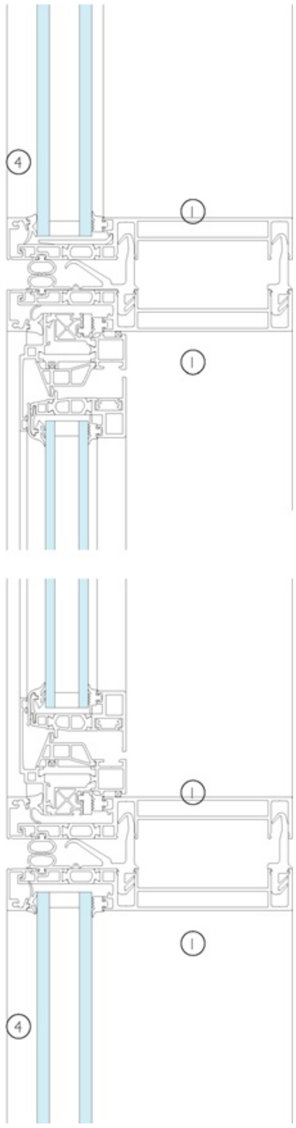
above one another. The complete bottom horizontal edge of the panel intersects with the top edge of the panel below. This joint comprises two lines of defence against air and water infiltration, and a further air seal at the interior face of the panels. In stick glazing, seals are provided by a set of pressure plates applied when the carrier frame and glass are already in place. In unitised glazing, the waterproofing is mostly fixed to the panel before installation and has to work when panels are simply slotted into place. An outer line of defence is provided by rubber-based baffles set on each panel so that they press together to form a seal. An aluminium drip profile is sometimes added to the outside of this as a first barrier against wind, but allowing water to drip out again behind this profile. Any water passing through this profile is stopped in a pressure equalised chamber that stops water getting any further. This is drained through the forward baffle and out of the front of the panel. At the back of the joint is an air seal. In warm humid countries, this rear chamber is usually ventilated to the outside as well as to release condensation that inevitably forms in the full depth of the profile. In this detail, the performance of the inner air seal is critical to the success of the system.

The vertical joint between two panels is formed as a vertical continuity of horizontal joints. The forward baffle forms an outer seal, the inner seal is lapped onto the horizontal joint, and the inner air seal is continuous with its horizontal counterpart.

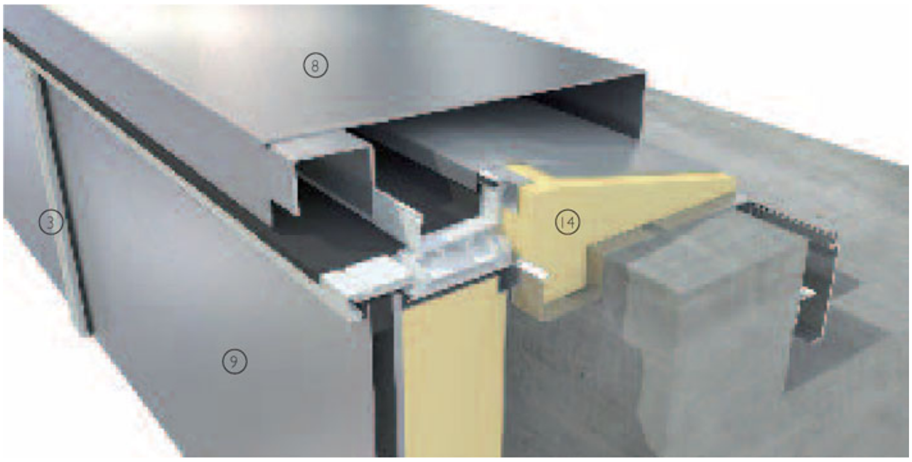
Both horizontal and vertical aluminium profiles have a thermal break set near the external face to avoid thermal bridging. How-



Vertical section 1:5. Parapet connection detail at top of unitised glazing panel



Vertical section 1:5. Outward opening window glazed into unitised panel



3-D cutaway view of parapet connection at top of opaque unitised panel

ever, since external air is allowed deep into the joint, thermal calculations are undertaken to check that the dewpoint falls in the pressure equalised drainage cavity. Spandrel panels are formed in the same way as with stick glazing with metal or glass panels. The transom dividing spandrel and glazing beneath is formed as one division within the unitised panel, though it can sometimes be at the position of the stack joint if the panels are seated on the fixing bracket at slab level rather than hanging from it.

Opening lights

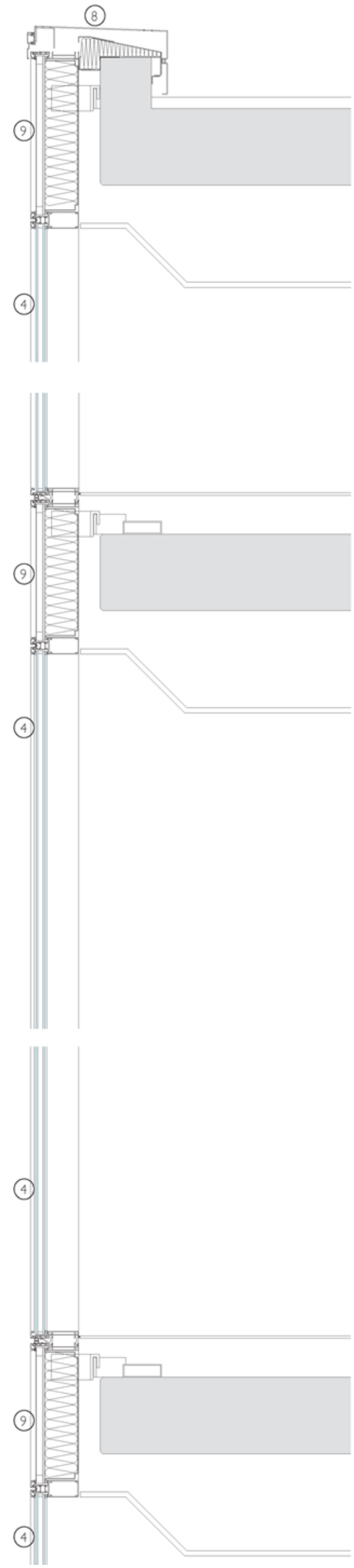
Opening lights such as smoke vents are formed within each panel with a secondary frame inserted within the edge frame of the panel. Doors are usually made as separate items that are glazed into the adjacent frame, unlike stick glazing where doors are glazed into the stick system, making the overall widths greater. However, air infiltration rates for doors are usually half that of unitised glazing at around 300 Pascals for doors when compared with 600 Pascals for unitised glazing. Stick glazing provides similar levels of air infiltration. The poorer performance of traditional doors can sometimes lead to the use of window profiles as doors since they have much lower air infiltration rates, some matching those of curtain walling.

Corner panels, parapets and cills

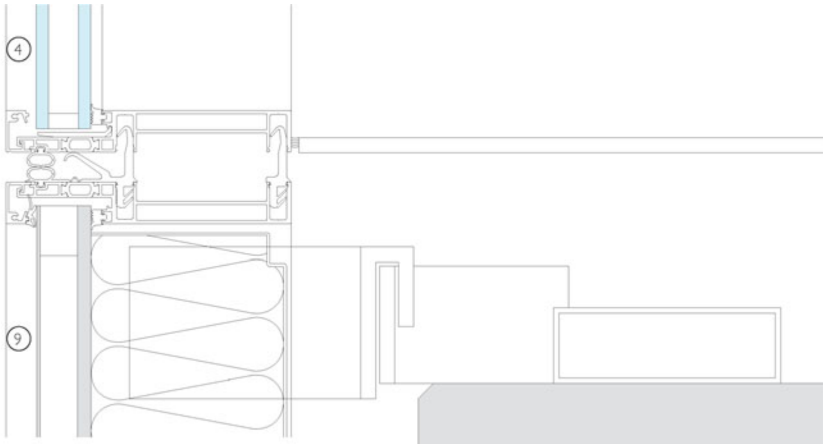
An advantage of unitised glazing is its ability to have frameless glazed corners, which is difficult to achieve in stick glazing, since the sealing joint between the two glazed units has to be achieved on site, where curing of the sili-

Details

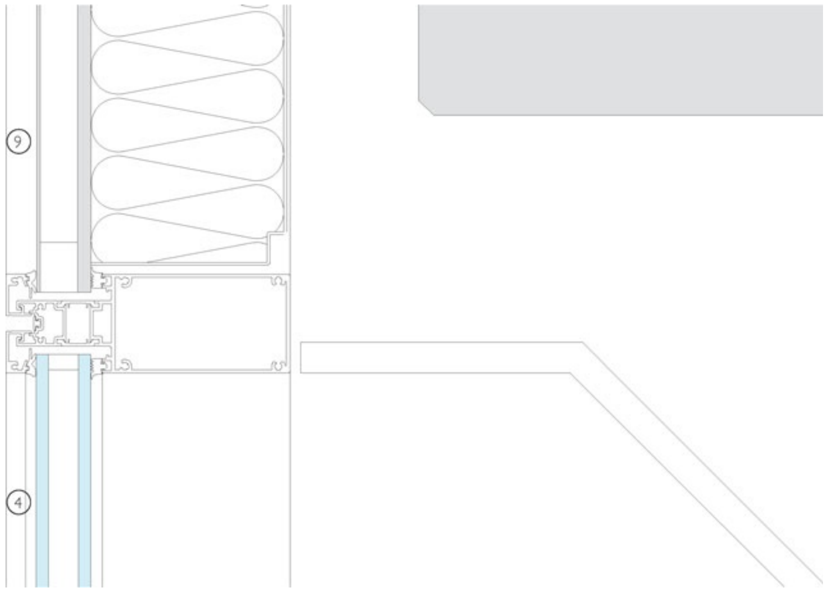
1. Interlocking transom
2. Plain transom
3. Interlocking mullion
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal parapet coping
9. Metal-faced or opaque glass-faced insulated panels
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer screen providing solar shading
14. Thermal insulation
15. Sheet metal seal
16. Cover cap
17. Smoke seal
18. Support bracket



Horizontal section 1:5. Unitised curtain wall supported from floor slabs with opaque spandrel panels



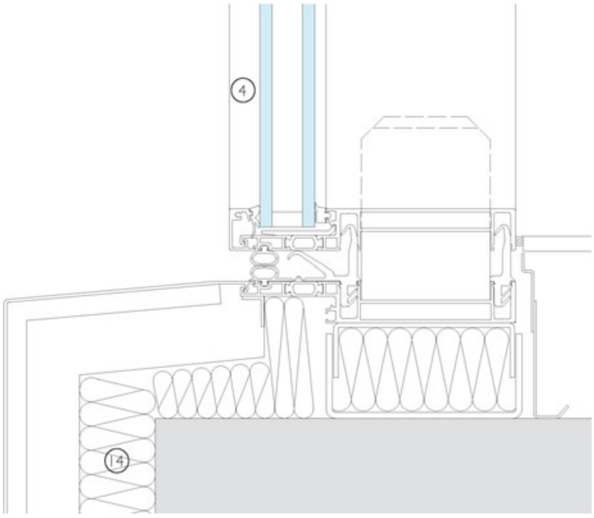
Vertical section 1:5. Unitised panel hung from top of slab with opaque glass panel to hide slab edge



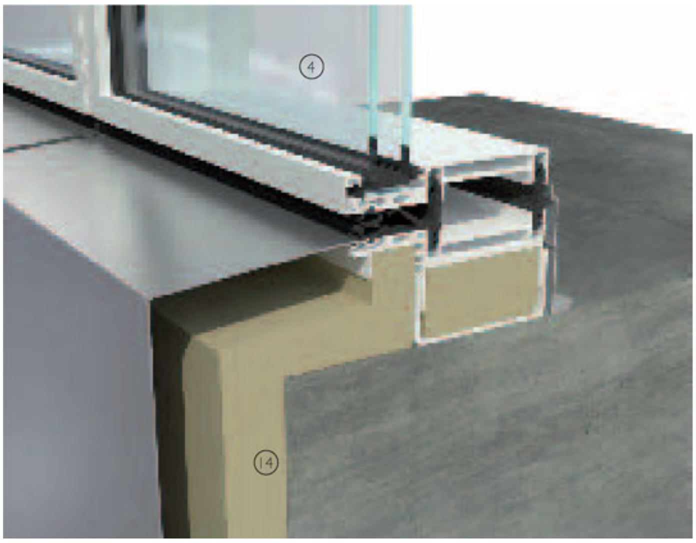
Vertical section 1:5. Connection between opaque glass spandrel panel and double glazed unit with stick transom at suspended ceiling level

cone is much more difficult than in the factory. Corner units with frameless corners are made by supporting the glass on three sides in a frame and bonding the two sides together. Usually a small square aluminium section, 30mm x 30mm (1.2in x 1.2in) approximately to match the thickness of the double glazed units, is used to support the corner of the panel when it is lifted by crane. This makes the corner of the panel slightly less all-glass than can be achieved by a double glazed bay window for example, with a fully glazed corner. In such a bay window the glass can be joined without the need for an additional aluminium post, using either a stepped or mitred joint. In a fully glazed corner in a unitised panel, the appearance of the corner is still around 40mm (1.5in), since the visible edging to the double glazed unit visually widens the joint to around 40mm. Panels can be formed either as equal corners, with up to around 1500mm (5ft) from each corner to a short corner of 1500mm (5ft) on one leg and 300mm (1ft) on the other leg. As the size of the corner panel increases, it becomes more difficult to lift and set in place, and consequently becomes more expensive. A corner unit with a framing member at the corner can be made either with a frame visible, or visible only from the inside, with a glass-to-glass junction as described in the paragraph. Sometimes the joint occurs on the corner of two flat panels, with either a mitred corner or a square corner with an infill piece.

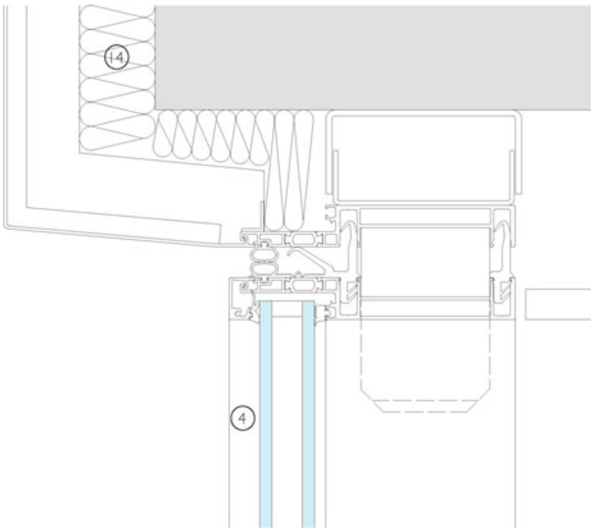
Both parapets and cills are formed in a similar way to those used on stick systems,



Vertical section 1:5. Unitised panel connection to top of floor slab with insulated metal slab capping



3-D view of unitised panel connection to top of floor slab



Vertical section 1:5. Unitised panel connection to underside of floor slab with insulated metal slab capping

3-D view of unitised panel connection to underside of floor slab

but are formed as separate panels unlike stick systems which are glazed into the top transom at roof level.

Penetrations

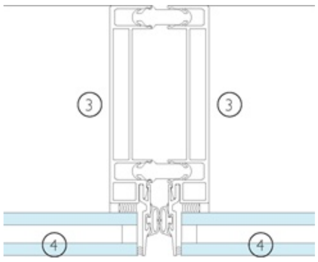
Penetrations through glazing for brackets, usually fixed at floor level to fix them back to the floor slab, occur at joints between panels through mullions or transoms. This is because the bracket can be far more easily sealed at this point, where the glazing system is drained and ventilated internally, than through spandrel panels, where it is difficult to apply a seal and where no mechanical pressure can be applied to the spandrel panel since there is no framing member behind.

Silicone-bonded glazing

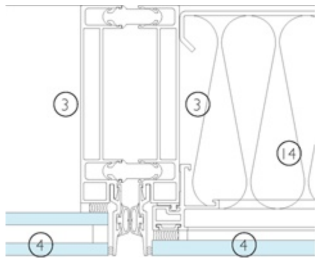
A development over the past ten years has been in silicone-bonded glazing. Although this is used in unitised systems, it is also used partially in stick glazing. The glass is restrained on two vertical sides by pressure plates and two horizontal sides by silicone. Alternatively, the glass is bonded on all four sides by silicone. This method avoids the need for visible cappings for mullions and/or transoms which are often around 1.5 times wider than an equivalent stick system. The use of silicone allows the joint between glass units to be flush rather than using a pressure plate which is set in front of the glass. This allows the facade to have no visible framing on the outside. Silicone is also used in the joint since this material cannot be combined with an EPDM, such

Details

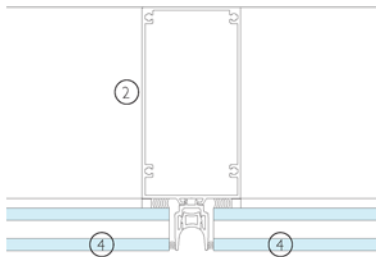
1. Interlocking transom
2. Plain transom
3. Interlocking mullion
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal parapet coping
9. Metal-faced or opaque glass-faced insulated panels
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer screen providing solar shading
14. Thermal insulation
15. Sheet metal seal
16. Cover cap
17. Smoke seal
18. Support bracket



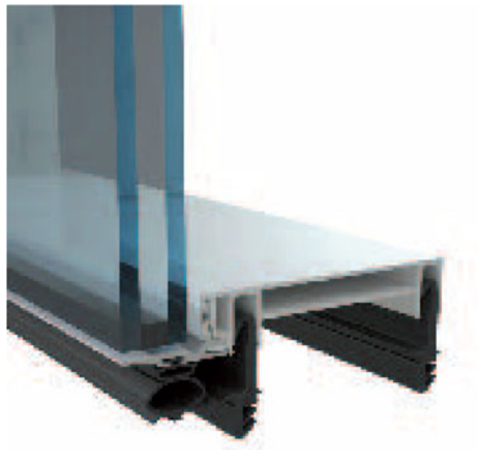
Horizontal section 1:5. Connection between unitised double glazed units with glass bonded to frame



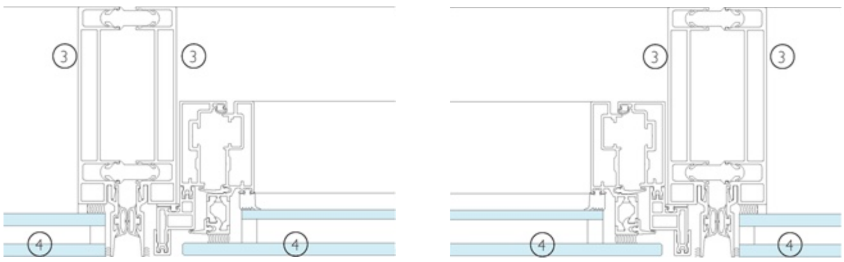
Horizontal section 1:5. Connection between double glazed unit and opaque glass unit with glass bonded to frame



Horizontal section 1:5. Stick mullion in unitised panel



3-D view of unitised double glazed panel with glass bonded to frame

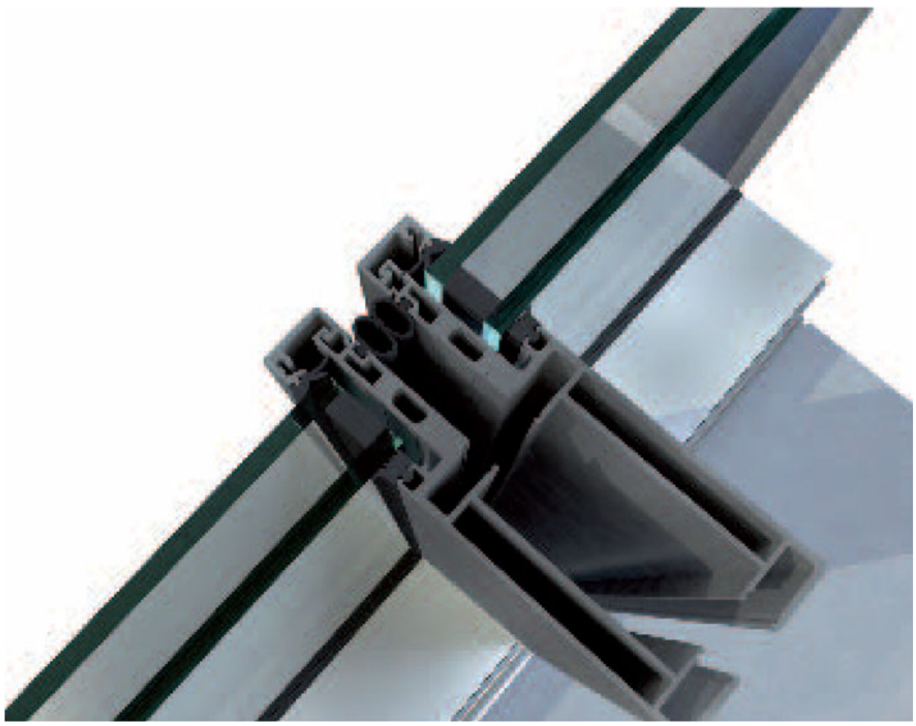


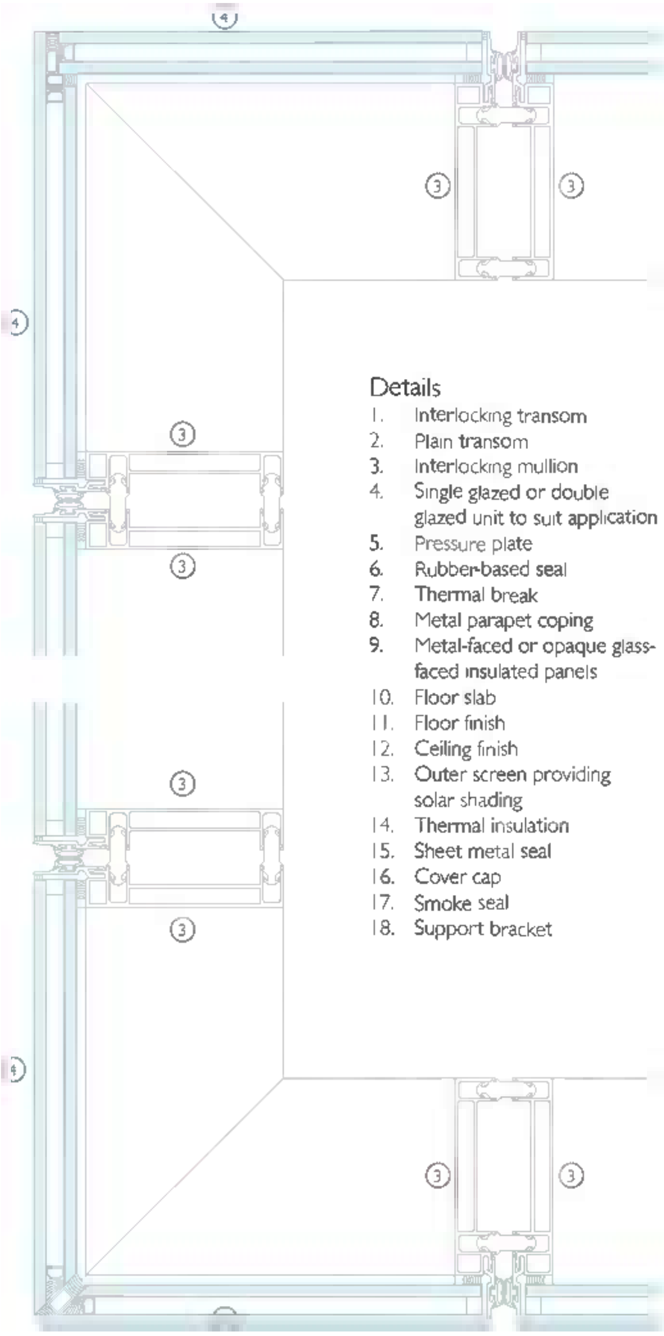
Horizontal section 1:5. Outward opening window within unitised panel with glass bonded to frame

as neoprene, used in seals in pressure plate systems.

The glass units are bonded to aluminium profiles to form a light frame at the edge of the glass. The glass is then mechanically fixed with screws to the carrier frame on site. This technique is increasingly used in unitised systems where damaged glass can be removed without the need to remove the complete panel. Although silicone-bonded glazing allows a facade to appear from the outside as a continuous glass surface interrupted only by smooth and narrow joints, with 20mm (0.78in) rather than 50mm (2in) minimum with pressure plates, the opaque zone across the frame is the same overall width as with pressure plates. This is because the area behind the double glazed units is made opaque with screen printing in order to conceal the width of the carrier frame behind.

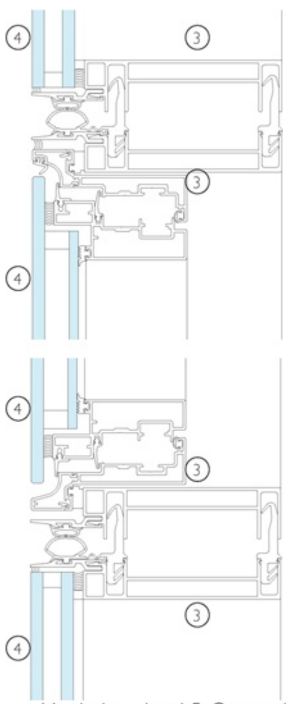
Some manufacturers bond a light aluminium frame around the edge of the frame within the depth of the double glazed unit, fixing the glass with short lengths of pressure plate in the conventional manner, then applying sealant into the joint. Sometimes the glass is secured by additional short clips along the horizontal edges to increase the safety of the system, but building codes around the world differ in this requirement.

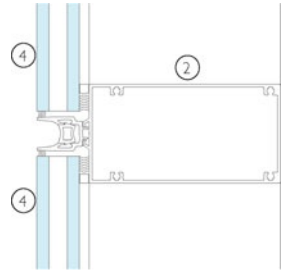




Details
1. Interlocking transom
2. Plain transom
3. Interlocking mullion
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal parapet coping
9. Metal-faced or opaque glass-faced insulated panels
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer screen providing solar shading
14. Thermal insulation
15. Sheet metal seal
16. Cover cap
17. Smoke seal
18. Support bracket

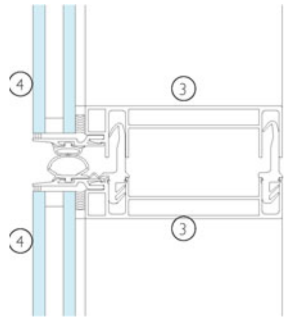
Horizontal section 1:5. Unitised corner panels with glass bonded to frame



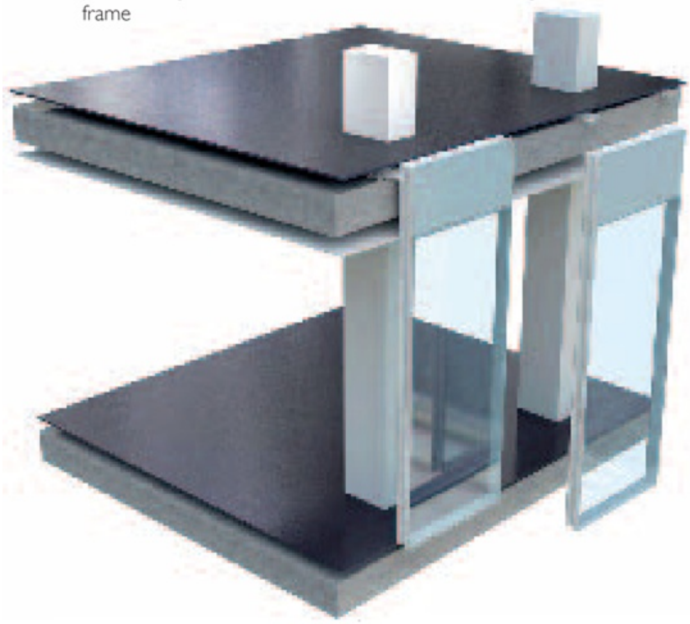


Vertical section 1:5. Stick mullion in unitised panel

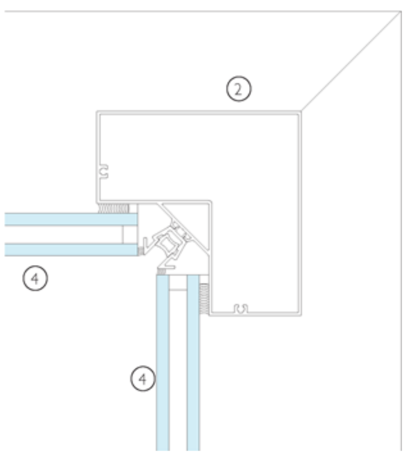
Vertical section 1:5. Outward opening window within unitised panel with glass bonded to frame



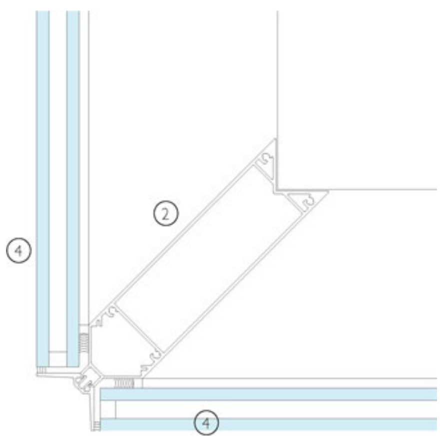
Vertical section 1:5. Connection between unitised double glazed units with glass bonded to frame



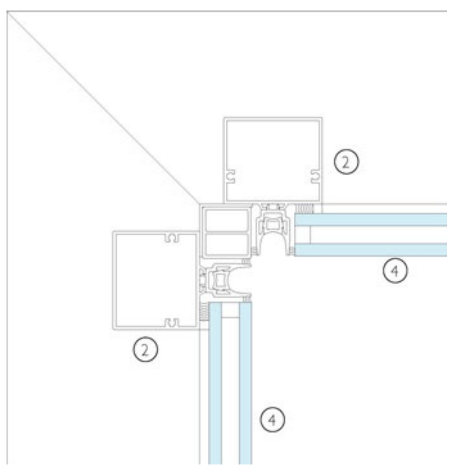
3-D view of unitised panel hung in front of slab incorporating double glazed unit and opaque spandrel panel



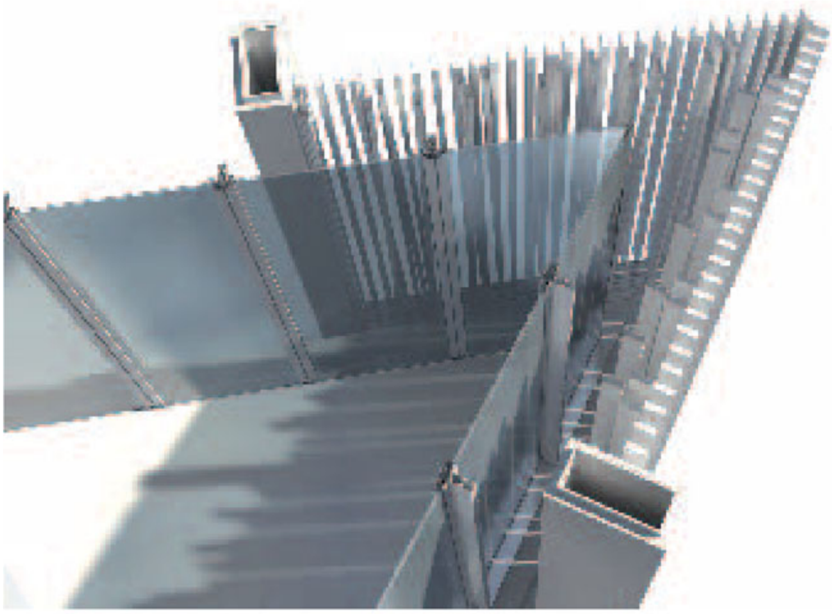
Horizontal section 1:5. Framed internal corner within unitised panel using bonded glass



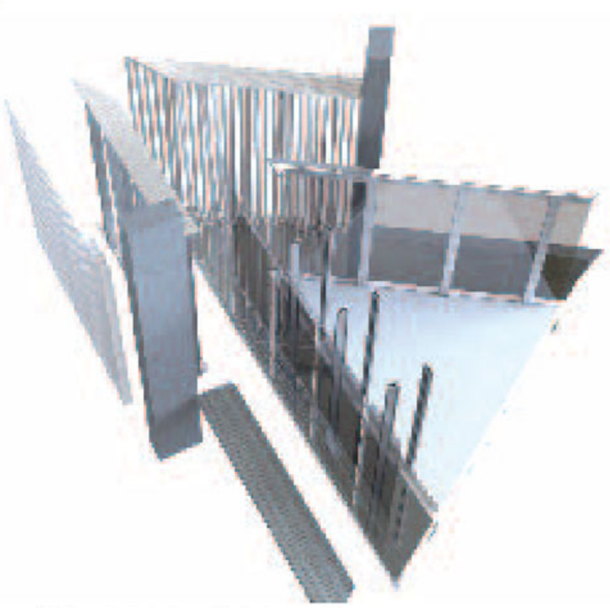
Horizontal section 1:5. Framed external corner within unitised panel using bonded glass



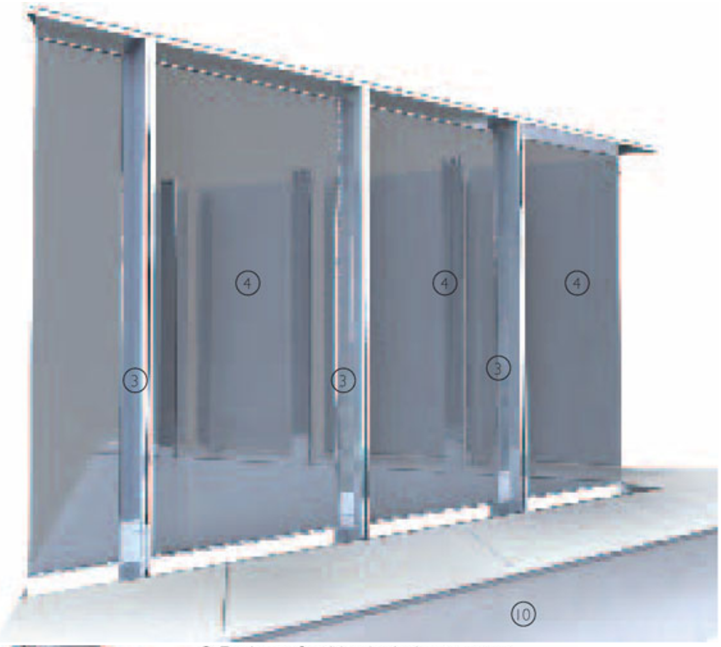
Horizontal section 1:5. Internal corner connection between unitised panels with bonded glass



3-D view of unitised window with louvre system in front



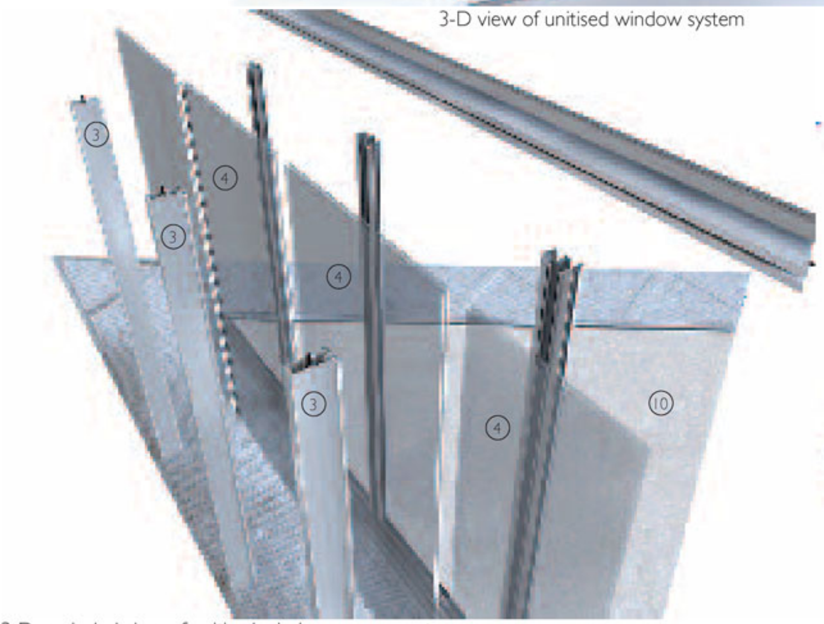
3-D exploded view of window and louvres



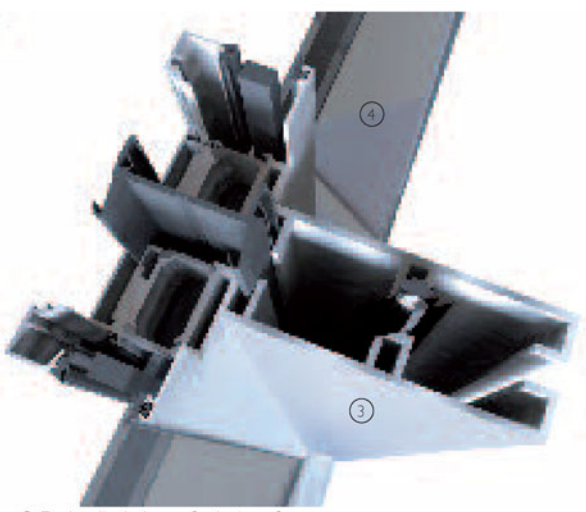
3-D view of unitised window system

Details

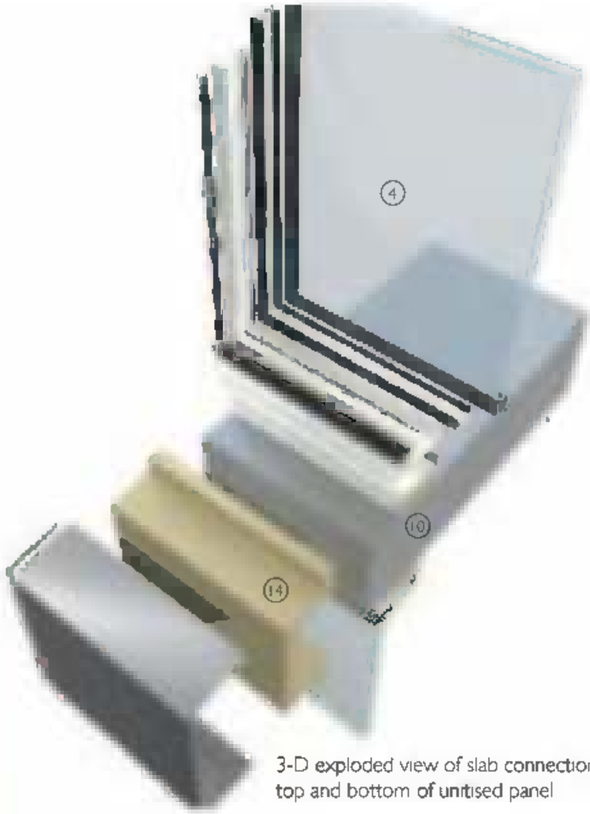
1. Interlocking transom
2. Plain transom
3. Interlocking mullion
4. Single glazed or double glazed unit to suit application
5. Pressure plate
6. Rubber-based seal
7. Thermal break
8. Metal parapet coping
9. Metal-faced or opaque glass-faced insulated panels
10. Floor slab
11. Floor finish
12. Ceiling finish
13. Outer screen providing solar shading
14. Thermal insulation
15. Sheet metal seal
16. Cover cap
17. Smoke seal
18. Support bracket



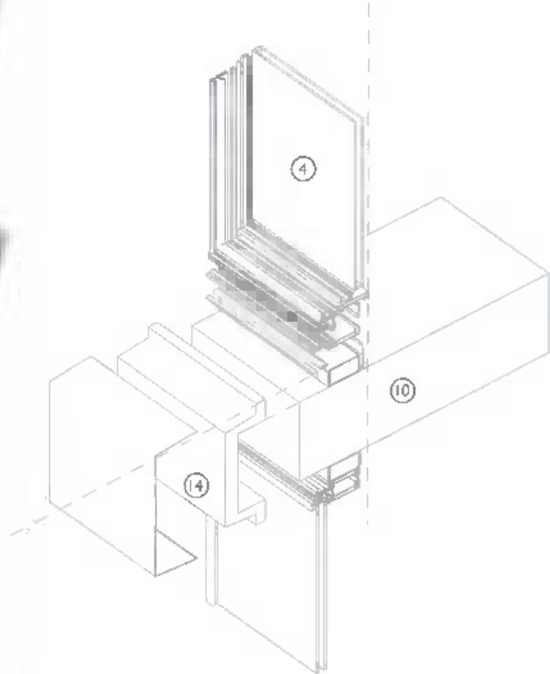
3-D exploded view of unitised window components



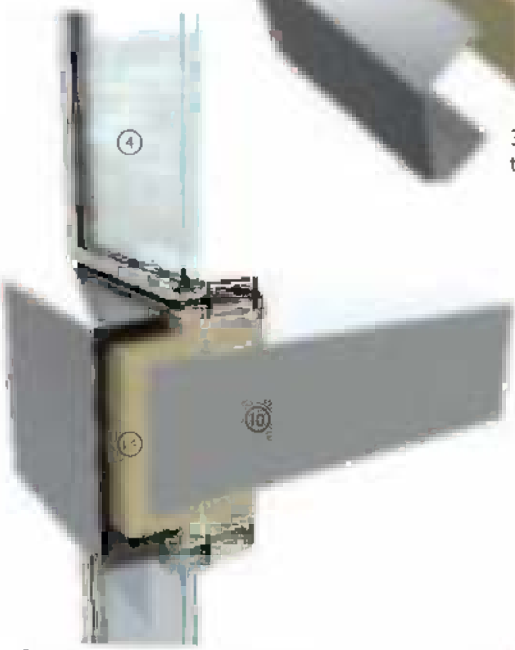
3-D detailed view of window frame



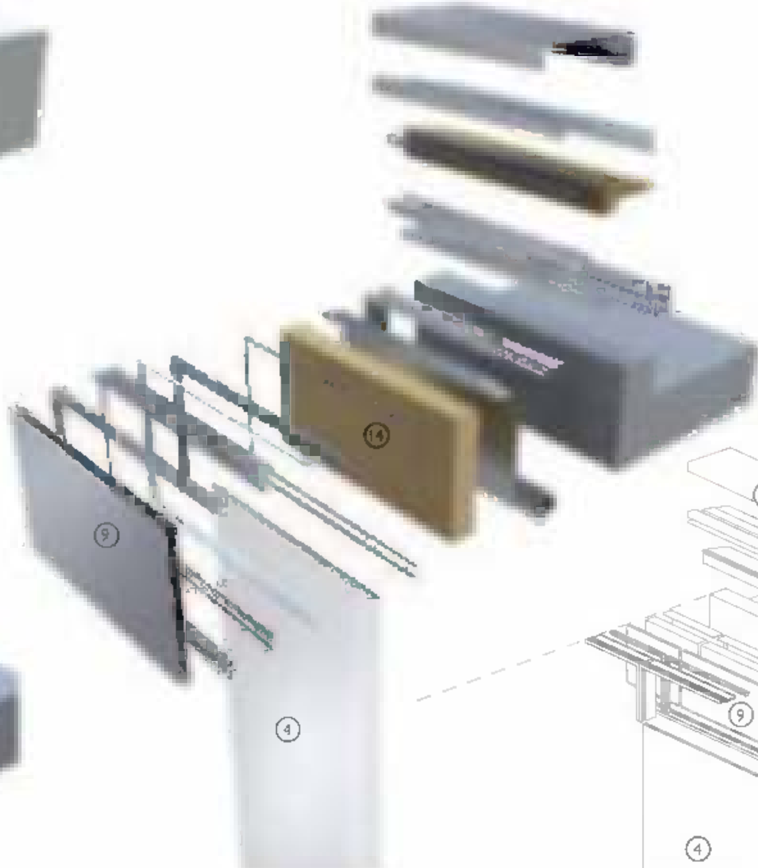
3-D exploded view of slab connection at top and bottom of unitised panel



Exploded axonomentric view of slab connection at top and bottom of unitised panel

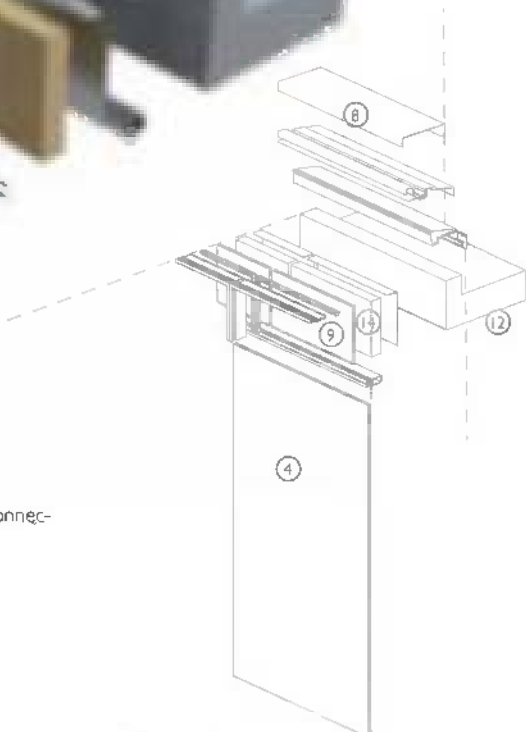


3-D view of slab connection at top and bottom of unitised panel

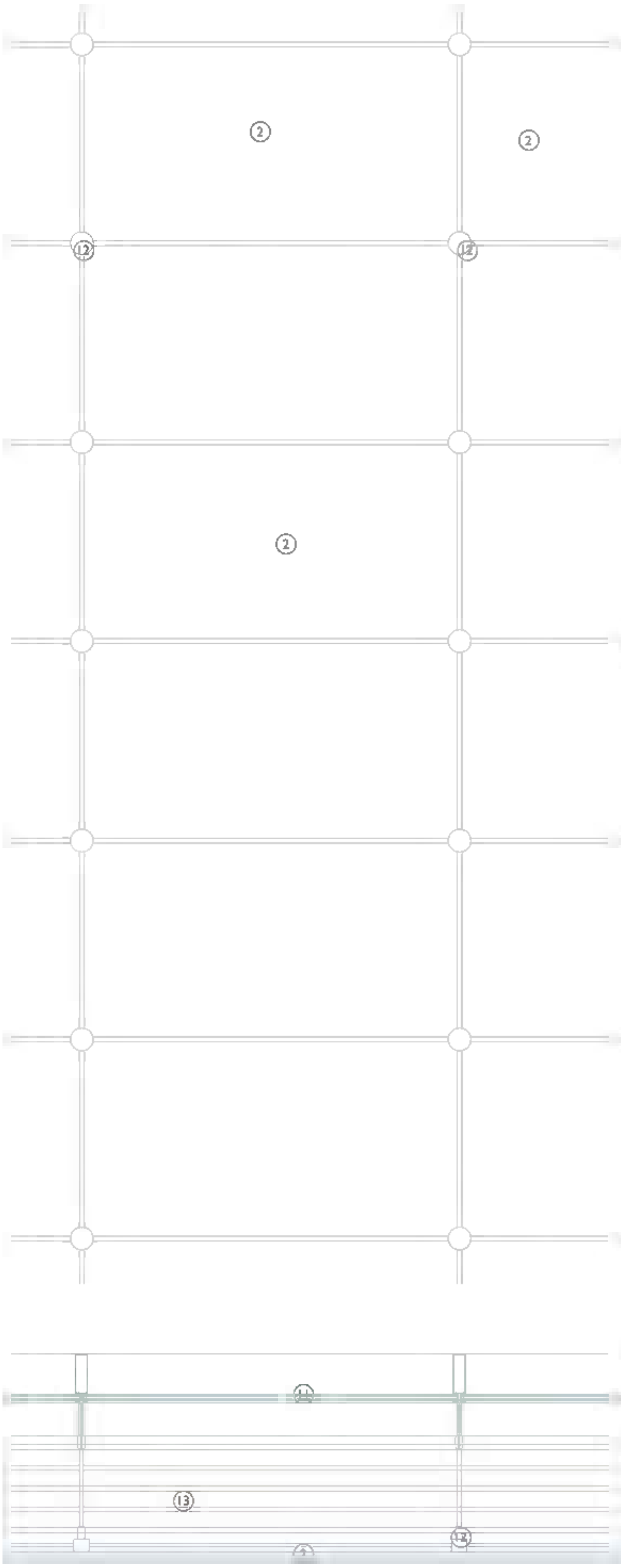


3-D exploded view of parapet connection at top of unitised panel

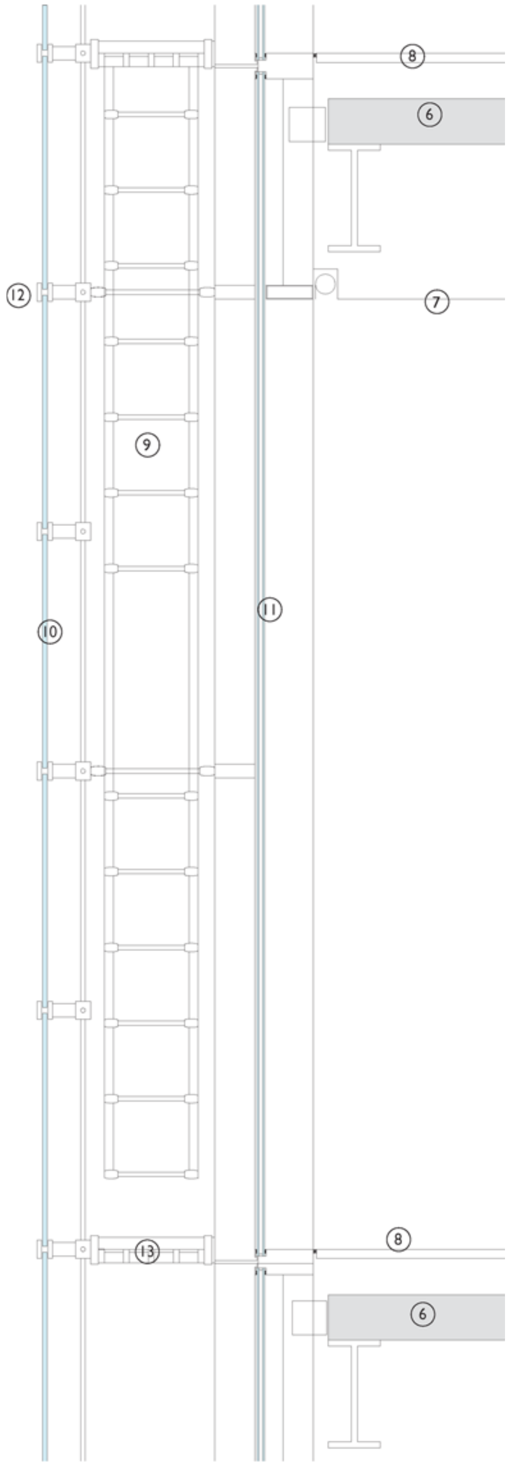
3-D view of parapet connection at top of unitised panel



Exploded axonometric view of parapet connection at top of unitised panel



Horizontal section & elevation 1:25. Glass clamped at corners to fixing suspended from cable support.

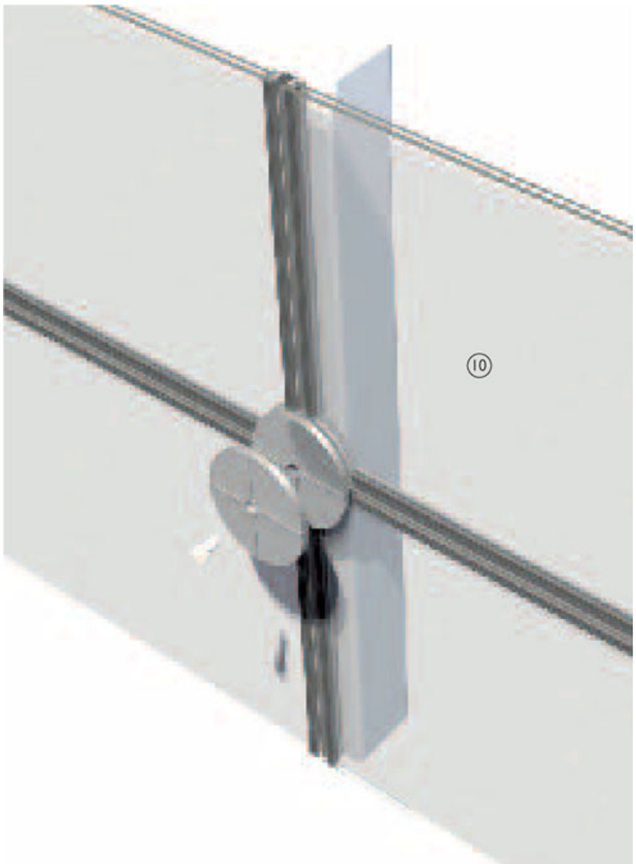


Vertical section 1:25. Clamped glazing outer layer in double skin facade with maintenance walkway

Details

1. Stainless steel patch plates
2. Single glazed or double glazed unit to suit application
3. Silicone seal
4. Glass fin
5. Support bracket
6. Floor slab
7. Ceiling finish
8. Floor finish
9. Access ladder
10. Clamped glazed wall
11. Inner framed curtain walling
12. Fixing bolt
13. Maintenance access deck

3-D view glazing clamped at corners and supported from cables



3-D view of corner clamped glazing system

This glazing method is suited primarily to single glazing but double glazed examples are being constructed that avoid some of the wide joints resulting from the visible black edges of double glazed units. The sealant between double glazed units is also usually black to match the unit edges.

Comparison with bolt fixed glazing

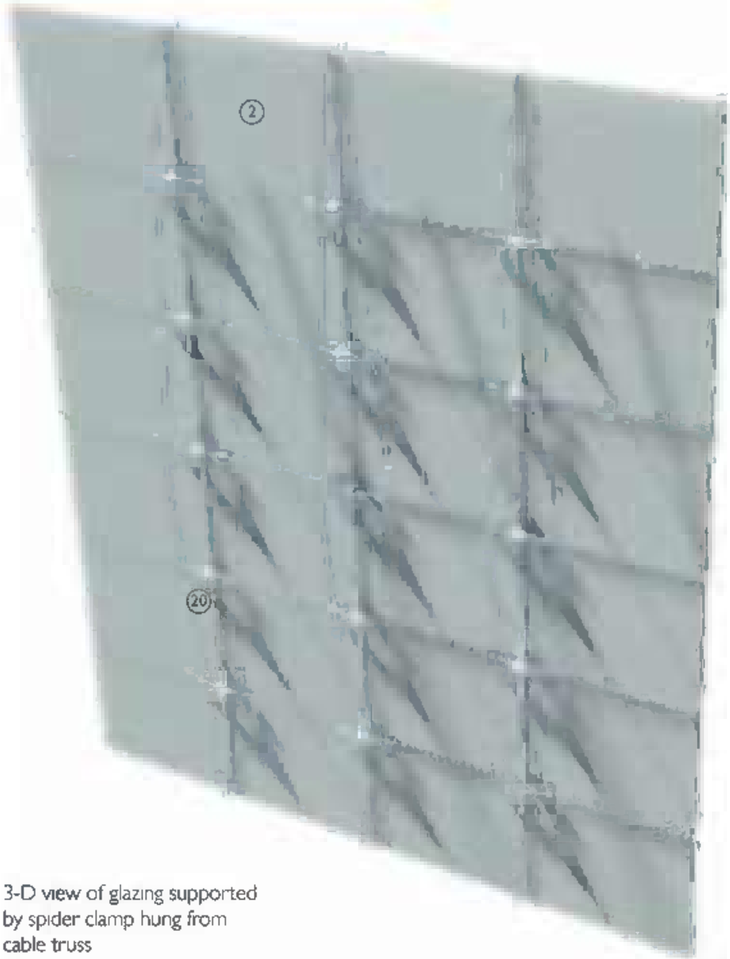
As a method of frameless glazing, clamped glazing is more economical than bolt fixed glazing. Whereas bolt fixed glazing requires drilling of glass, clamped glazing does not, as glass is fixed with patches or clamps that pass through the joint between the glass sheets or double glazed units. The ability of clamp brackets to be simple and easily made allows the glass to be supported at different angles to one another in a tiled, non-planar manner. Glass has been lapped in the manner of traditional patent glazing and tiled in the manner of wood shingles, where glass is lapped on two edges to give a rich, undulating texture across glass facades. Because the facade is more visually vibrant, the fittings themselves can also project from the facade to allow less expensive stainless steel angle-type brackets to be used. These contrast both in the appearance and higher costs associated with bolt fixed glazing. A disadvantage of clamped glazing is that glass thicknesses are usually thicker than those in bolt fixed glazing, where the distances between fixings are reduced (reducing the span of the glass) by setting them into the material.

This combination of easily fabricated, easily modified brackets and fixing through the joint allows a geometrically complex facade to be fixed back to a rectilinear, economic supporting structure. This contrasts with the need to repeat expensive bolt fixings where there is little possibility of changing the geometry to allow for different fixing positions of the glass.

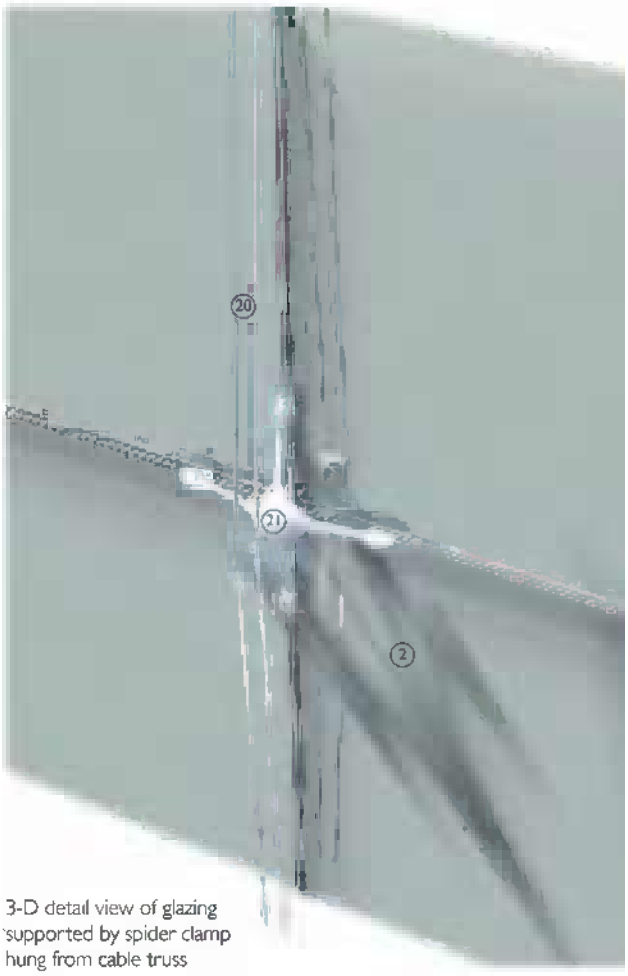
Clamped glazing is increasingly used in rainscreen configuration with open joints or open, lapped joints with an accessible area behind, as used in 'twin wall' glazed facades. The outer screen acts primarily as a weather barrier, allowing the inner wall to have opening windows where they would otherwise not be possible, as in tall buildings or buildings in areas of high ambient noise. The rainscreen principle has been developed further to avoid fixing clamps directly to the glass but instead to silicone bond an edge frame around the glass and fix the frames back to supporting structure with clamps. This silicone-bonded variation of clamped glazing is very useful in opaque or translucent glazing in a full rainscreen to an opaque backing wall. Joints between the glass can be sealed with rubber-based strips to avoid dirt getting into the void behind the glass and staining the back of the glass. The advantage of this system is in clamping the glass by means of a secondary frame that avoids penetrating an outer seal, thus making it suitable for glass rainscreen walls without visible framing and without the need for cleaning the inner face of the glass sheets.

Patch plate glazing

This method uses angles and plates that are bolted through the glass rather than through the joints. This is an earlier form of frameless glazing and was the forerunner of bolt fixed glazing. Although cheaper than bolt fixed glaz-



3-D view of glazing supported by spider clamp hung from cable truss



3-D detail view of glazing supported by spider clamp hung from cable truss

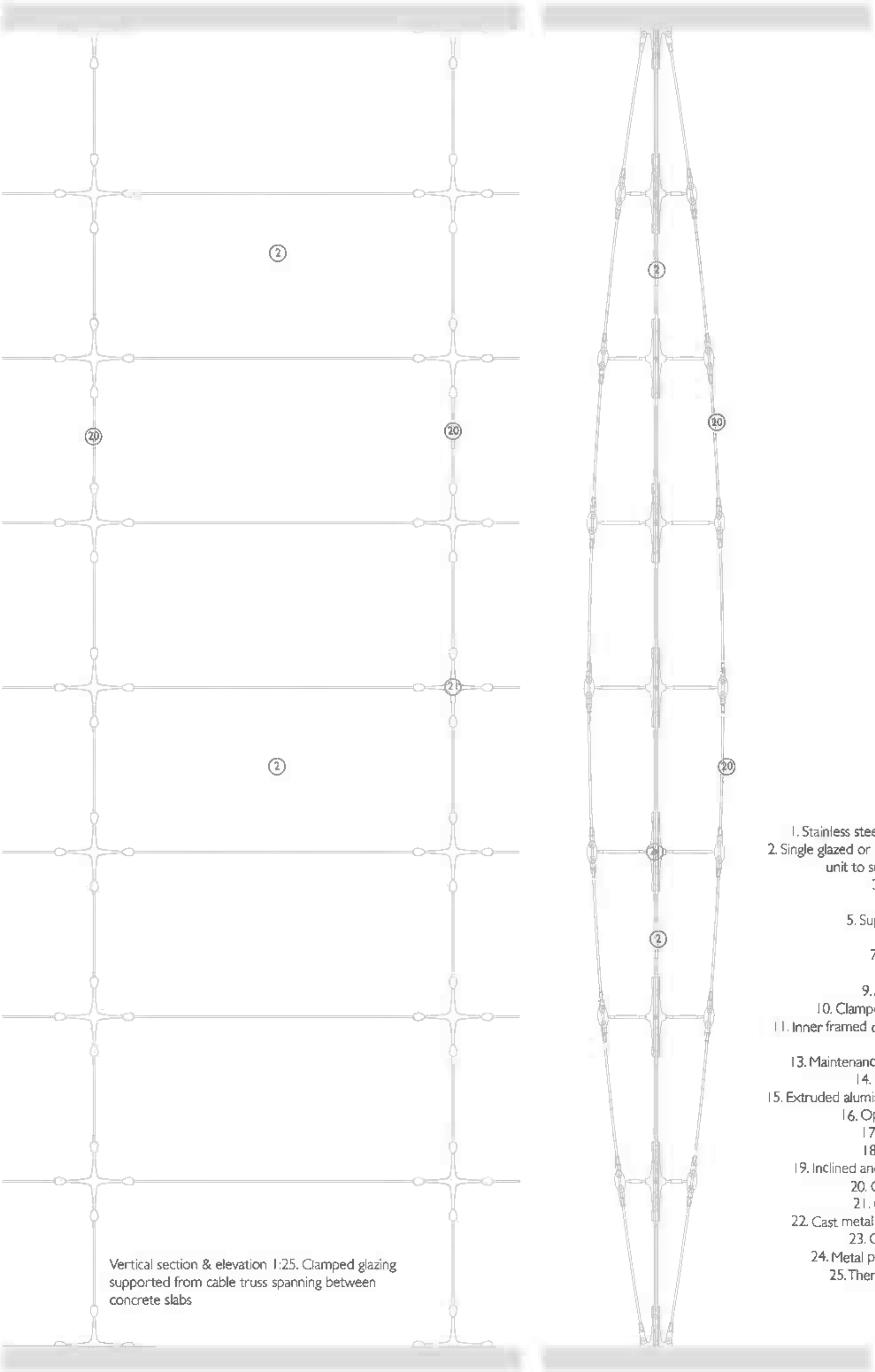
ing, it is restricted to single glazing. Glass sheets are fixed at their corners with a patch fitting that connects four sheets together. Like framed glazing in either stick or unitised systems, the glazing is either hung from the top with either brackets or continuous stainless steel angles fixed back to the primary structure, or seated on support angles at its base. Patch fittings are not usually at top or base of a wall. Instead, continuous angles or a glazing channel is visually preferred both top and bottom in order to provide a weathertight seal. Clamped angles are used where they are concealed beneath floor finishes. Glazing channels are used either for convenience or where the channel is visible at floor level. Where glazed balustrades are used, these clamps are not sufficient for cantilevered glass, that is, where the glass is fixed only at floor level and not restrained at the level of the handrail. Doors are fixed using patch plates where the door is hung, and are seated on pivots, with a floor spring when the door is supported at floor level. Where patch plate glazing is hung from the top, doors are also hung in order to accommodate movement in the supporting structure. Similarly, if the glazed wall is supported at its base then the door should also be supported at floor level. If the glazing is hung and the door is supported differently, at its base, then a difference in movement between wall and door will either damage the door or prevent it from working properly.

The use of bolts through the glass makes the size of each patch plate relatively big compared with other clamping methods, with up to four bolts per fixing in elevation. This method is often used with glass fins, that provide stability, in an all-glass wall. The brackets securing the fins can have from four to six bolts per bracket, giving a very strong appearance. Since stainless steel brackets and bolts are required for durability (mild steel is not sufficiently durable), these brackets are finished as polished to avoid surface tarnishing. The use of this polished finish gives this glazing a very particular appearance which is difficult to adapt to something lighter. Although the glazed wall itself is very transparent, the patch fittings have a strong visual presence.

Clamped glazing

This method avoids drilling through the glass by passing through the joint between glass sheets or units rather than by drilling holes in the glass itself. This allows double glazed units to be used, since plates either side of a unit can be clamped at its edge strip.

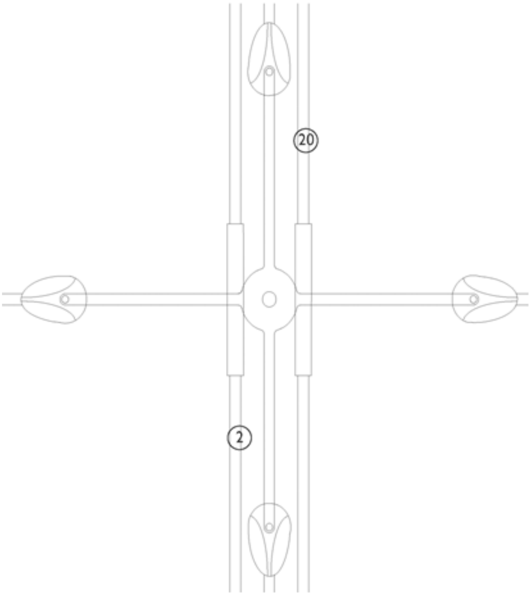
The disc or square plate either side of the joint is secured together and fixed back to a supporting cable, rod or tube structure. This method is more economic than the patch plate type, but still requires comparatively large discs to secure the glass. The use of discs has been combined with stick glazing where the discs are used to secure the glass to stick glazed aluminium extrusions. Glass is set into rubber-based gaskets fixed to the carrier frame and discs are used to hold the glass in place. The gap between the double glazed units is filled with silicone sealant. This has the advantage of being a drained and pressure equalised (ventilated) system.



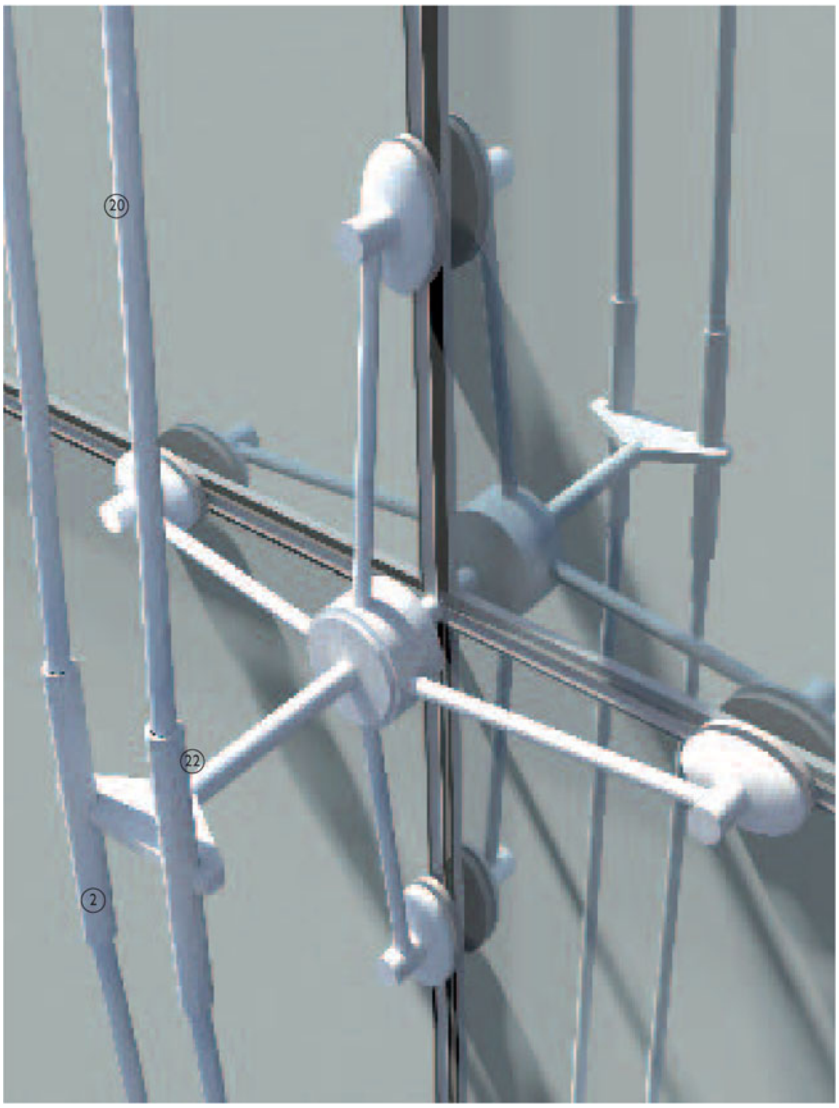
Vertical section & elevation 1:25. Clamped glazing supported from cable truss spanning between concrete slabs

Details

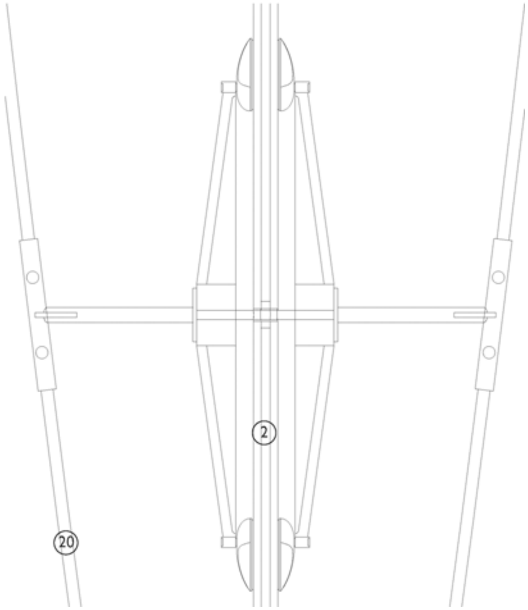
1. Stainless steel patch plates
2. Single glazed or double glazed unit to suit application
3. Silicone seal
4. Glass fin
5. Support bracket
6. Floor slab
7. Ceiling finish
8. Floor finish
9. Access ladder
10. Clamped glazed wall
11. Inner framed curtain walling
12. Fixing bolt
13. Maintenance access deck
14. Fixing bracket
15. Extruded aluminium mullions
16. Opaque Glazing
17. Ground Slab
18. Backing Wall
19. Inclined and lapped glass
20. Cable support
21. Corner clamp
22. Cast metal fixing bracket
23. Clamp bracket
24. Metal parapet coping
25. Thermal insulation



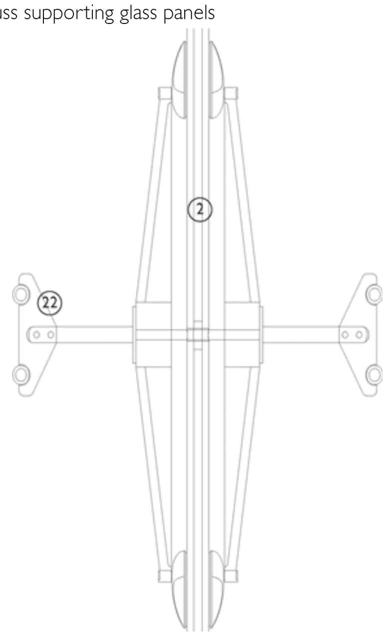
Elevation 1:5. Spider clamp supporting glass panels



3-D detail view of glazing supported by spider clamp hung from cable truss



Vertical section 1:5. Spider clamp hung from cable truss supporting glass panels

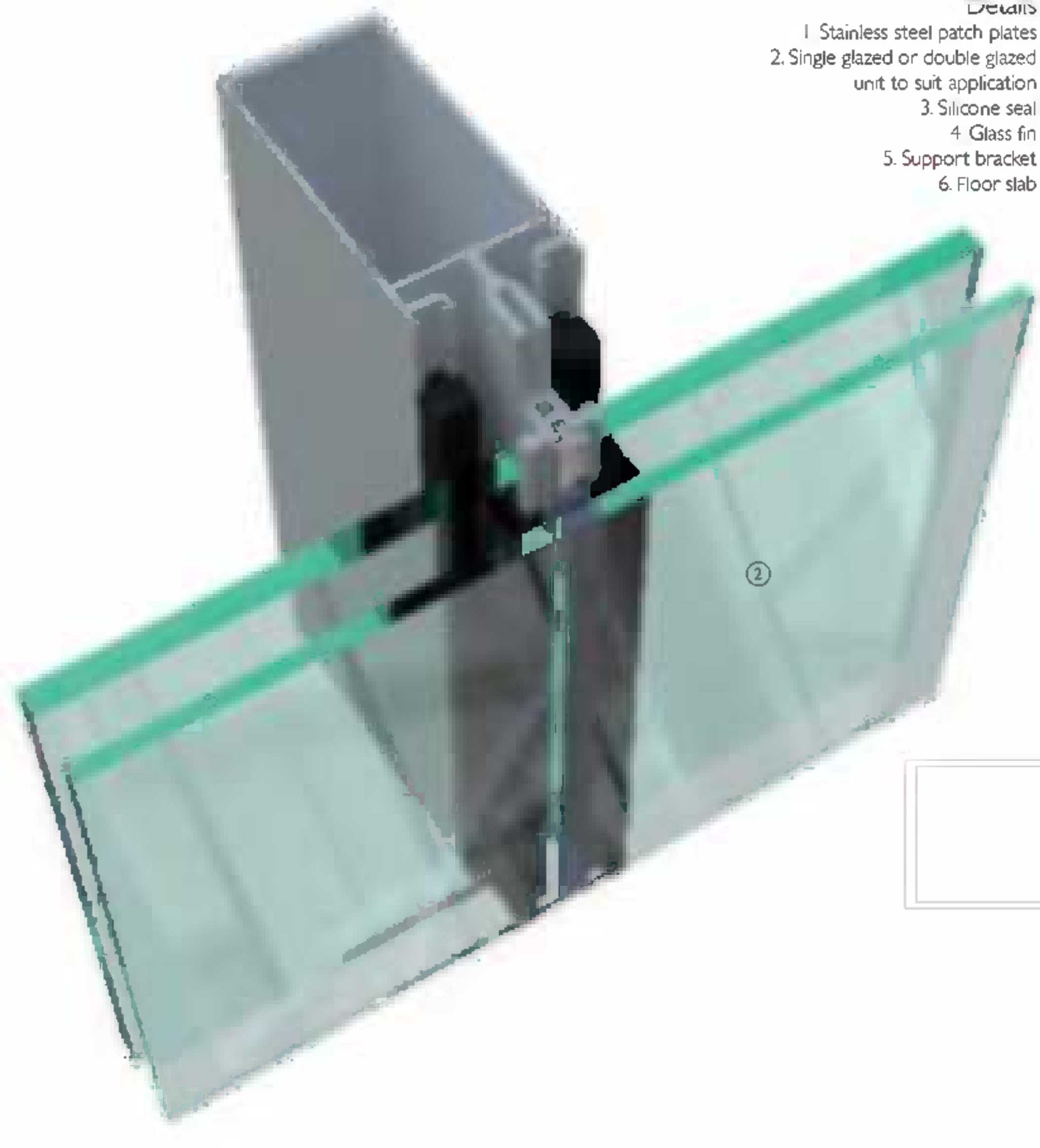


Horizontal section 1:5. Spider clamp hung from cable truss supporting glass panels

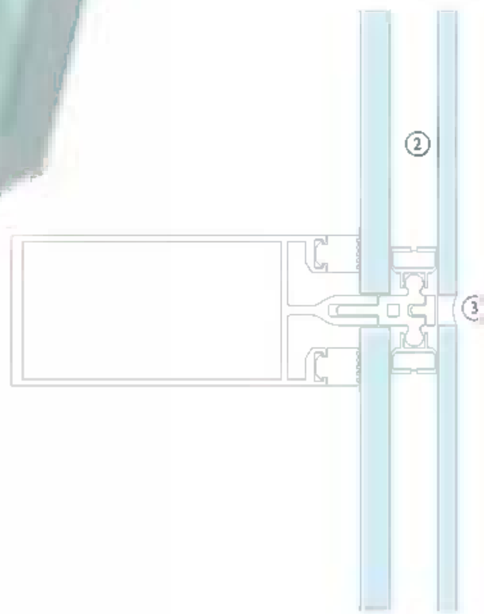
The glass is fixed back to either cables or rods if the glass is hung, or back to a tube if the glass is bottom supported. If top hung, cables or thin rods are hung from the top and tensioned at the bottom. The glass is fixed to the cables with discs, usually at the edges of the glass to reduce the number of cables to a minimum. If wide sheets of glass are used, then the glass may be supported in from the edge. The use of cables provides a very thin wall, but with deflections that are much higher than a framed wall. Maximum deflections can reach up to 600mm to 800m (2ft to 2ft 8in) for walls around 20 metres (65ft) high, but this can be safely accommodated within the structural design. The usual difficulty is in accommodating doors which can deflect only tiny amounts in order to function normally. Doors are usually set into a separate frame and do not form part of the cable structure. If the glazing is supported at its base, then supporting steel tubes provide much more stiffness in the glazed wall, but with a more visible supporting structure. An advantage of such a supporting structure is that the glass can be fixed with a wide range of different geometries. Lapped glazing or 'fishscale' or 'shingled' glazing is possible. Glass is held in a bracket that can support the bottom of the glass in a different position from the top of the glass below. With double glazed units the glass can be drilled to combine the advantage of clamped glazing with the seals provided by extruded silicone gasket 'flippers' that exclude rainwater without being punctured by the brackets, which pass

Details

1 Stainless steel patch plates
2. Single glazed or double glazed unit to suit application
3. Silicone seal
4 Glass fin
5. Support bracket
6. Floor slab
7. Ceiling finish
8. Floor finish
9 Access ladder
10. Clamped glazed wall
11. Inner framed curtain walling
12. Fixing bolt
13. Maintenance access deck
14. Fixing bracket
15. Extruded aluminium mullions
16. Opaque glazing
17 Ground slab
18. Backing wall
19. Inclined and lapped glass
20. Cable support
21. Corner clamp
22. Cast metal fixing bracket
23. Clamp bracket
24. Metal parapet coping
25. Thermal insulation



3-D view of toggle fixed glazing connection



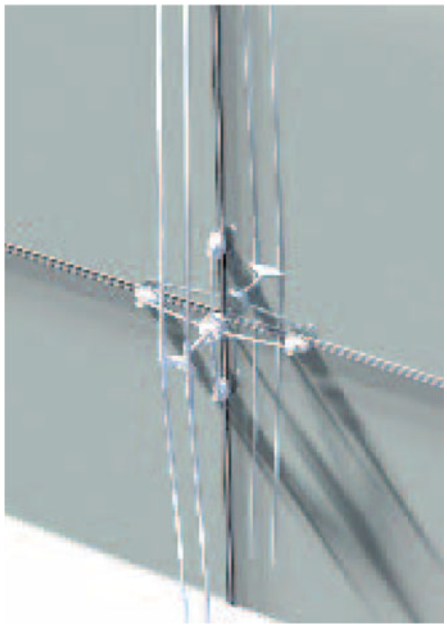
Horizontal section 1:5. Double glazed units fixed to supporting frame with 'toggle' connection and

through holes in the glass beneath. Such brackets are 'shoes' which support the glass usually away from corners to avoid the corner of the glass being unevenly supported. The glass is not structurally supported along its vertical edges as it is easier to sit them in the shoes. Sometimes clips along vertical joints are used for lateral restraint but this depends very much on the specific design.

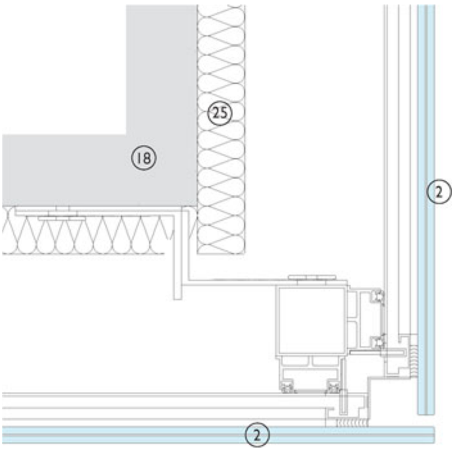
An alternative method of fixing the glass is to use a silicone-bonded frame around the glass and fixing that to cables or steel tubes. The joint between the glass is sealed with extruded silicone gaskets that can provide two lines of defence against windblown rain instead of the single line provided by site-applied silicone sealant. The use of extruded silicone allows the seal to be fixed to the unit in the factory, allowing the wall to be built in the manner of unitised glazing without the need for site scaffolding. Units are fixed from mast climbers or from scaffolding.

Opaque glazing

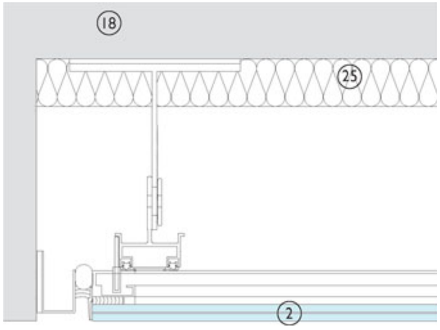
This system comprises single glazing bonded back to aluminium frames which are clamped to a supporting structure, typically a concrete blockwork wall or hollow terracotta block. Clamps are fixed between joints from the front as short lengths of pressure plate. Alternatively, panels may be hooked onto rainscreen-type support brackets before being clamped in place. Unlike rainscreen construction, the joints between panels are sealed with an extruded profile or rubber-based seal onto which the glass is fixed. Para-



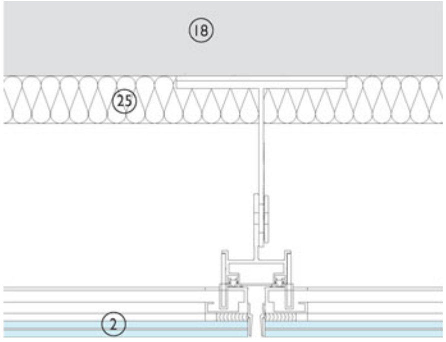
3-D view showing spider clamp hung from cable truss supporting glass panels



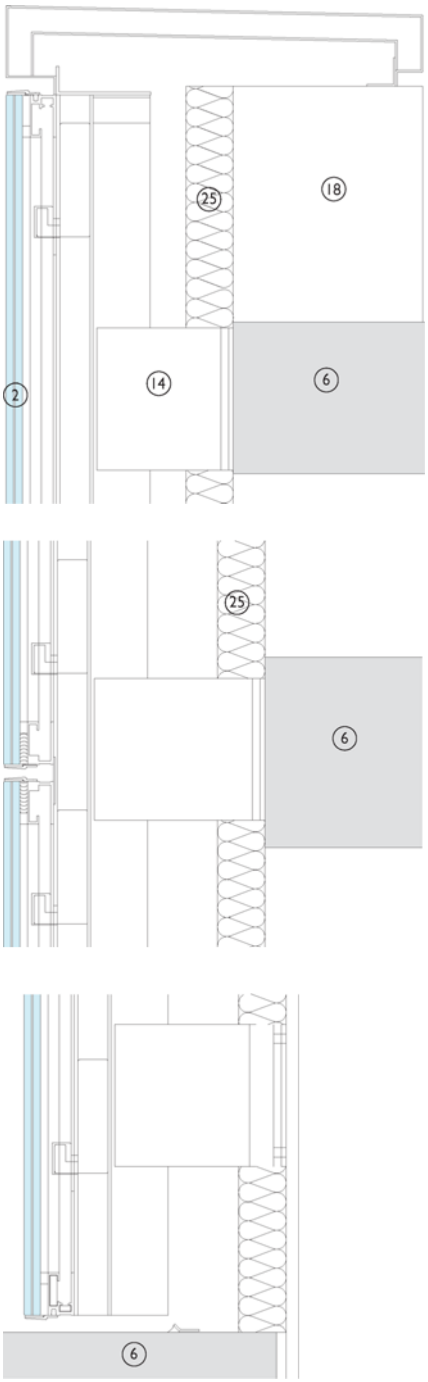
Horizontal section 1:10. External corner connection of glazing clamped to aluminium carrier frame



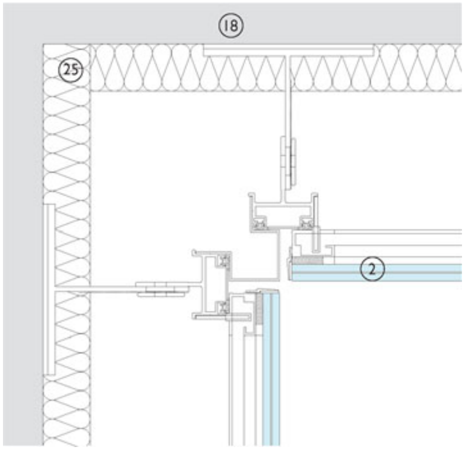
Horizontal section 1:10. Connection between wall and glazing unit clamped to aluminium carrier frame



Horizontal section 1:10. Connection between glazing units clamped to aluminium carrier frame



Vertical section 1:10. Glazing clamped to aluminium carrier frame



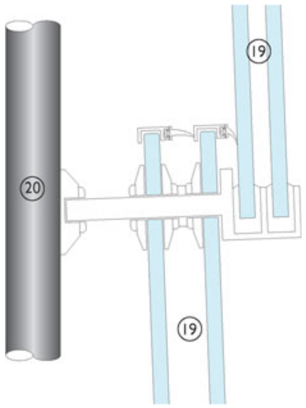
Horizontal section 1:10. Internal corner connection of glazing clamped to aluminium carrier frame

Details
1. Stainless steel patch plates
2. Single glazed or double glazed unit to suit application
3. Silicone seal
4. Glass fin
5. Support bracket
6. Floor slab
7. Ceiling finish
8. Floor finish
9. Access ladder
10. Clamped glazed wall
11. Inner framed curtain walling
12. Fixing bolt
13. Maintenance access deck
14. Fixing bracket
15. Extruded aluminium mullions
16. Opaque glazing
17. Ground slab
18. Backing wall
19. Inclined and lapped glass
20. Cable support
21. Corner clamp
22. Cast metal fixing bracket
23. Clamp bracket
24. Metal parapet coping
25. Thermal insulation

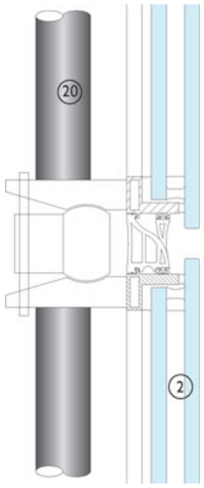
pets are partially ventilated to avoid most of the water ingress but allow some ventilation. The bottom is also ventilated, allowing moisture to find its way out. Opaque glazing can be easily integrated into adjacent areas of clear glazing by setting the aluminium extrusion away from the edge and fixing the edge of the glass into the adjacent glazing system.

Sealing clamped glazing

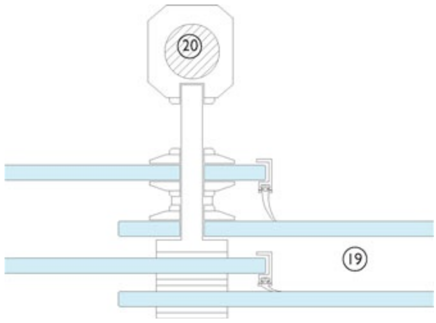
With all forms of clamped glazing, the movement or deflection of any fixed edges must be compatible with that of the general support system. This is particularly important in the case of cable-supported glazing, where high deflections associated with the cables must be integrated with the small amounts of movement when the glass at the edge of the wall is fixed onto an adjacent form of construction such as a reinforced concrete wall. The edge channel or fixings must allow the glass to rotate within it to take up movement from deflection in a cable supporting the other end of the glass. Seals are usually formed by glazing channels or steel angles that provide a weathertight seal. High amounts of movement can be taken up at junctions with a flexible metal strip that is silicone-bonded to the edge of the glass to provide a flexible seal.



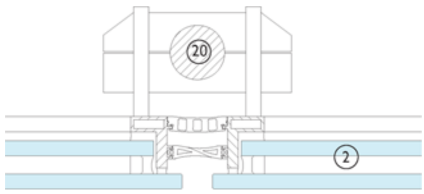
Vertical section 1:5. Lapped glazing in clamped fixing supported on steel frame



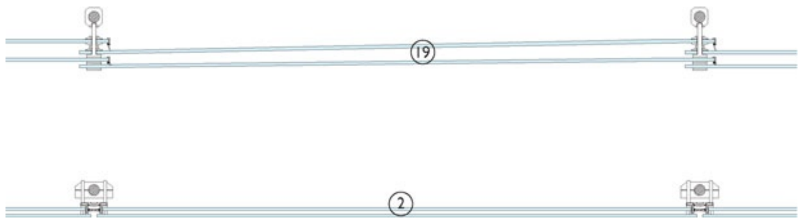
Vertical section 1:5. Double glazed units clamped to steel frame



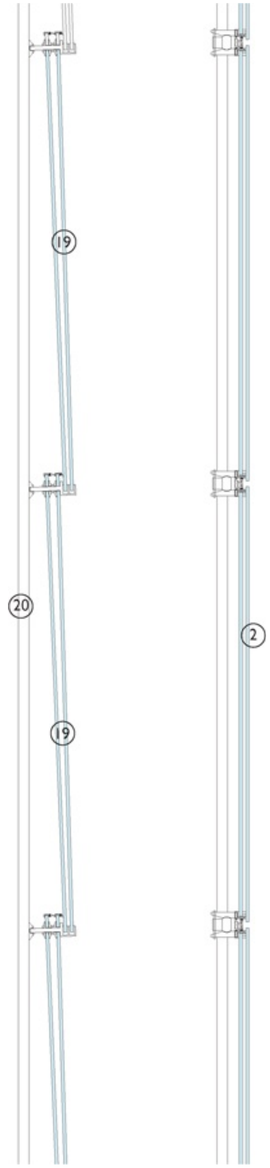
Horizontal section 1:5. Lapped glazing in clamped fixing supported on steel frame



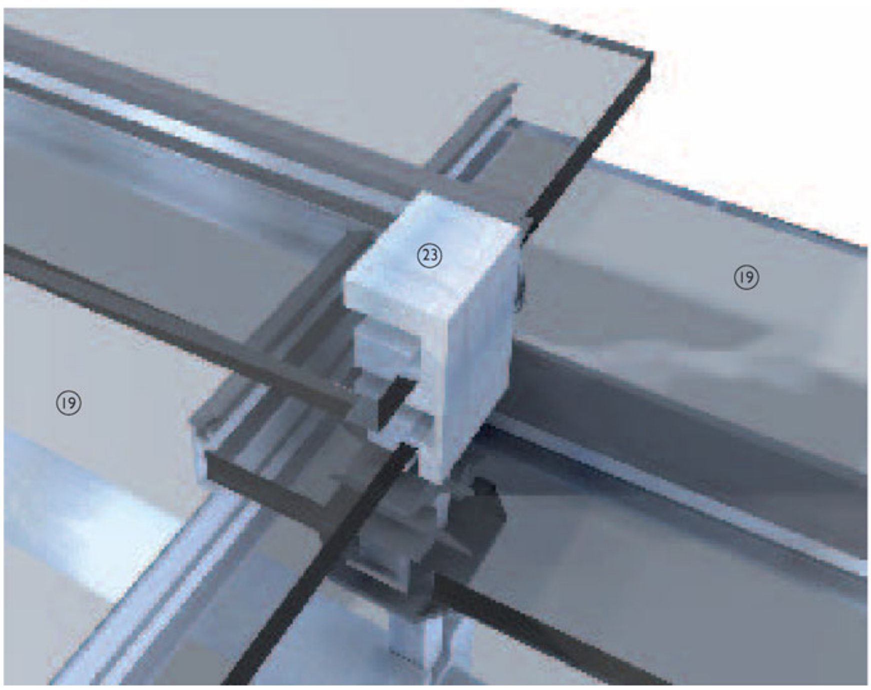
Horizontal section 1:5. Double glazed units clamped to steel frame

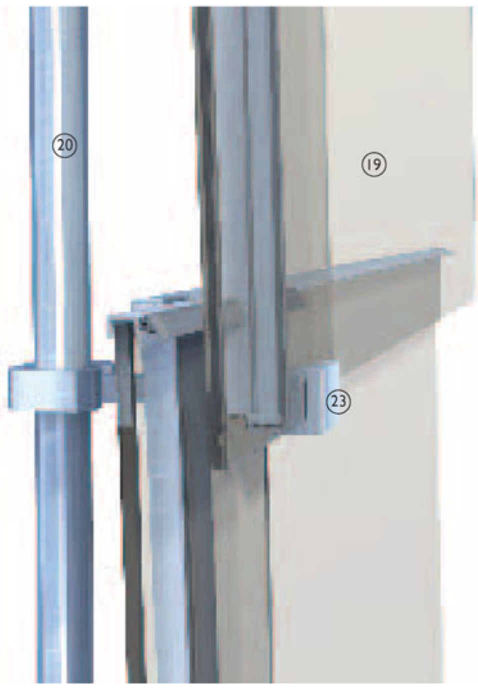


Horizontal section 1:25. Clamped glazing in lapped and flush panel arrangement



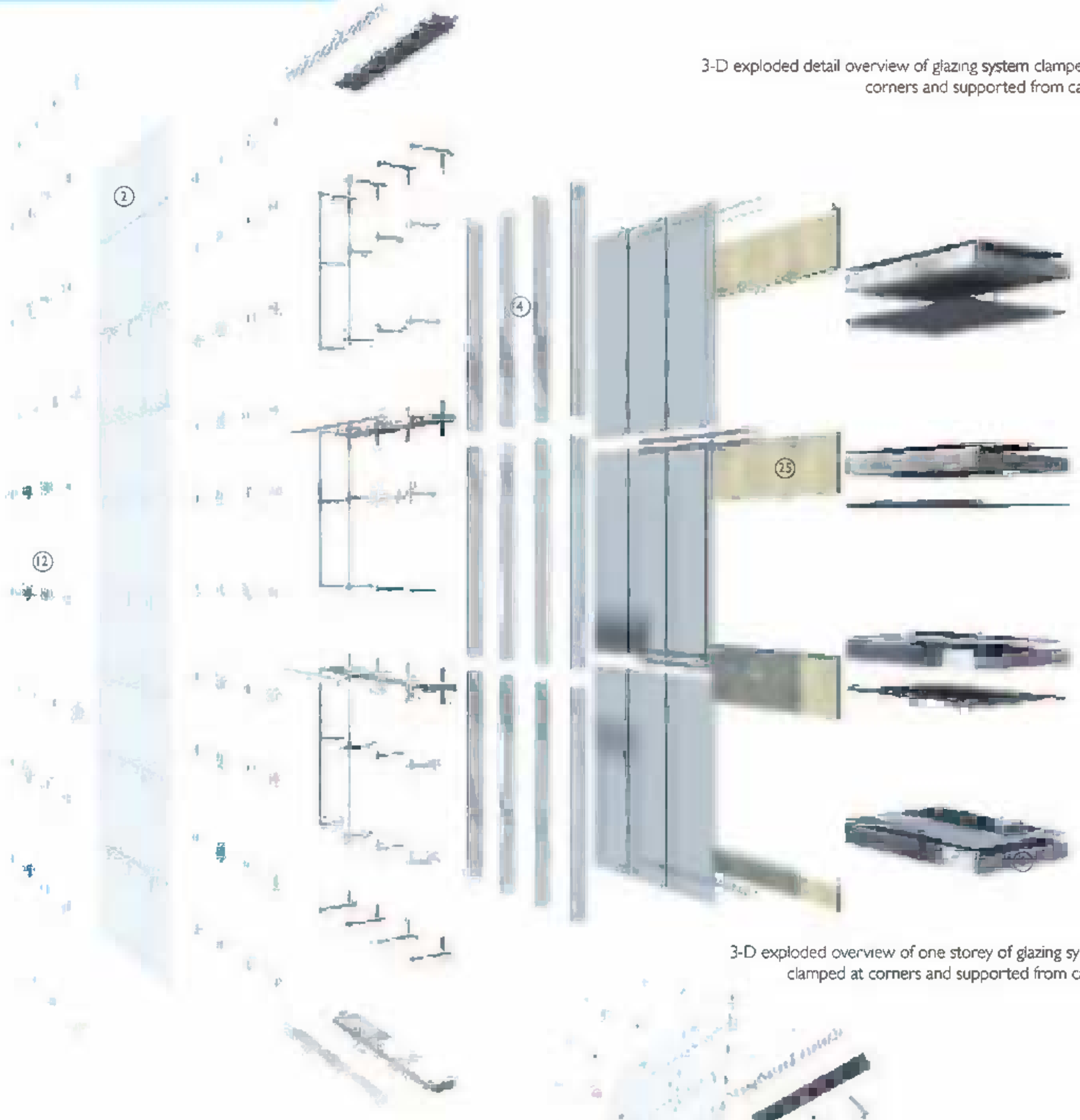
Vertical section 1:25. Clamped glazing in lapped and flush panel arrangement





3-D views showing lapped, clamped glazing fixing method supported on steel frame

Clamped glazing

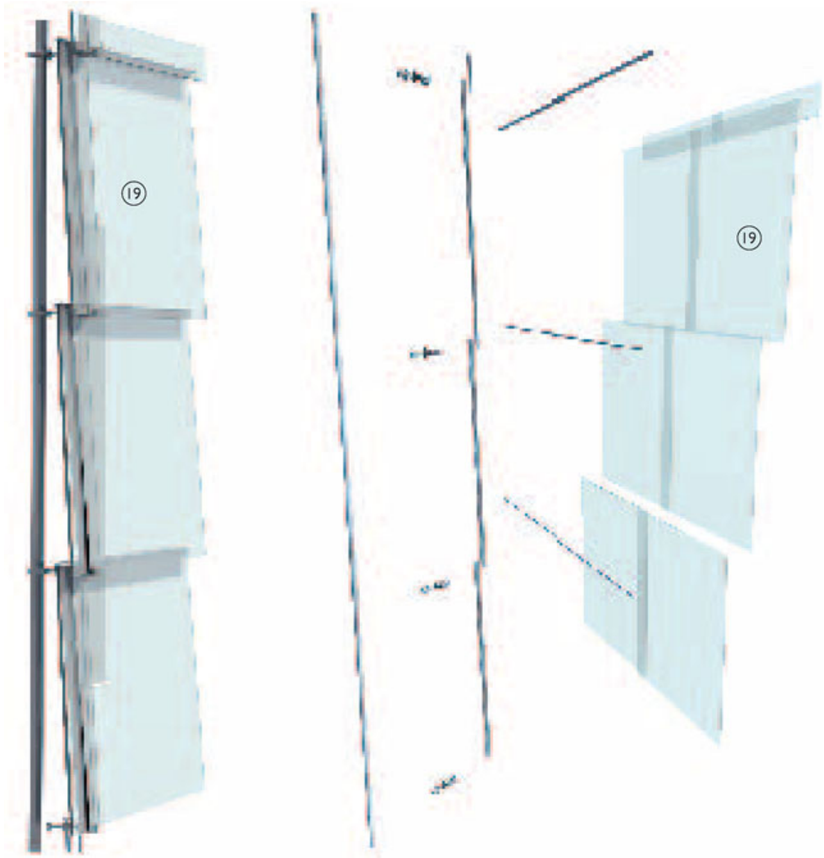


3-D exploded detail overview of glazing system clamped at corners and supported from cables

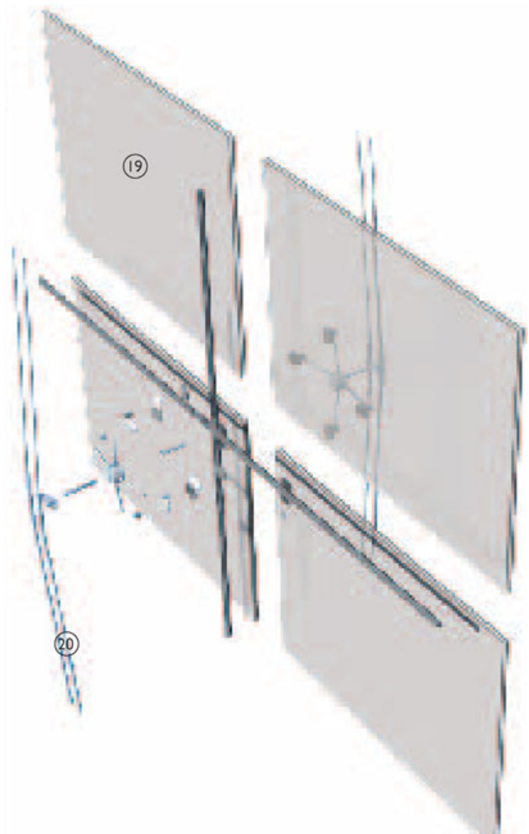
3-D exploded overview of one storey of glazing system clamped at corners and supported from cables

Details

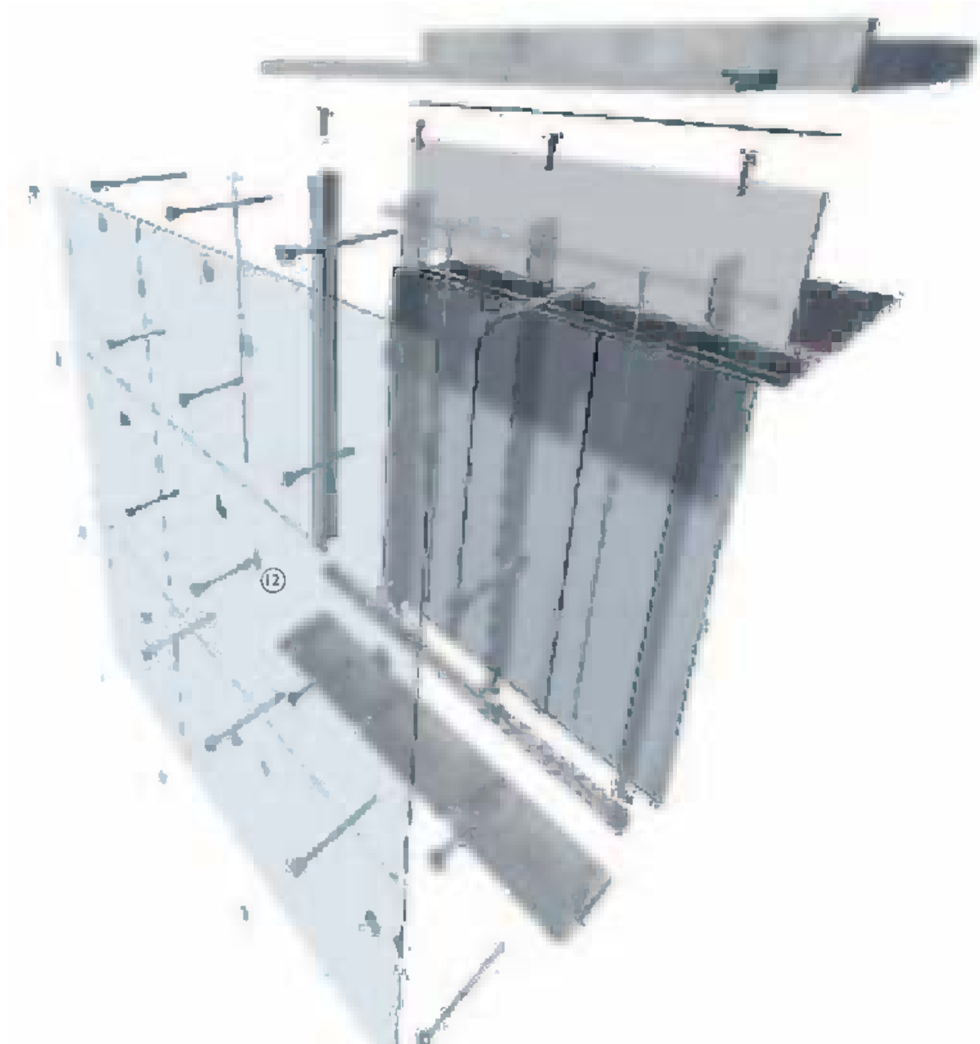
1. Stainless steel patch plates
2. Single glazed or double glazed unit to suit application
3. Silicone seal
4. Glass fin
5. Support bracket
6. Floor slab
7. Ceiling finish
8. Floor finish
9. Access ladder
10. Clamped glazed wall
11. Inner framed curtain walling
12. Fixing bolt
13. Maintenance access deck
14. Fixing bracket
15. Extruded aluminium mullions
16. Opaque glazing
17. Ground slab
18. Backing wall
19. Inclined and lapped glass
20. Cable support
21. Corner clamp
22. Cast metal fixing bracket
23. Clamp bracket
24. Metal parapet coping
25. Thermal insulation
26. Single or double glazed unit



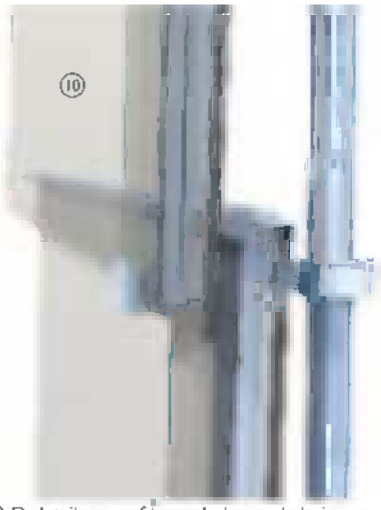
3-D fragment views of lapped, clamped glazing system, in-tact and exploded



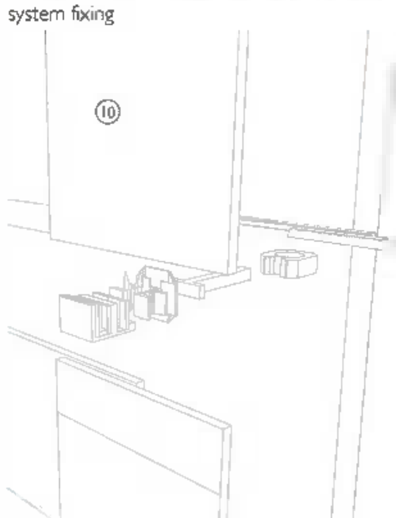
3-D exploded view of fixing detail for glazing supported by spider clamp hung from cable truss



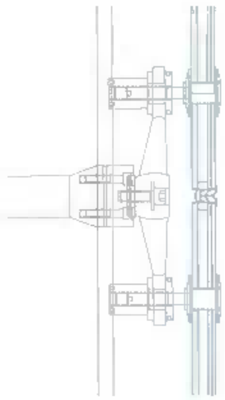
3-D exploded fragment view of one storey of glazing system clamped at corners and supported from cables



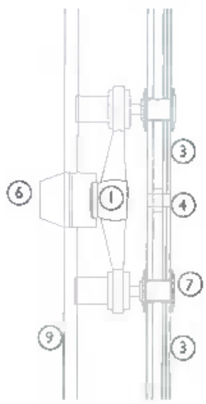
3-D detail view of lapped, clamped glazing system fixing



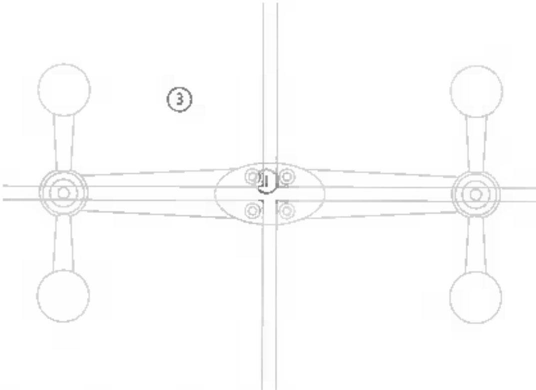
3-D exploded detail view of lapped, clamped glazing system fixing



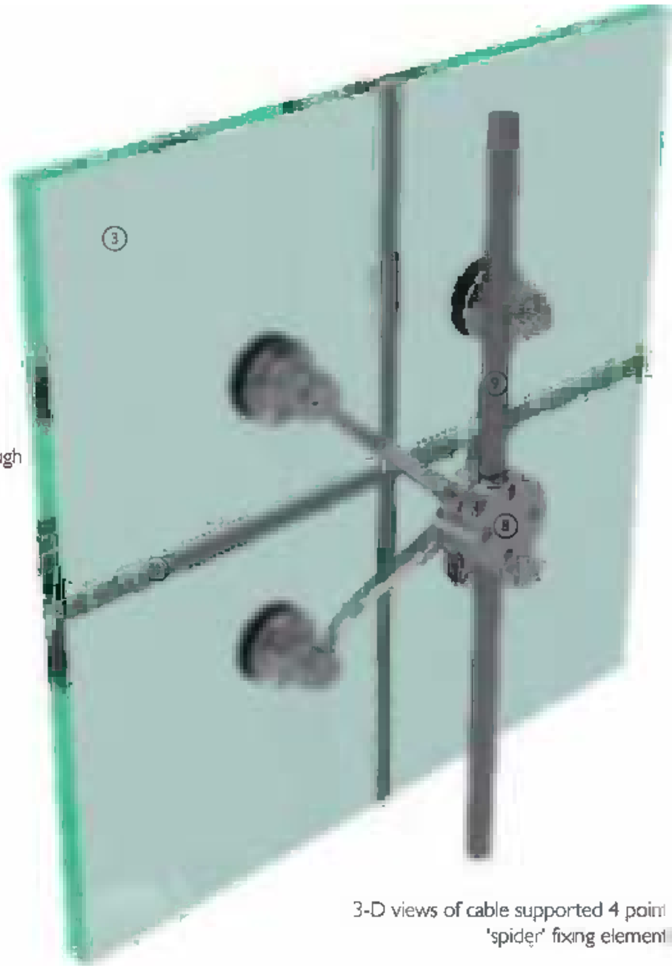
ertical section 1:10. Section through olt fixing element



Vertical section 1:10. Section through glazing



levation 1:10. 'H' style bolt fixing connection



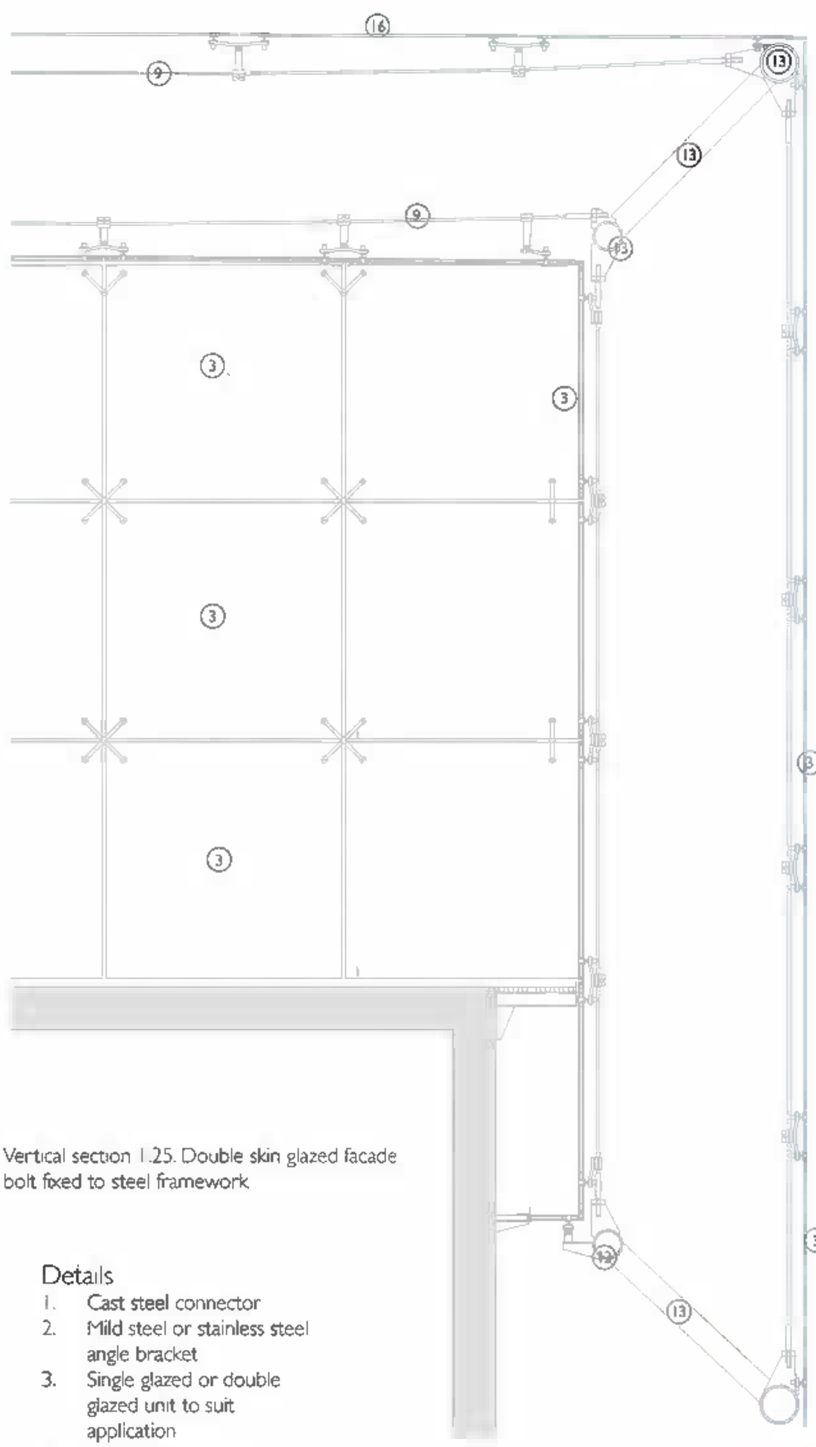
3-D views of cable supported 4 poin 'spider' fixing element

Like clamped glazing, bolt fixed glazing has a high degree of transparency provided by the bolts which replace the need for metal framing around the edges of the glass sheet or double glazed units. One of the main advantages of bolt fixed glazing is the small size of the fixings when compared to the larger and more frequent clamped fixings. This system can also be double glazed much more easily since a spacer can be introduced into double glazed units during manufacture, away from the edge of the glass, where it also has the advantage of reducing the glass span, thus minimising glass thickness. However, the sight lines associated with double glazed units are almost the same as those for stick glazing, with the black line around the edge of two adjacent units, plus a 20mm (0.78in) average joint in silicone giving an overall 50mm (2in) thick joint width in a dark colour. Since the edges of double glazed units are made opaque to conceal the edging strip, translucent silicone is not used in the joint between two opaque edges. Instead, a dark coloured silicone is used, usually black.

Support methods

In common with some other glazed wall types, bolt fixed glazing is either hung from the top of the unit or is supported at the bottom. When hung from the top, bolt fixings are secured to stainless steel cables or rods fixed at the top and tensioned at the bottom. Fixing tolerances are provided in three directions: vertically, horizontally and laterally. Because the joints between the glass units or sheets are visible, and need to be well aligned, and the fact that the glass is drilled during the manufacture of the glass, fixing tolerances have to be provided by the bolt fixing and its connection to the supporting bracket.

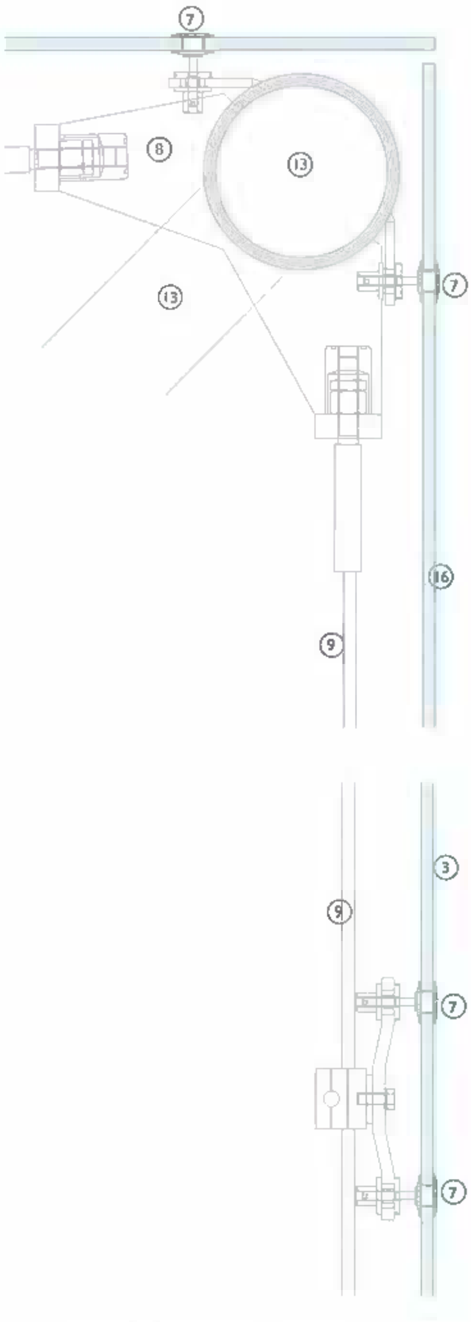
The bolt fixings themselves vary in complexity from economic types where a threaded bolt is secured with nuts to a fixing bracket, to sophisticated types where all threads are concealed behind sleeves to give a very smooth appearance. All bolt types allow rotation to occur between the glass and the fixing usually to a maximum of 12 degrees. A ball joint is housed where the fixing intersects with the glass for this purpose. Any sleeve that is set over the threaded rod behind the disc is positioned so that it does not interfere with the free movement of the ball joint. Support brackets to bolts are either cast or are machined and welded from plate. The choice will depend largely on shape and the number of brackets needed, since castings are economic only in large numbers cast from a single mould. Castings can be formed to take up complex geometries that look very cumbersome in welded plate, but are more expensive and time-consuming to produce, except in large quantities. The choice of painted mild steel or stainless steel (polished or brushed) for the support bracket is very much a visual decision, particularly where a large amount of welding is required. If the welding is not performed to the highest standards then the results can be visually disappointing. However, the bolts themselves are always in stainless steel. Junctions between mild steel and stainless steel are isolated to avoid the strong electrolytic corrosion that occurs between these two metals.



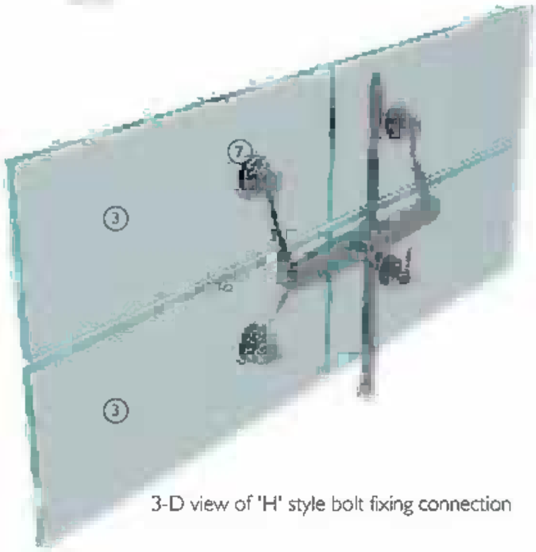
Vertical section 1.25. Double skin glazed facade bolt fixed to steel framework

Details

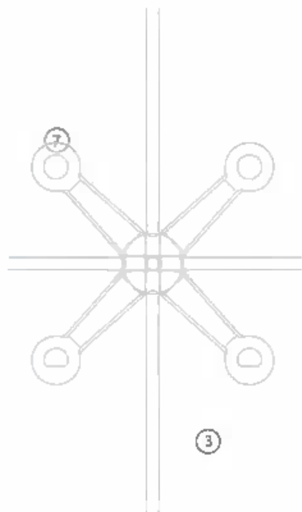
1. Cast steel connector
2. Mild steel or stainless steel angle bracket
3. Single glazed or double glazed unit to suit application
4. Outer silicone seal with inner rubber-based extruded seal
5. Insulated panel
6. Bolt-based cable end
7. Stainless steel bolt fixing
8. Steel connector fixed to steel tube
9. Stainless steel cable
10. Floor slab/structural wall
11. Glazing channel at floor level
12. Structural column Concrete shown
13. Steel arm for lateral support
14. Steel rod
15. Glass fin
16. Single glazed solar shading glass



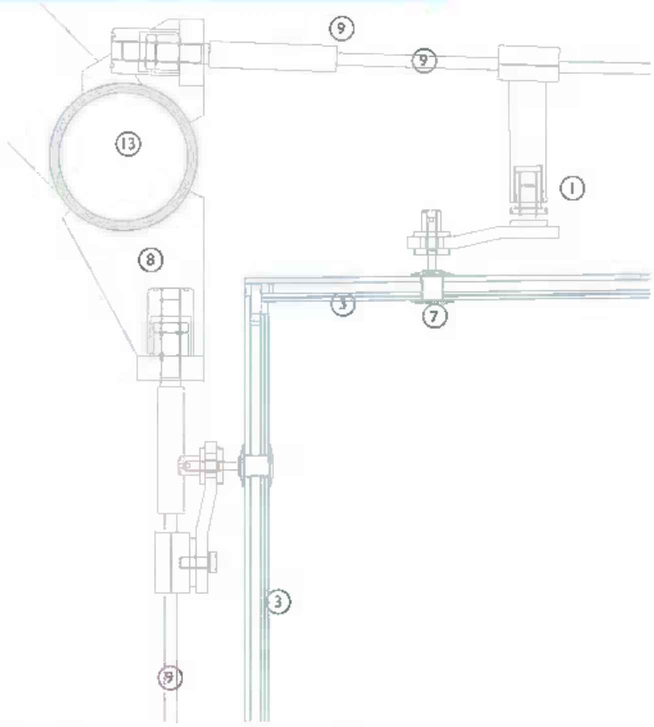
Vertical section 1:10. Open joined bolt fixed connection between glass units



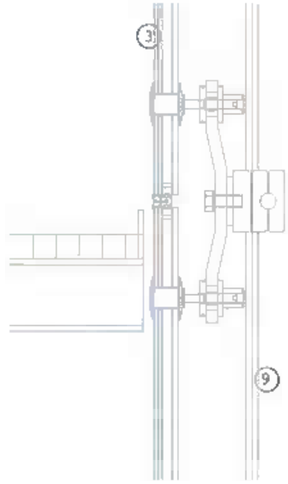
3-D view of 'H' style bolt fixing connection



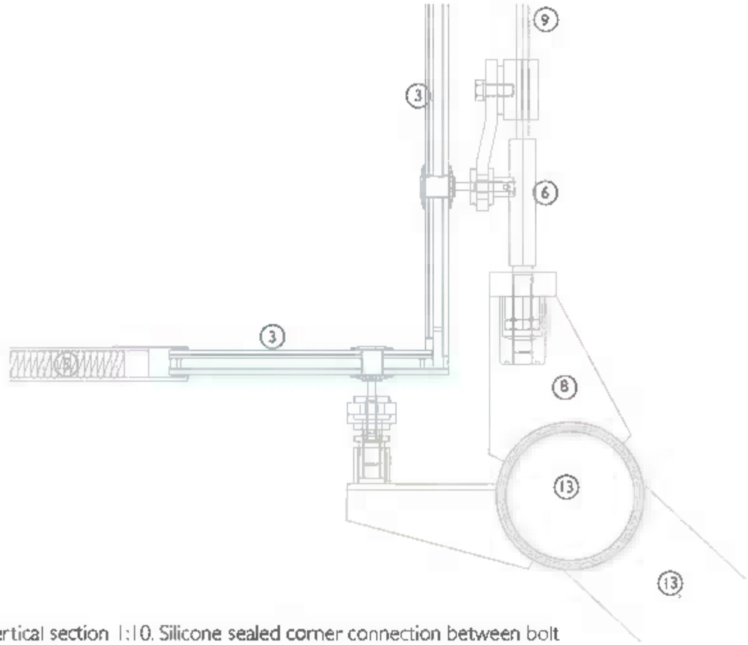
Elevation 1:10. 'X' style bolt fixing connection



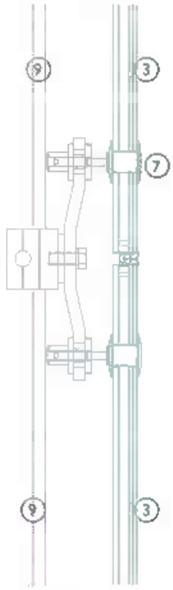
Vertical section 1:10. Silicone sealed corner connection between bolt fixed glazing with external structure



Vertical section 1:10. Silicone sealed connection between bolt fixed glazing at floor level



Vertical section 1:10. Silicone sealed corner connection between bolt fixed glazing with external structure

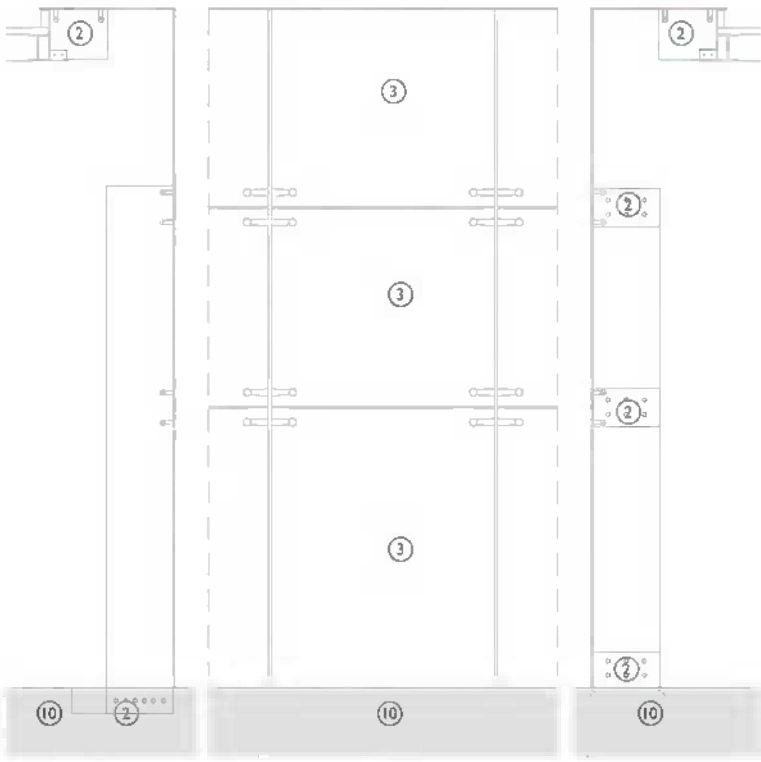


Vertical section 1:10. Silicone sealed connection between bolt fixed glazing with external structure

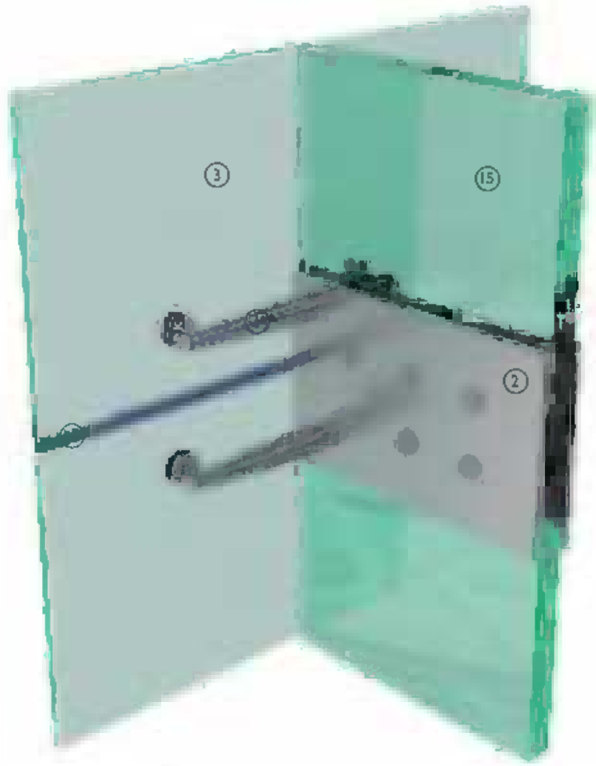
3-D view of cast aluminium spider clamp for bolt fixing glazing

Construction tolerances between supporting structure and glass panels are accommodated between the glass and the bolt fixing, between the bolt fixing and the support bracket or 'spider' and between the support bracket and the supporting column or truss. The gap between glass bolt and fixing is to allow three of the typical four bolt fixings on a glass unit to move freely, while the fourth unit is clamped tight without damaging the glass at the edge of the hole. If adjustment is provided between bolt fixing and support bracket in order to take up dimensional differences between glass and supporting structure then this results in different joint widths between glass units, with slightly uneven corners where four glass units meet. This method does, however, allow the support spider to be set in a fixed relationship with the supporting truss or column. If this adjustment is instead formed between spider and primary structure, then the glass remains in perfect alignment but the alignment between spider and column/truss will vary. The choice of where to position the dimensional adjustment varies between designs and is largely based on visual preference.

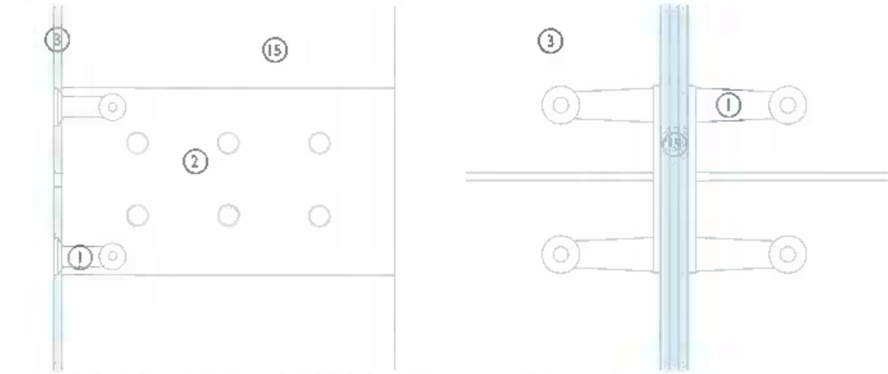
Because all components in bolt fixed glazing are visible, both from inside and outside, the choice of fixing bolts and screws is visually very significant, as is the extent of visible thread on the bolt fixing itself. Countersunk bolts and pig-nose bolts (those with two small holes on their face to provide points for tightening) are often preferred to the more common hexagonal head types.



Vertical section & elevation 1:50. Bolt fixed glazing supported on glass fins



3-D view showing glass fin supported within bolt fixed glazing system



Vertical section & elevation 1:10. Bolt fixed glazing supported on glass fins

Bolts with Allen keys (a square hole cut into a circular bolt head tightened with a socket wrench) are also preferred as are smooth circular washers with small holes for tightening drilled into their edges.

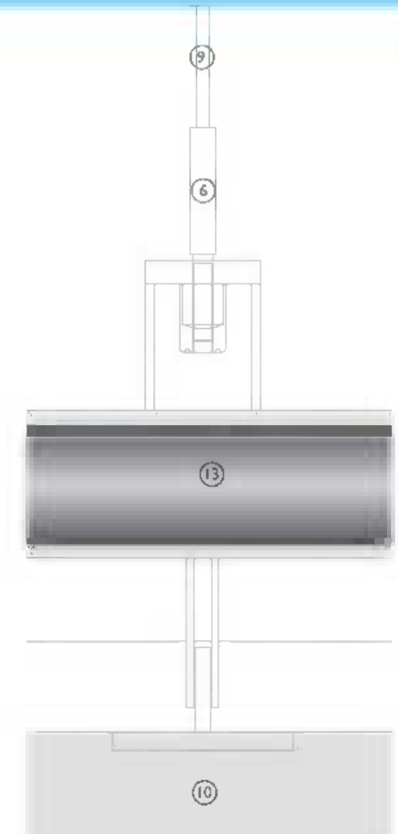
Bottom supported glazing

Glass supported at its base can be fixed by a variety of methods. Glass units are most commonly supported with glass fins or steel posts. When glass fins are used, the glass is stacked from its base, with the dead load passing partly to the fins, and partly through the bolt fixings to the glass below, depending on the design. The glass fins serve primarily to stiffen the glass wall and resist wind loads. This method is very much a development of the patch plate system described in the previous topic in order to provide maximum transparency with a minimum of metal supporting structure.

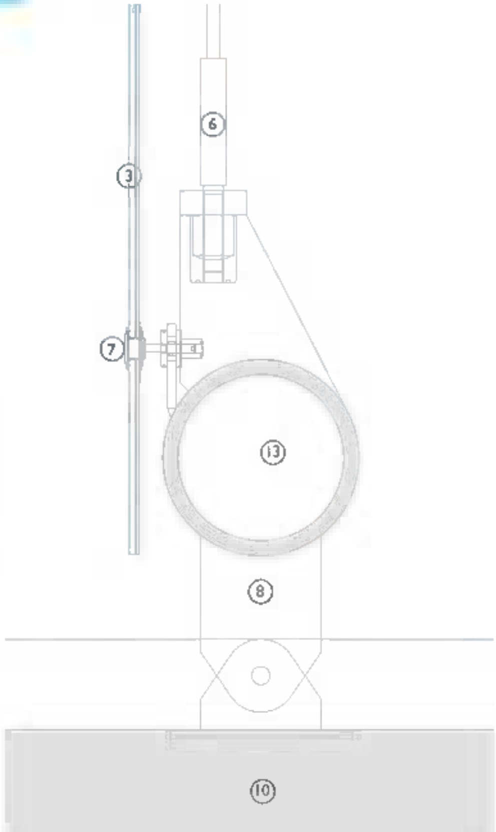
The glass units and fins are clamped at their base to the floor slab. Because the clamping plates are big, secured by four to six bolts which pass through the glass, they are often concealed below the finished floor level. The floor slab supporting the glazed wall is either stepped down to accommodate the base clamps or form part of a raised floor zone. With either method, the pocket formed can also be used to accommodate convector heating used to reduce down-draughts in temperate climates. Above the base level, glass units are fixed with bolt fixings that transfer loads from the top glass to lower ones.

Details

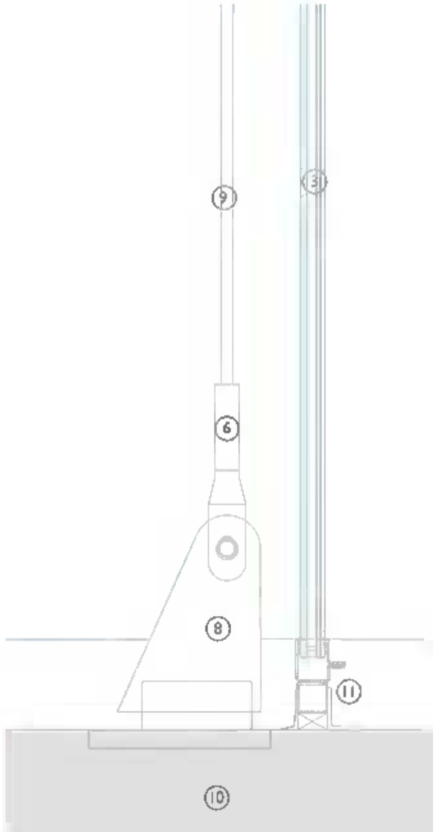
1. Cast steel connector
2. Mild steel or stainless steel angle bracket
3. Single glazed or double glazed unit to suit application
4. Outer silicone seal with inner rubber-based extruded seal
5. Insulated panel
6. Bolt-based cable end
7. Stainless steel bolt fixing
8. Steel connector fixed to steel tube
9. Stainless steel cable
10. Floor slab/structural wall
11. Glazing channel at floor level
12. Structural column. Concrete shown
13. Steel arm for lateral support
14. Steel rod
15. Glass fin
16. Single glazed solar shading glass



Vertical section 1:10. Connection at ground level with glass bolt fixed to steelwork



Vertical section 1:10. Connection at ground level with glass bolt fixed to steelwork



Vertical section 1:10. Sealed connection at ground level with glazing fixed to slab

Structural posts, usually in mild steel, are an alternative method of supporting the glazing without introducing a visually intrusive element, though concrete columns are sometimes used where they form a necessary part of the primary structure. This method has the advantage of allowing each glass to be individually supported. In generic examples, the glass is fixed back to a steel post at each vertical joint. Lateral restraint is provided by vertical or horizontal wind trusses in either steel tube or cable. Cable is preferred for its visual lightness. The size (diameter) of the supporting posts or trusses can be reduced by adding outrigger brackets to posts set at wider centres. This reduces the number of support posts by two thirds, but each post will necessarily be bigger. The outriggers can also be reduced to become lateral restraints only by introducing small diameter posts, typically around 10mm (0.4in), to take the vertical load.

In all cases the bolts supporting the glass are fixed back to steel columns with brackets or to outriggers with similar brackets. The general shape of the bracket is determined both by the position of the holes in relation to the edge as well as by the method of fixing the bracket back to its supporting structure. Positions of the holes are usually so as to reduce the span of the glass in order to keep it within an economic thickness, typically 12mm (0.5in). An essential aspect of bracket design is in accommodating fixing tolerances. Since the supporting structure is erected before the glass, tolerances are introduced into the bolt and bracket fixing to take up the differences.

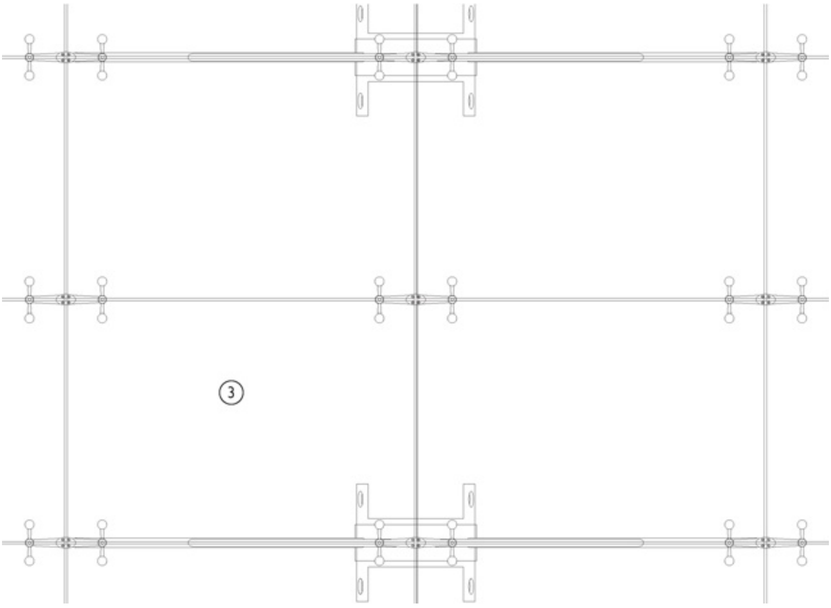
Top hung glazing

Supporting structure to bolt fixed glazing can be made visually very lightweight by the use of cables or rods hung from the top and tensioned at the base. Stainless steel cables or painted mild steel rods are used. The choice is usually made for visual reasons. However, like clamped glazing this method is associated with high deflections under wind load. This can be accepted either in the design (some cable-assisted walls deflect up to 800mm/2ft 8in at their centre) or be restrained with cable trusses or outriggers, typically at floor levels. Bolt fixings are secured with brackets that are secured directly to the cable or rod. They usually fit together in two halves when secured to cable. Where rod is used, the material is usually in lengths that connect into a fixing made as a single piece.

Again, the mixture of stainless steel and mild steel requires separators to avoid bimetallic corrosion, caused by contact between different metals in the presence of rainwater. While mild steel rod can be painted to match other parts of the construction such as adjacent supporting structure, care must be taken during assembly on site to ensure that factory-coated components and assemblies are not damaged. Where stainless steel is used instead of either mild steel rod or stainless steel cable, the diameter of the rod will be bigger than either of the other two options.

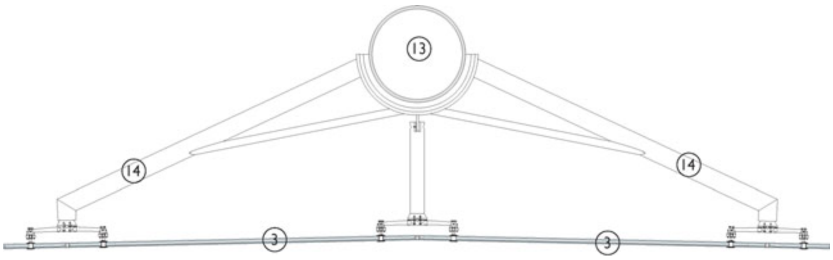
Corners

Corners are made by either introducing supporting structure at the corner or alternatively by cantilevering or fixing the glass at the corner and pinning the glass together with



Elevation 1:50. Bolt fixed glazing supported by branching steel framework

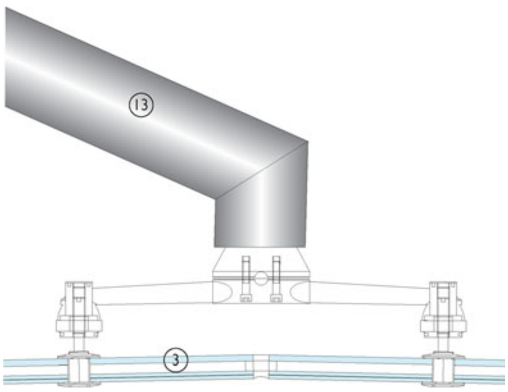
Horizontal section 1:50. Bolt fixed glazing supported by branching steel framework



Horizontal section 1:50. Bolt fixed glazing supported by branching steel framework

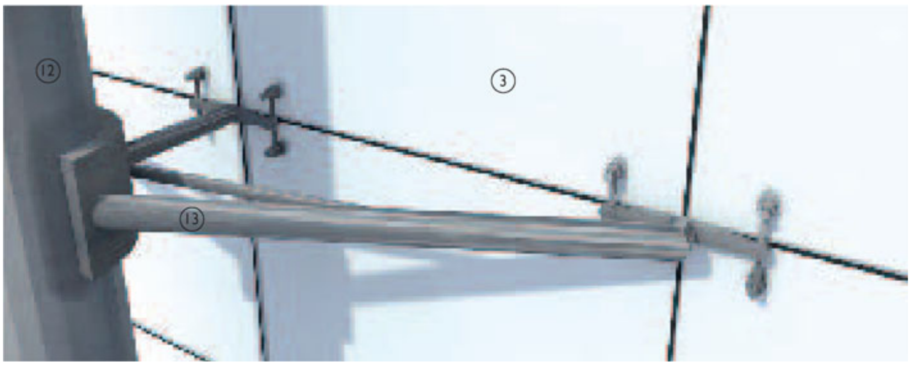
Details

1. Cast steel connector
2. Mild steel or stainless steel angle bracket
3. Single glazed or double glazed unit to suit application
4. Outer silicone seal with inner rubber-based extruded seal
5. Insulated panel
6. Bolt-based cable end
7. Stainless steel bolt fixing
8. Steel connector fixed to steel tube
9. Stainless steel cable
10. Floor slab/structural wall
11. Glazing channel at floor level
12. Structural column
13. Steel arm for lateral support
14. Steel rod
15. Glass fin
16. Single glazed solar shading glass

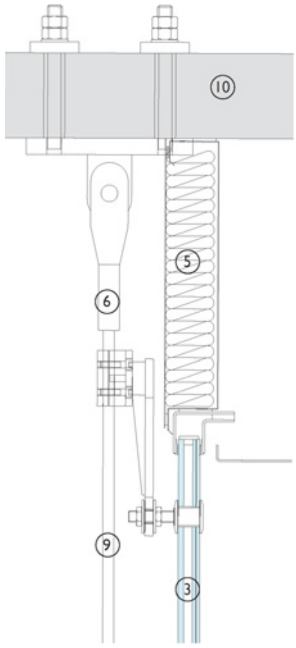


Horizontal section 1:10. Bolt fixed glazing connection fixed to branching steel framework

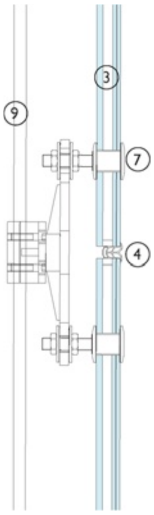
3-D view of bolt fixed glazing supported by branching steel framework



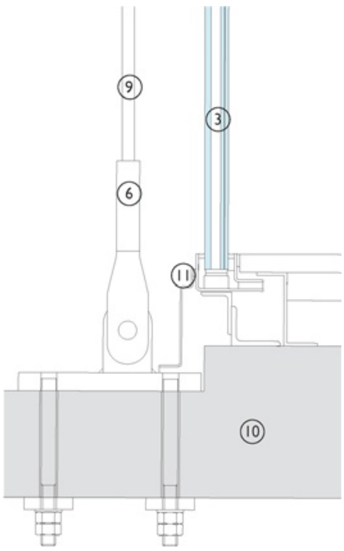
3-D view of supporting branching steel framework structure for bolt fixed glazing



Vertical section 1:10. Top of bolt fixed glazed wall supported from cable spanning between slabs



Vertical section 1:10. Silicone sealed connection in bolt fixed glazed wall supported from cable spanning between slabs



Vertical section 1:10. Base of bolt fixed glazed wall supported from cable spanning between slabs

3-D views showing clamped glazing system with steel structural support system

Details

1. Cast steel connector
2. Mild steel or stainless steel angle bracket
3. Single glazed or double glazed unit to suit application
4. Outer silicone seal with inner rubber-based extruded seal
5. Insulated panel
6. Bolt-based cable end
7. Stainless steel bolt fixing
8. Steel connector fixed to steel tube
9. Stainless steel cable
10. Floor slab/structural wall
11. Glazing channel at floor level

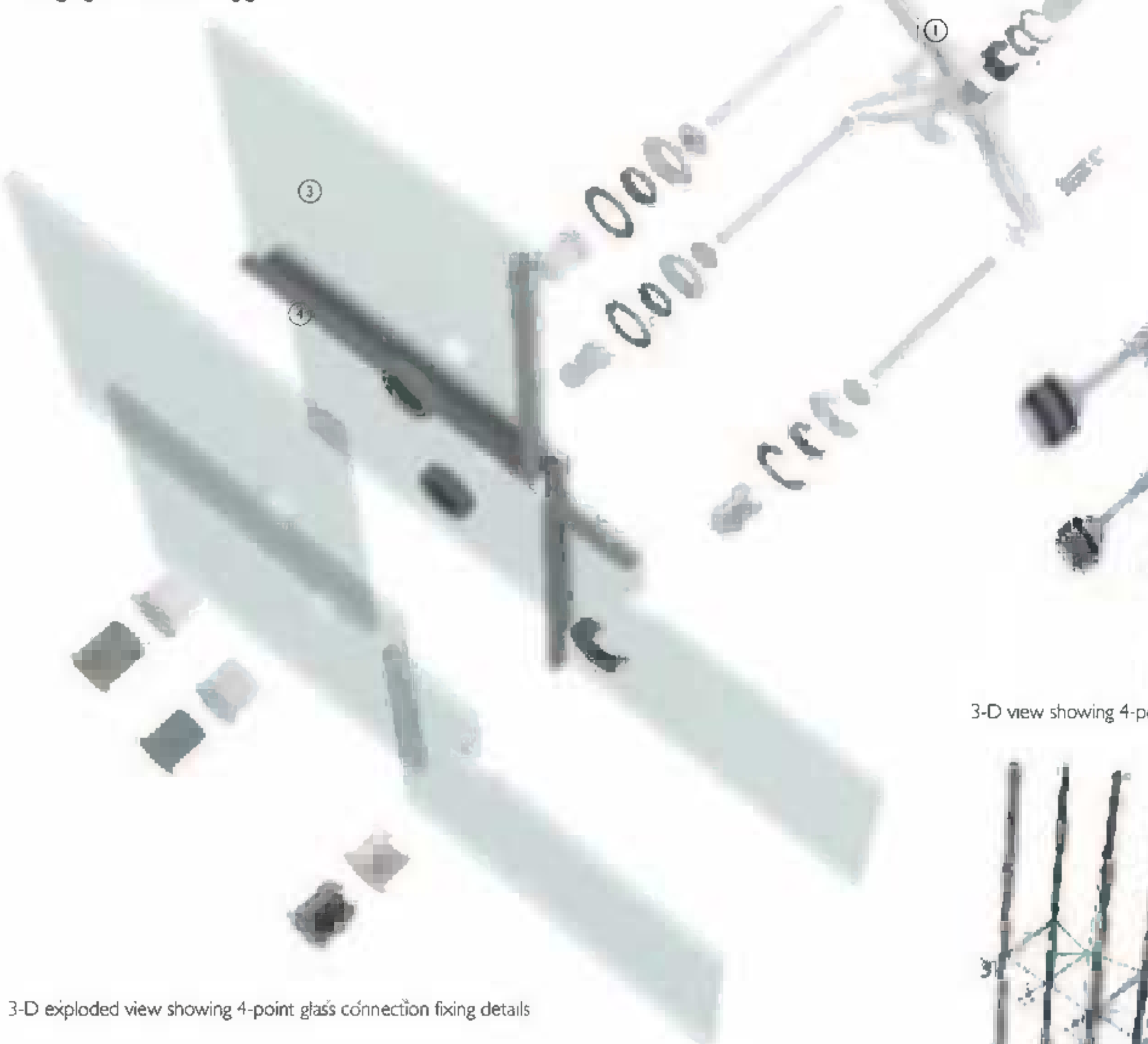
two bolts forming a corner bracket. Where structural support is provided at a corner, a special bracket is usually required, though manufacturers are increasingly providing standard corner brackets as part of their systems. Variations of corner condition are usually as economic as one another. Where double glazed units are used, care is taken to avoid exposed edges of glass where they are vulnerable to damage, usually from cleaning equipment.

Seals and interfaces

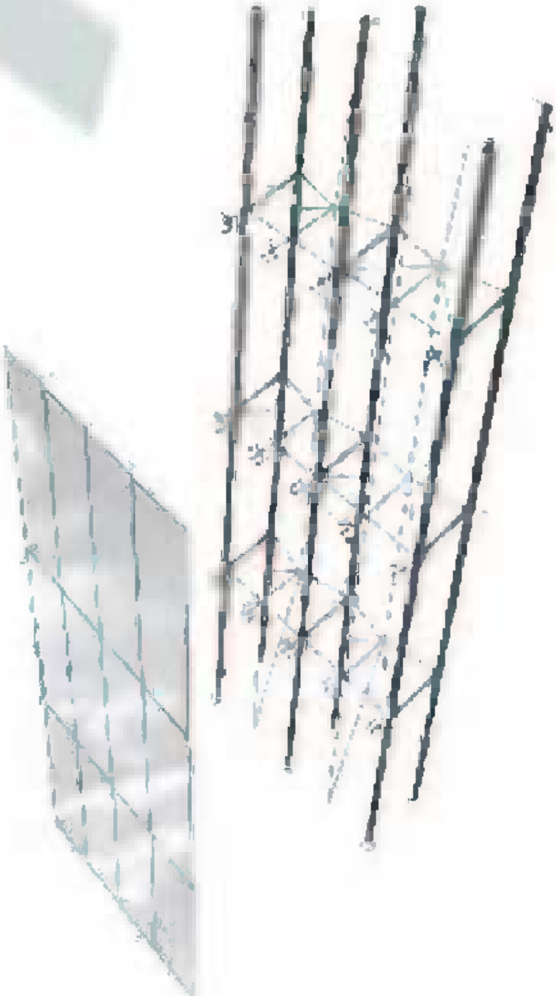
Like clamped glazing, bolt fixed glazing has essentially a single barrier to water penetration. The workmanship of the silicone sealant on site is critical to its successful application. In common with clamped glazing, silicone extrusions are slowly being introduced to make installation easier. The depth of double glazed units (often around 30mm/1.2in) allows a small drainage channel to be introduced. This information can be found in the section on Clamped Glazing.

Where bolt fixed glazing interfaces with adjacent glazing systems, the edge of the glass is usually glazed-in directly to those systems. Where it meets a wall type in a non-glazed material, the bolt fixed glazing is usually terminated by a glazing channel or metal angles that are fixed to the adjacent wall. The detail is formed in a way that conceals the angles, leaving only the glass visible. Where bolt fixings are used at the interface with another material, half brackets are used.

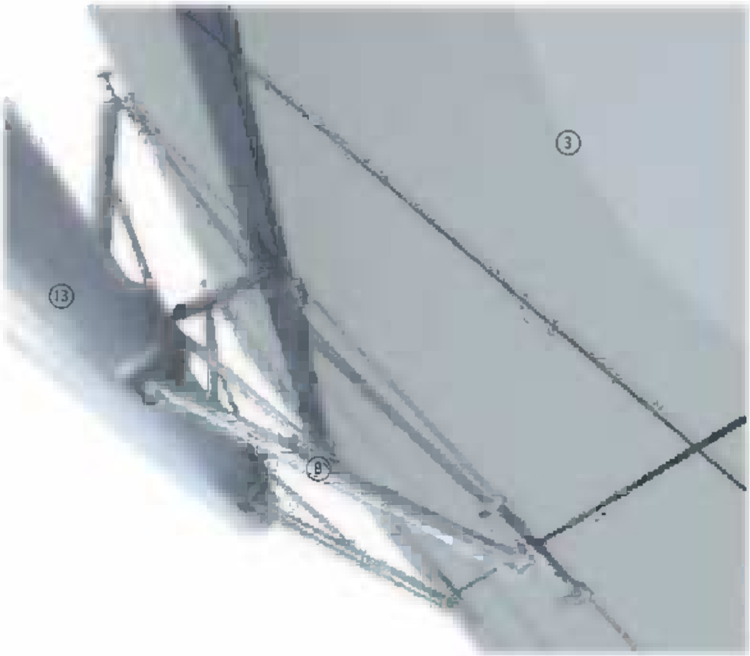
12. Structural column. (Concrete shown)
13. Steel arm for lateral support
14. Steel rod
15. Glass fin
16. Single glazed solar shading glass



3-D view showing 4-point glass connection

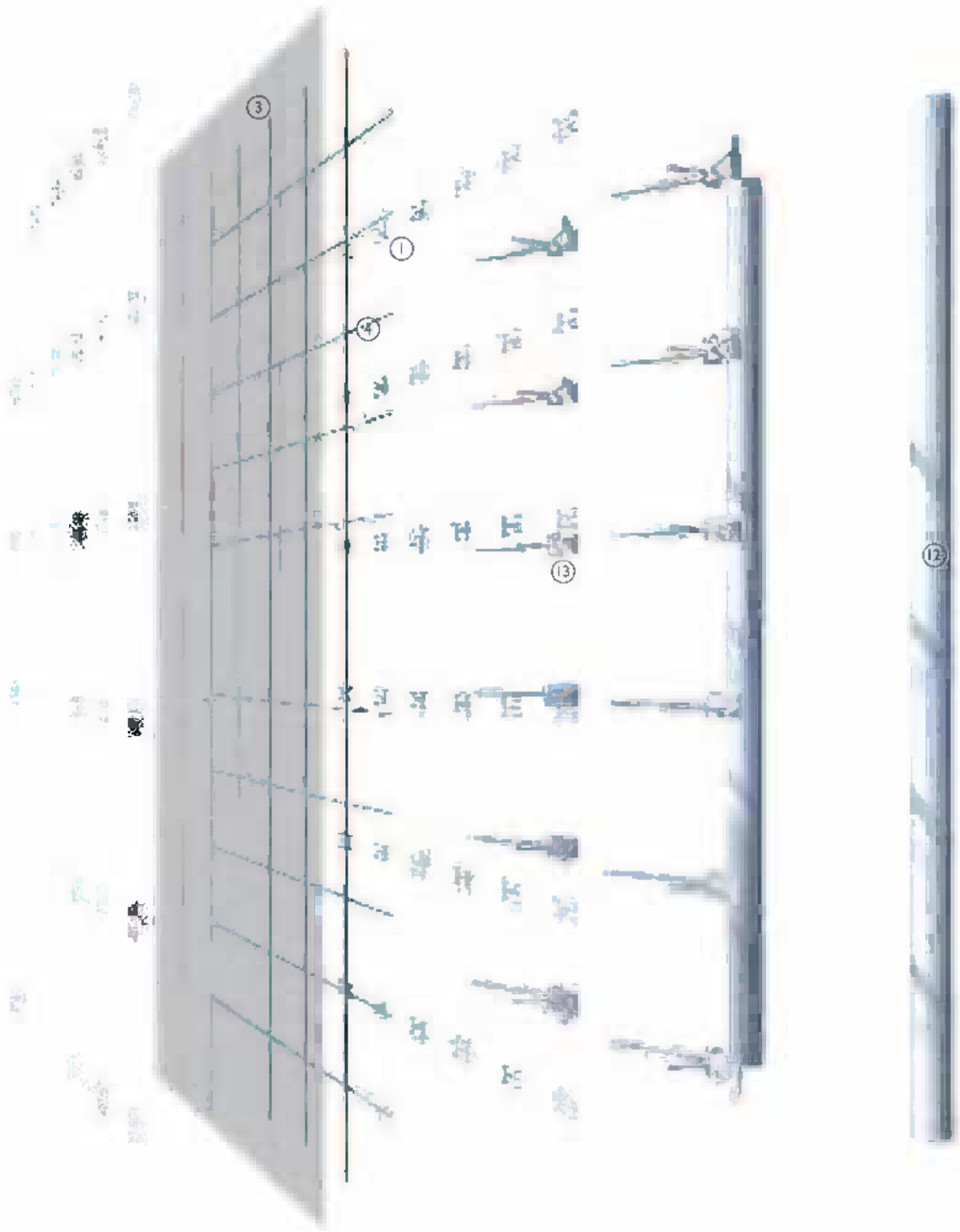


3-D exploded view showing 4-point glass connection fixing details



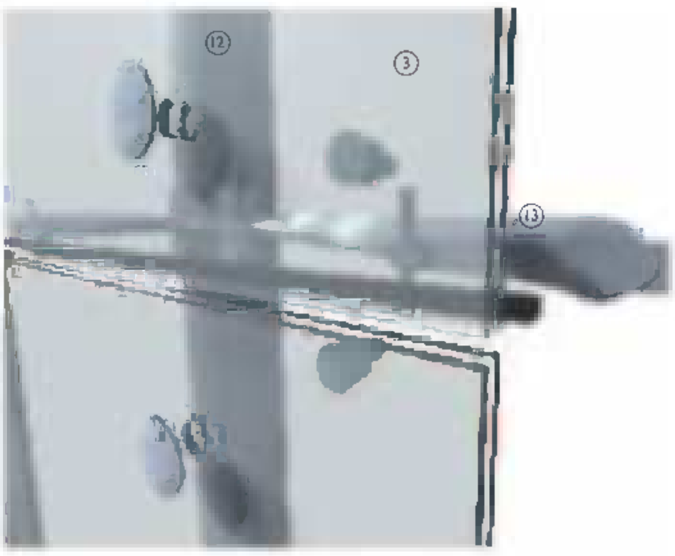
3-D view showing 4-point glass connections as part of steel structural support system with branching steel framework structure for bolt fixed glazing

3-D exploded view showing clamped glazing system with steel structural support system



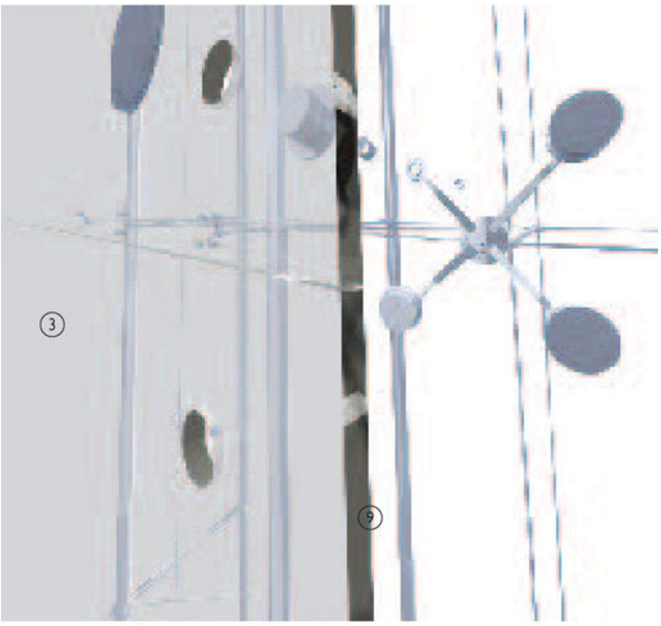
3-D exploded view bolt fixed glazing system supported from cables

3-D close up views of truss elements on cable supported system



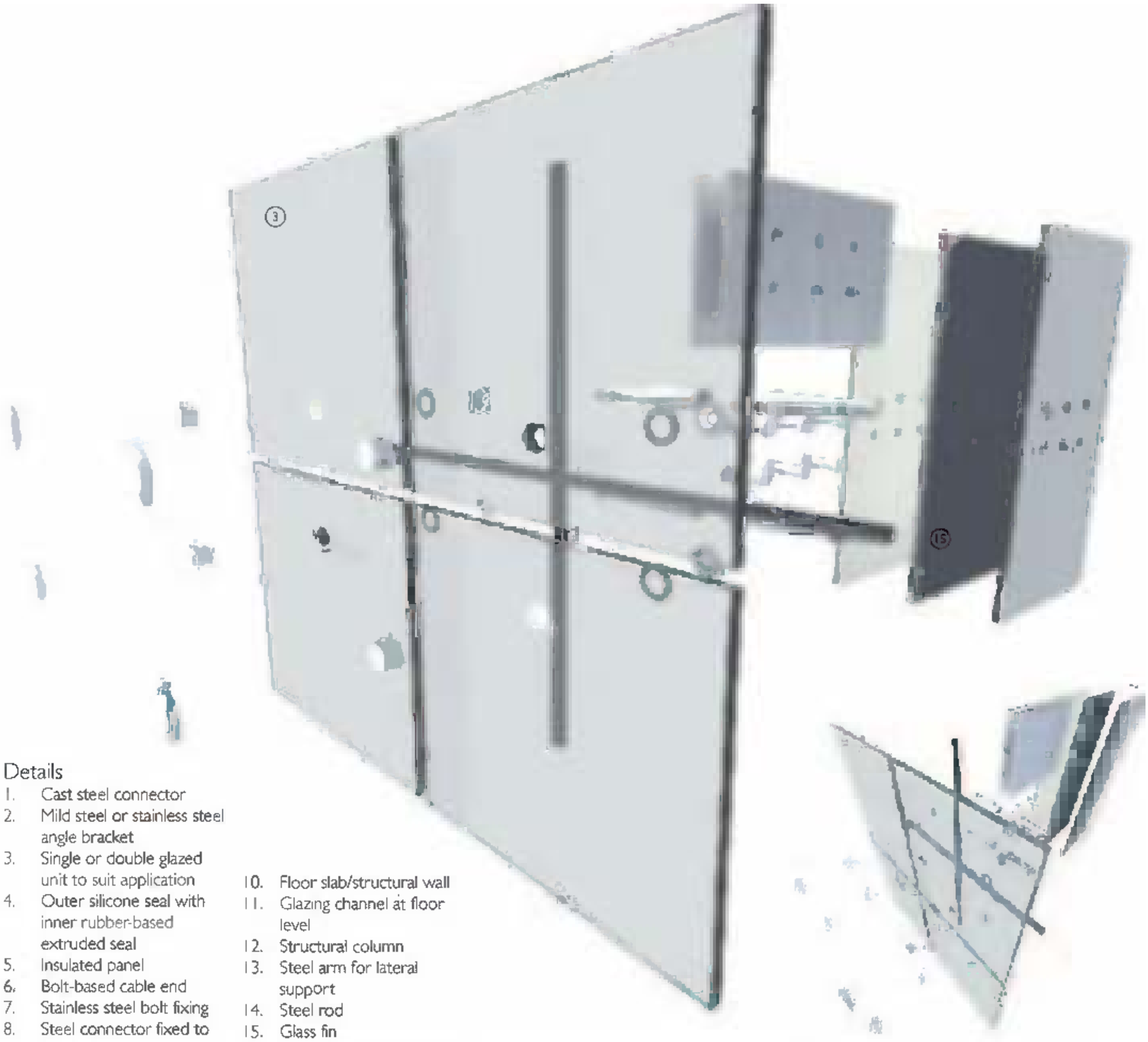
3-D exploded detail view of bolt fixing method

3-D exploded detail view of glazing fixings



3-D exploded view of cable supported 4 point 'spider' fixing element

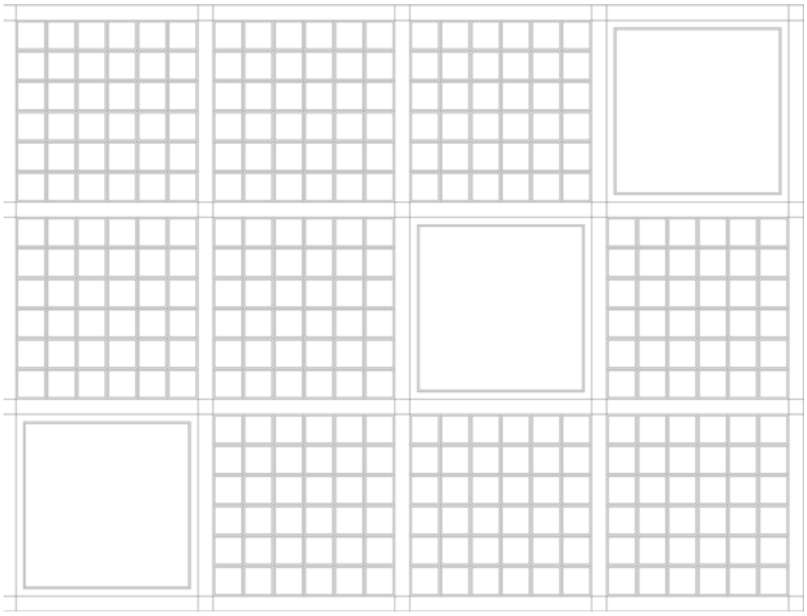
3-D exploded view of cable supported 4 point 'spider' fixing element



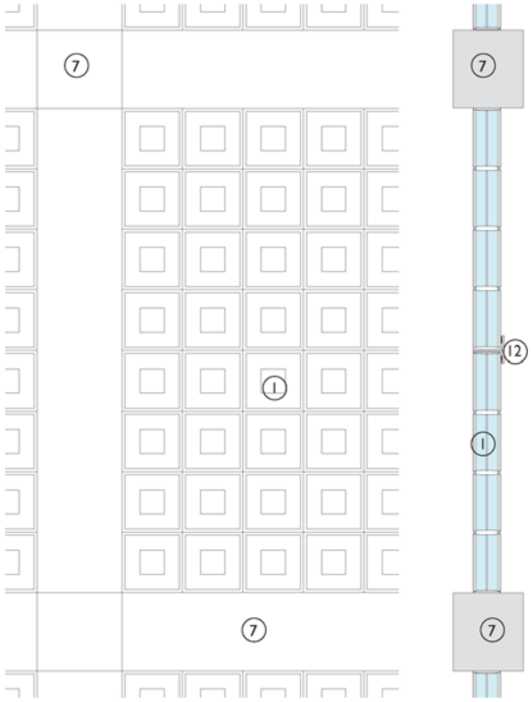
Details

1. Cast steel connector
2. Mild steel or stainless steel angle bracket
3. Single or double glazed unit to suit application
4. Outer silicone seal with inner rubber-based extruded seal
5. Insulated panel
6. Bolt-based cable end
7. Stainless steel bolt fixing
8. Steel connector fixed to steel tube
9. Stainless steel cable
10. Floor slab/structural wall
11. Glazing channel at floor level
12. Structural column
13. Steel arm for lateral support
14. Steel rod
15. Glass fin
16. Single glazed solar shading glass

3-D exploded views of bolt fixed glazing supported on glass fin



Elevation 1:50. Glass blocks and windows set into concrete frame to form glazed wall



Elevation & section 1:50. Glass blocks supported by concrete frame to form glazed wall

Glass blocks are used to form a robust, translucent and fire resisting glazed wall construction. Glass blocks are made as either solid or hollow components, but the hollow type has better thermal and acoustic insulation due to the partially air evacuated void within and is most commonly used in wall construction.

Glass blocks are made by pressing together two half blocks of glass which are held at high temperature. The half blocks are made as either pressed or cast shapes. As the block cools after manufacture, a partial vacuum is created as the air pressure drops with temperature.

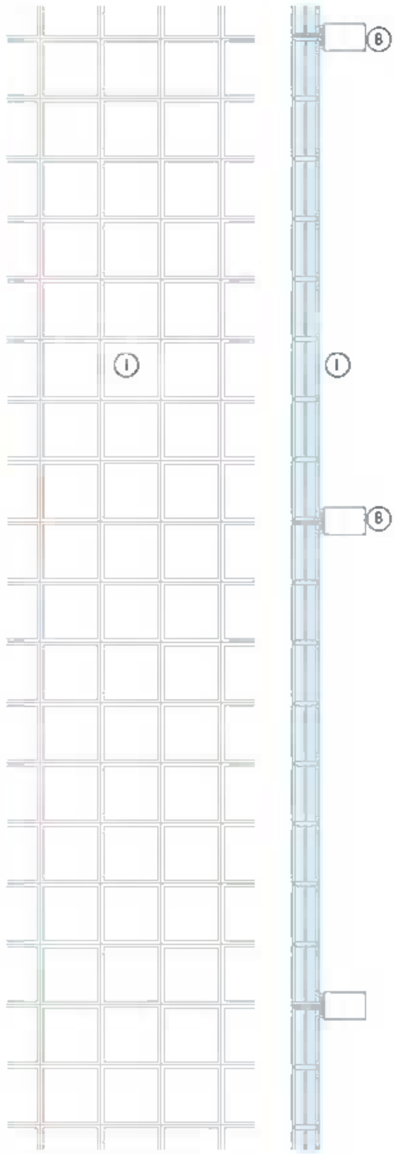
The most common sizes of glass block for walls are as follows:

190mm x 190mm thick (metric size)
8 x 8 x 4in thick (imperial size)
150mm x 150mm (nominal 6 x 6in)
200mm x 200mm (nominal 8 x 8in)
200mm x 100mm (nominal 8 x 4in)
300mm x 300mm (nominal 12 x 12in)
Typical thickness 100mm (nominal 4in)

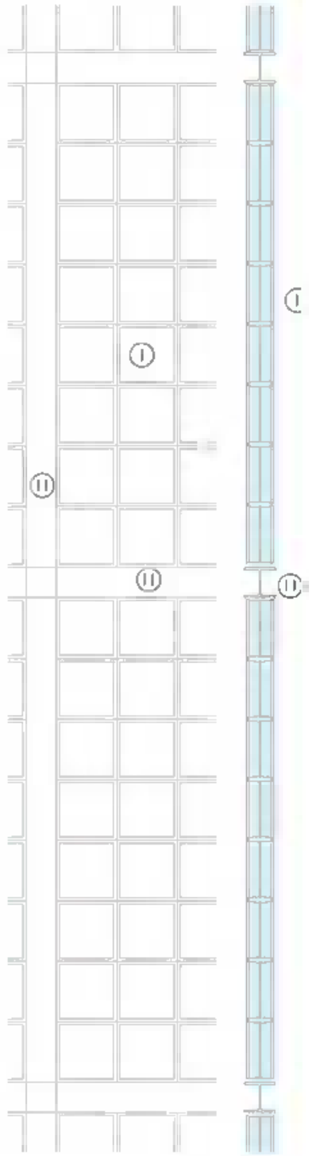
General properties of glass blocks are as follows:
Thermal conductivity approximately 0.88 W/m^2 °C (0.51 Btu/hrft°F)
Light transmission = 75% for hollow block

Although glass blocks are set in courses in the manner of masonry construction, they are used as a non-loadbearing material. Blocks are arranged in a rectilinear grid or 'stack bond' of continuous vertical and horizontal joints that give this material the appearance more of glazing than of masonry construction. Recently there has been a development in design by setting glass blocks forward of floor slabs instead of being seated on them, in the manner of glazed curtain walling. With this method, a stiffening frame is set within the joints between blocks, with additional supports set away from the glass blocks visually to lighten their appearance. Glass blocks are most commonly either set into concrete or masonry backing walls or are set into a reinforced concrete or steel support frame. For non-fire rated construction, maximum panel sizes vary from around 3600 x 3600mm (12 x 12ft) to around 4500 x 4500mm (15ft x 15ft) depending on block thickness. This overall area can be adapted to suit a maximum height of around 6000mm (20ft) and a maximum width of around 7500mm (25ft).

When used as fire resisting construction, glass blocks can reach 90 minutes fire integrity, but above 60 minutes fire resisting construction, a metal channel restraint is used in the jointing for its greater reliability in fire over mortar or silicone types materials. One hour fire rated panels of glass block can be made to a maximum size of approximately 3000 x 3000mm (9ft x 9ft) with a maximum of 4000mm (12ft) in either height or width, depending on individual building codes. Thermal insulation of glass block is poor compared to double glazed units, with some condensation risk on the inside face in temperate climates. For this reason, blocks are often used with concrete and steel frames that do not have thermal insulation, often where the interior face of the wall is ventilated but not heated, as in semi-external circulation areas. An ideal environment for glass blocks is in regions which have a warm temperate cli-



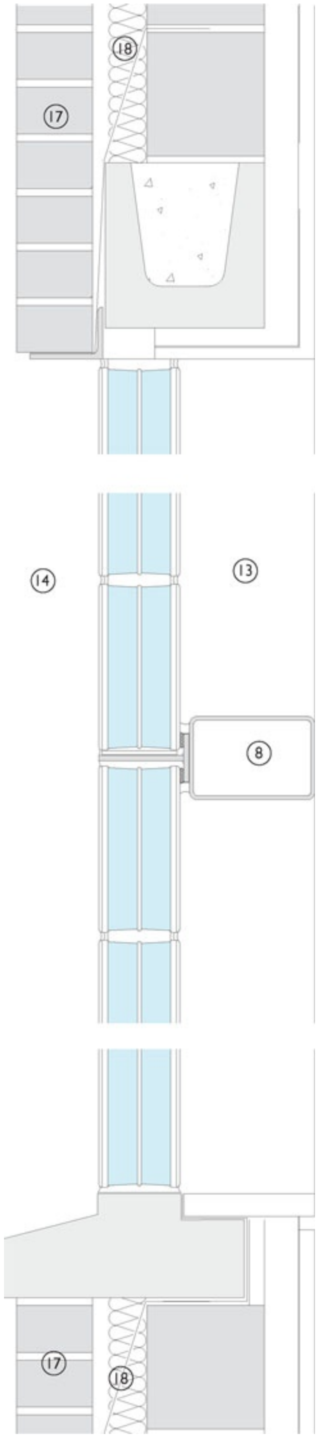
Vertical section & elevation 1:25. Glass block wall supported from steel frame



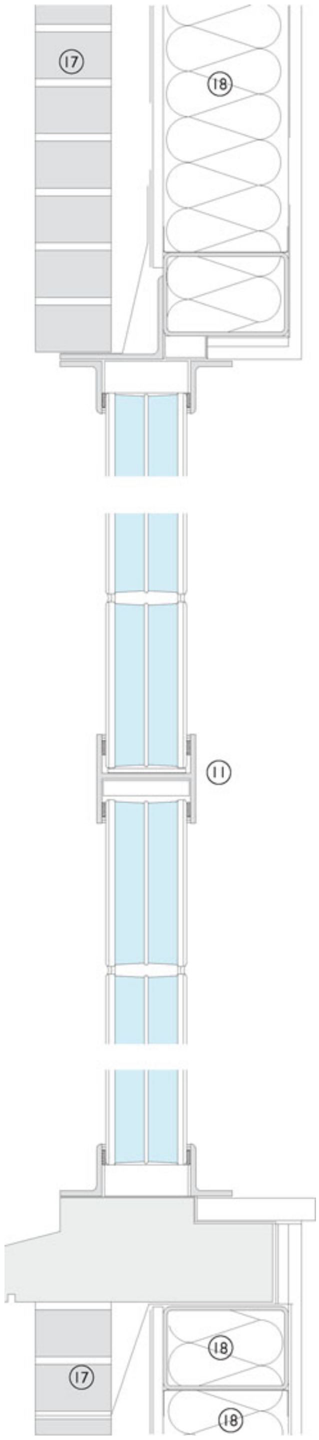
Vertical section & elevation 1:25. Glass block wall supported between steel framework

Details
1. Glass block
2. Bedding reinforcement
3. Bedding compound, mortar or silicone-based bond.
4. Adjacent blockwork wall with rainscreen
5. Adjacent concrete wall
6. Adjacent light gauge steel framed wall
7. Reinforced concrete frame
8. Steel box section
9. 90° corner block
10. 45° corner block
11. Steel I-section, usually specially fabricated
12. Steel angle
13. Inside
14. Outside
15. Floor deck
16. Steel T-section
17. Adjacent brick cavity wall construction
18. Thermal insulation
19. Extruded aluminium sections providing support
20. Adjacent reinforced concrete wall

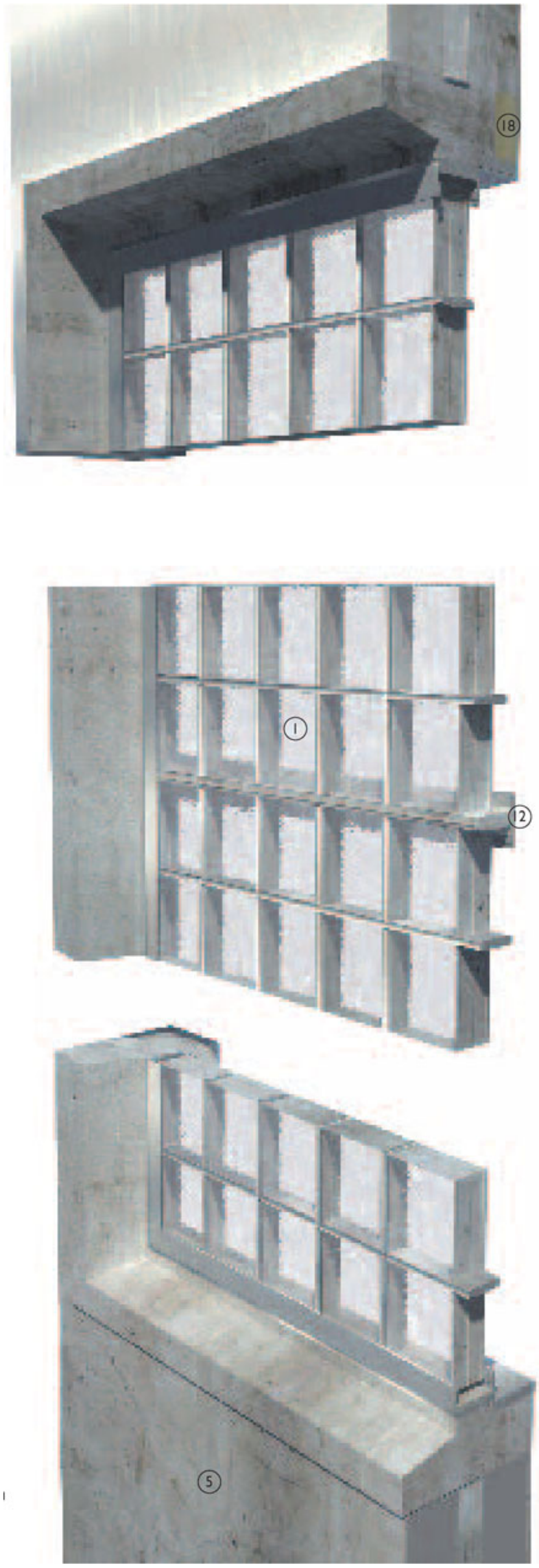
Typical glass block types



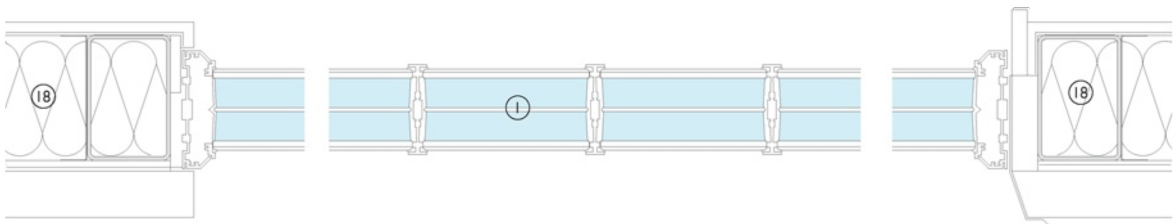
Vertical section 1:10. Glass block window with intermediate steel box frame set into cavity wall construction



Vertical section 1:10. Glass block window with intermediate steel section set into cavity wall construction



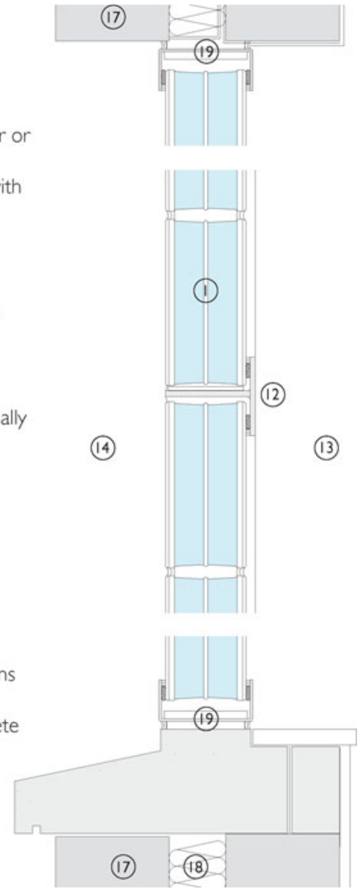
3-D view of glass block window set in cavity wall construction



Horizontal section 1:10. Glass block window supported on thermally broken aluminium framework

3-D view of glass block window supported on thermally broken aluminium framework

Details
1. Glass block
2. Bedding reinforcement
3. Bedding compound, mortar or silicone-based bond.
4. Adjacent blockwork wall with rainscreen
5. Adjacent concrete wall
6. Adjacent light gauge steel framed wall
7. Reinforced concrete frame
8. Steel box section
9. 90° corner block
10. 45° corner block
11. Steel I-section, usually specially fabricated
12. Steel angle
13. Inside
14. Outside
15. Floor deck
16. Steel T-section
17. Adjacent brick cavity wall construction
18. Thermal insulation
19. Extruded aluminium sections providing support
20. Adjacent reinforced concrete wall



Vertical section 1:10. Glass block window supported on thermally broken aluminium framework

mate for most of the year, where thermal insulation is not required.

Fixing glass blocks

Blocks are fixed in different ways. When supported on reinforced concrete floor slabs, they are bedded in mortar on all joints, with a flexible joint (sometimes with an additional aluminium edge frame) at the top and sides to allow for structural movement. Blocks can also be glued together with bonding silicone, using a sealing silicone on the outside faces. Blocks can also be fixed together with extruded aluminium clips that hold all the blocks together. Angle-shaped clips are used to fix the glass block panels to the structural opening without the use of a perimeter frame, the clips allowing for structural movement between the panel of blocks and the structural opening. The outside faces are also sealed with silicone.

Support frames and walls

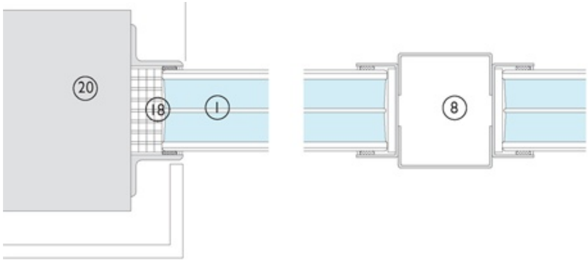
In a generic example, glass blocks are fixed in panels to a maximum of around 3500mm x 3500mm (11ft 6in x 11ft 6in) square, in storey height frames, though half storey frames can also be used to reduce the thickness of the block as well as the need for additional bed reinforcement. Blocks are set on the edge of the floor slab. Block courses are laid on a bed of mortar with the head of each panel of glass blocks allowing for the structural deflection of floor slabs. A reinforced concrete floor slab spanning 7500mm (25ft) between columns can have a deflection of around 20mm (0.8 in) at its centre. This deflection is allowed for the head of the block with an aluminium channel restraint used at the perimeter to hold the glass blocks in place but allow the slab above to deflect under load.

Glass blocks can be laid out in visually continuous lengths, but are divided up with steel T-sections at 2.0 - 3.0 metre (6ft 6in - 10ft) centres to provide the lateral stability of the panels. The additional T-section results in a wider joint than those used elsewhere in the panel but in a long run of glass blocks this is barely visible from the outside, though visible on the inside. Curved panels have the advantage of inherent structural stability but minimum radius dimensions for different block sizes as follows:

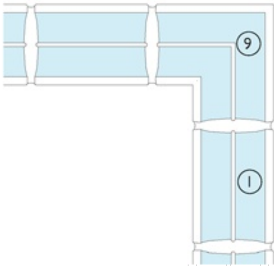
150mmx150mm blocks: 1200mm min. radius
(6in x 6in blocks: 48in min. radius)
200mmx200mm blocks: 1600mm min. radius
(8in x 8in blocks: 65in min. radius)
300mmx300mm blocks: 2500mm min. radius
(12inx12in blocks: 98in min. radius)

Movement joints are set at the junction of straight and curved panels. These joints usually serve also as structural joints for the blocks.

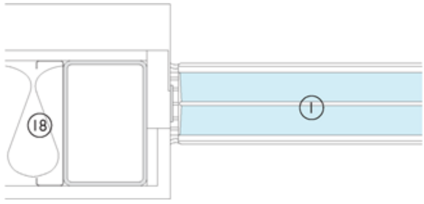
In alternative generic examples, glass blocks are set in openings in a reinforced concrete wall. Openings in the wall have to be formed in close tolerances in order to have even edges if the concrete is to be left exposed. Where openings cannot be formed so accurately, the glass blocks are set into an aluminium edge frame that laps over the concrete or forms a shadow gap around the opening. If the concrete wall is clad in a different material, such as metal or masonry rainscreen panels, then the cladding can be



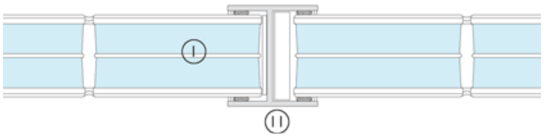
Horizontal section 1:10. Connection between glass blocks, concrete wall and concrete column



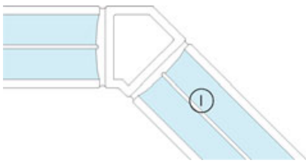
Horizontal section 1:10. Corner glass block



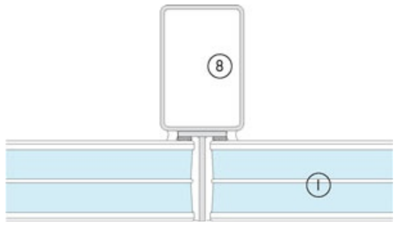
Horizontal section 1:10. Connection between glass block and insulated external wall



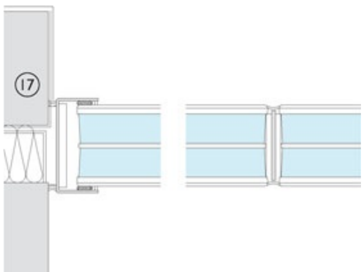
Horizontal section 1:10. Connection between glass blocks, and supporting steel section



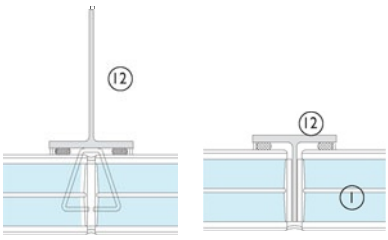
Horizontal section 1:10. Spacer forming 45° corner



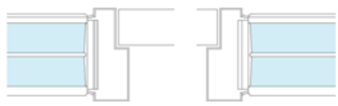
Horizontal section 1:10. Connection between glass blocks supported by steel box frame



Horizontal section 1:10. Connection between glass blocks & cavity wall

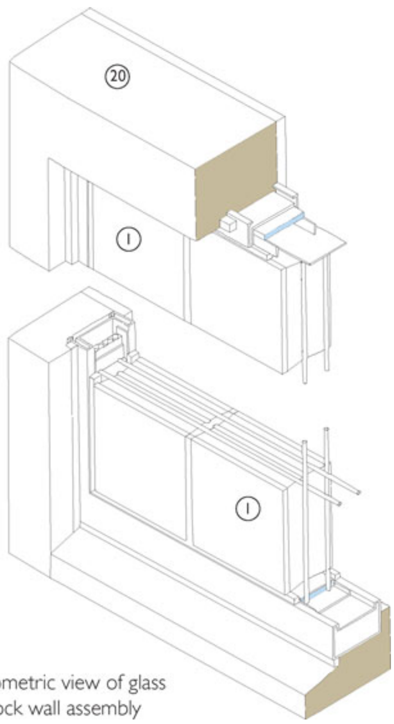


Horizontal section 1:10. Glass blocks supported by steel sections



Horizontal section 1:10. Detail of door set into glass block wall

Horizontal section 1:10. Glass end block



Isometric view of glass block wall assembly

adjusted to meet the glass blocks neatly without the makeup piece in the opening being visible.

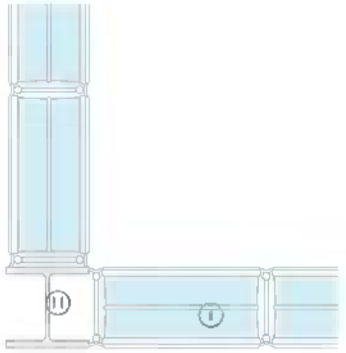
Steel support frames

Glass blocks can also be supported on steel frames. These have the advantage of making the glass blocks appear to have a continuous surface uninterrupted by supporting structure.

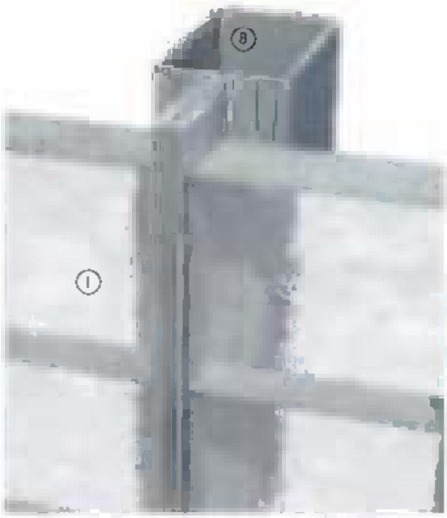
In other cases, steel T-sections support the blocks for modest spans, which can be increased from 1.5 metres to 3.0 metres (5ft to 10ft) with the use of a box section set behind it to form a continuous supporting frame both vertically and horizontally. With both options, the frame is partially visible from outside, as a shadow line in daylight, and as a strong frame when lit internally at night, from outside.

A complete frame of rolled steel sections can support glass blocks by setting the blocks directly onto the steels. This method requires close dimensional co-ordination of steel size and block width in order for the blocks to be aligned on the outer face to drain water down the face of the steel without the need for a drip, which is visually obtrusive.

A recent development in glass block design has been to insert a steel support frame into the joints between individual blocks. This is made more economic by using the largest 300 x 300mm (12in x 12in) blocks and adapting their edges in order to conceal the steel box section within. This concealed steel frame can be supported by

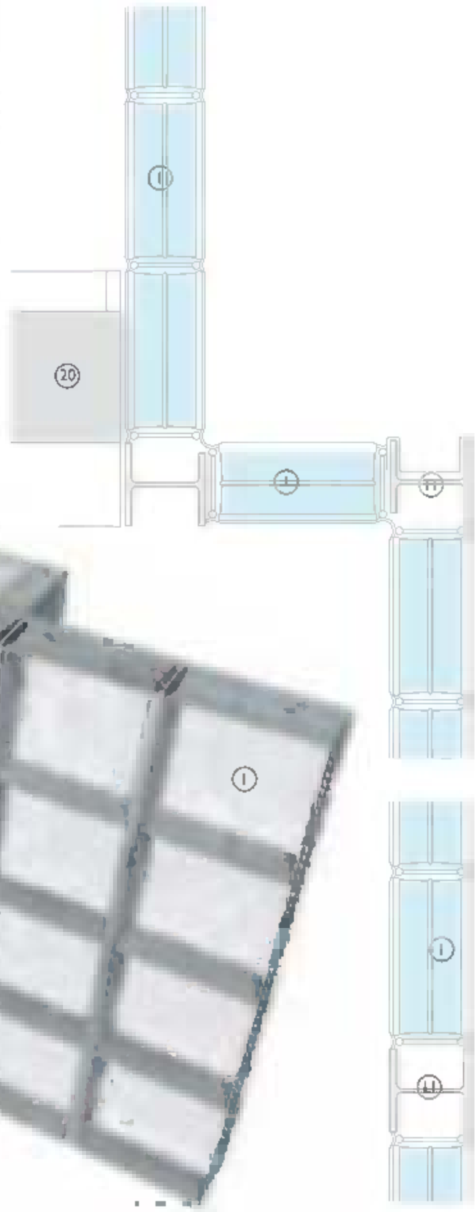


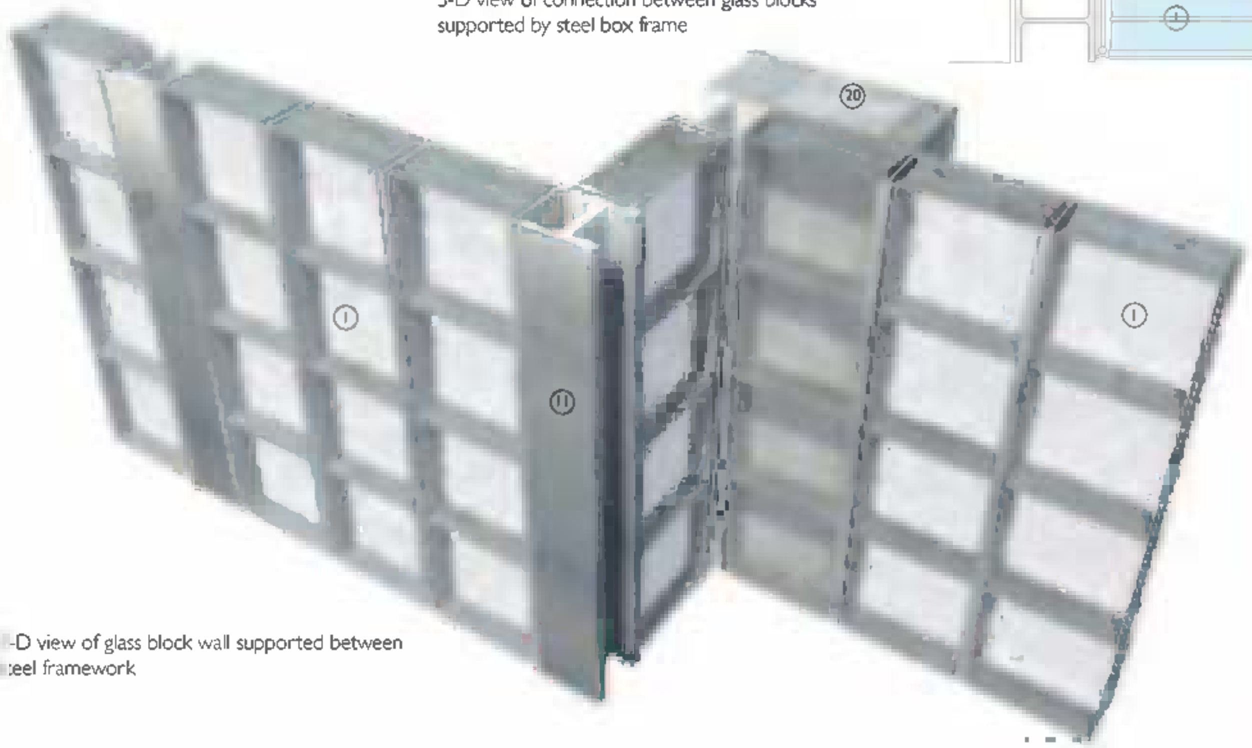
-lorizontal section 1 10. Framed corner in lass block wall



3-D view of connection between glass blocks supported by steel box frame

Ho tal io 1.10. Glass block wall suppo by steel framework





-D view of glass block wall supported between :eel framework

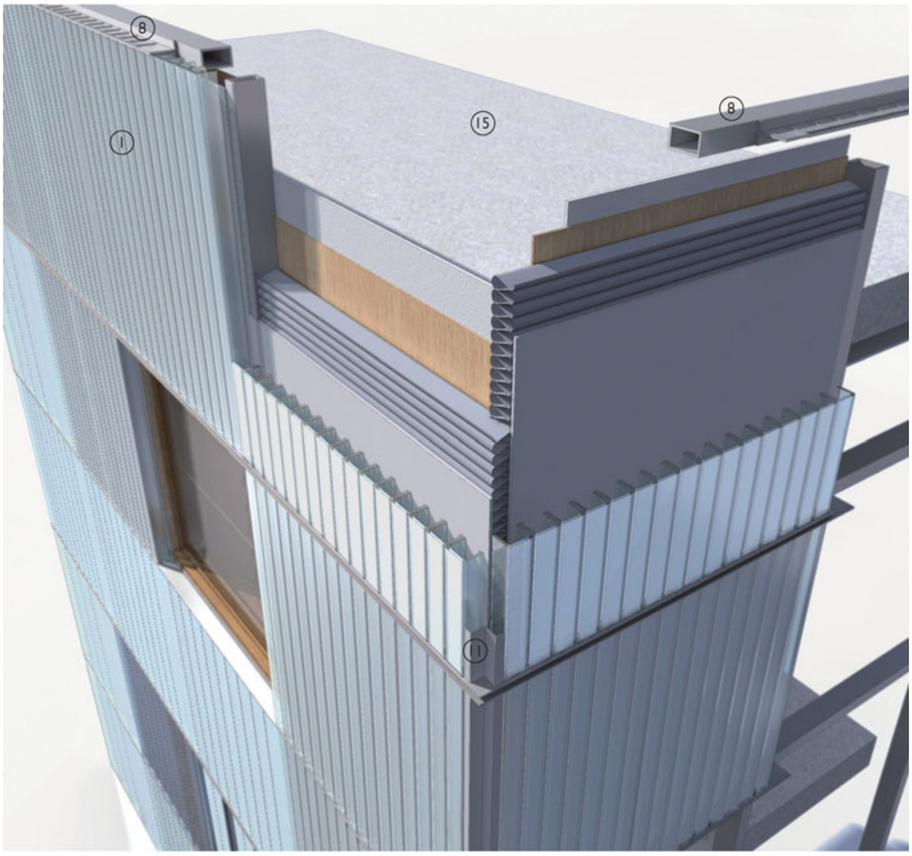
brackets back to secondary vertical posts, such as tubes. Alternatively, the concealed steel frame can be made to hang or sit on supporting structure in the manner of curtain walling, using steel posts to provide lateral stability through its height. Glass blocks are bonded together with silicone which allows for the higher amounts of structural movement associated with steel supports than those in reinforced concrete structures. The continuous surface of blocks, uninterrupted by floor slabs or concrete beams, do not require any drips to throw water clear of these surfaces, giving an overall smooth appearance to the glass block wall.

Masonry and timber framed window openings

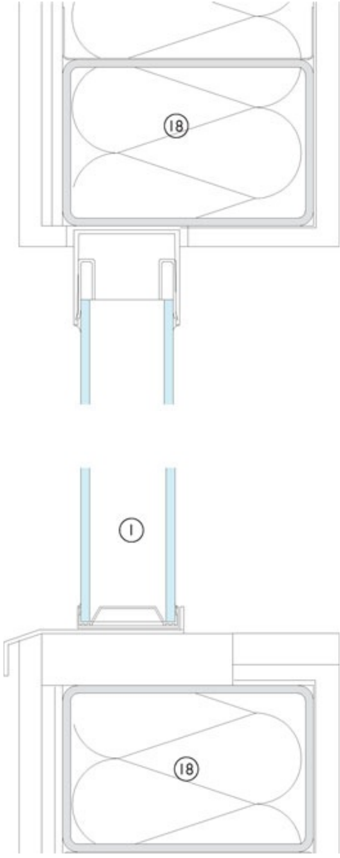
Glass blocks cannot be bedded directly into masonry walls, such as concrete blocks, since any movement at joints between blocks will result in a crack in the nearest glass blocks. For this reason when glass blocks are held in masonry openings, they can be set directly onto a concrete cill if one is used. Sometimes the concrete cill can form a complete reinforced concrete frame, around 50 -75mm (2in-3in) wide in which the glass blocks are set. Openings in timber framed walls, and openings in cavity wall construction (typically brick outer leaf, air gap and inner block/timber wall) use an extruded aluminium frame to hold the glass blocks in place, which is usually polyester powder coated. The aluminium

Details

1. Glass block
2. Bedding reinforcement
3. Bedding compound, mortar or silicone-based bond.
4. Adjacent blockwork wall with rainscreen
5. Adjacent concrete wall
6. Adjacent light gauge steel framed wall
7. Reinforced concrete frame
8. Steel box section
9. 90° corner block
10. 45° corner block
11. Steel I-section, usually specially fabricated
12. Steel angle
13. Inside
14. Outside
15. Floor deck
16. Steel T-section
17. Adjacent brick cavity wall construction
18. Thermal insulation
19. Extruded aluminium sections providing support
20. Adjacent reinforced concrete wall



3-D view of storey height glass channels as cladding system



Vertical section 1:10. Vertically set glass channels used as window

frames are thermally broken, fixed to the masonry opening, usually with screws. Similar aluminium sections are used between some joints to provide additional support if required. Where glass blocks are set into an opening in a timber frame, the aluminium profile edge can be combined with a timber cill to give a continuous timber appearance both internally and externally.

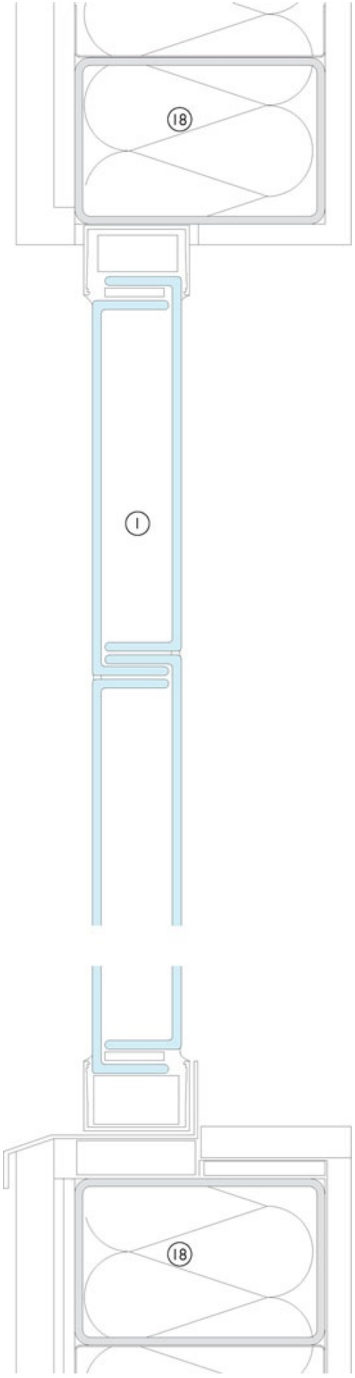
Cast glass channels

The effect of translucency provided by thick glass can also be provided by cast glass channels. These are like half blocks in section which are made in lengths up to around 2.5 metres (1ft 6in). Most are around 250mm wide x 60mm deep (10in x 2.5in) with glass around 6-7mm (0.25in) thick. Planks can be set both vertically and horizontally, but vertical applications are the most common as they are far easier to fix. When set horizontally, glass planks cannot sit on top of one another; each plank is supported individually at its end to provide a waterproof seal between planks that can accommodate thermal movement.

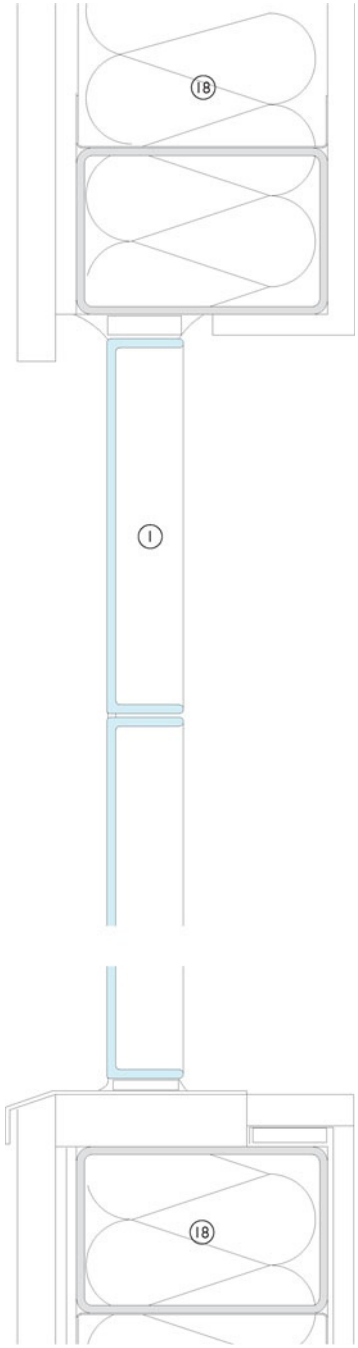
An advantage of cast glass channels or 'planks' over glass blocks is that they are self-supporting, with the ability to span their full length of around 2.5 metres (8ft). The glass is held in place with thermally broken aluminium extrusions at its ends, using sections similar to those used for glass blocks in window openings. The extrusions are anodised or polyester powder coated to suit the design. Light transmission is around 85%, reducing to 70% if two channels are interlocked to form a wall of double thickness to improve thermal insulation and increased sound reduction through the wall. A double thickness of interlocking channels can provide a sound reduction similar to that of a double glazed unit in a glazed wall of around 40dB, with thermal insulation also similar to that of a double glazed unit at around 2.0 W/m^{2}K if a hard low emissivity (low e) coating is applied to the inner face of the outer channel. An advantage of cast glass channel glazing is that it is much cheaper than a conventional glazed wall system. This coating changes the surface appearance slightly. A hard coating allows the channels to be assembled on site. The higher performance soft coatings are required to be sealed as double glazed units in the factory, which is not possible with cast glass channels as their ends are open until installed in the aluminium edge framing already described.

Cast glass channels are sealed together with silicone, with translucent white being the most commonly used colour, to match the glass as closely as possible. Unlike glass blocks, cast glass channels can provide only very limited fire resistance of around 30 minutes when the length of the plank is restricted to around 2.5 metres (8ft). The glass is reinforced with a grid of wires, giving the appearance of traditional wired glass, and joints use a fire retardant silicone.

3-D view of storey height glass channels used as cladding system



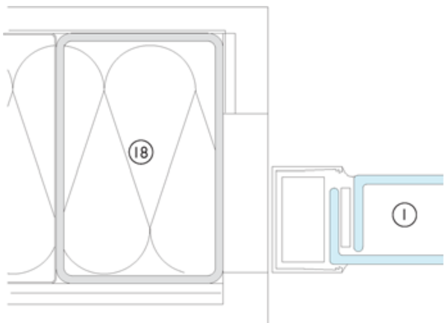
Vertical section 1:10. Interlocking horizontally set glass channels used as window



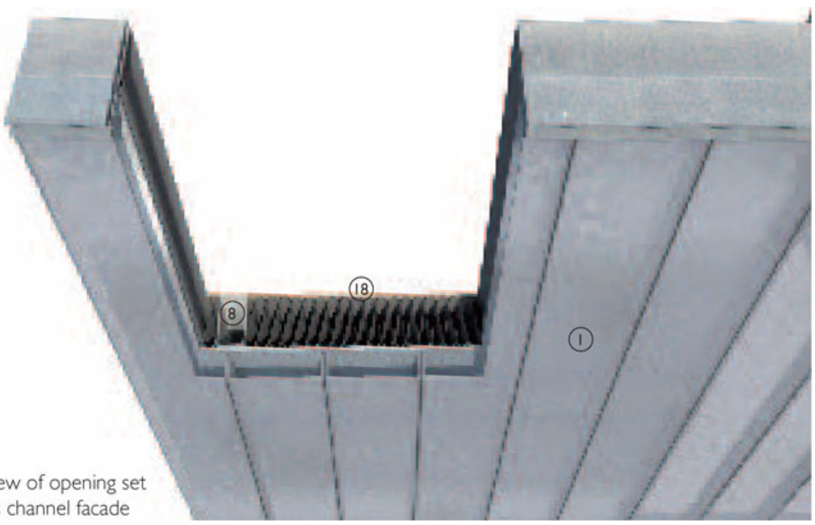
Vertical section 1:10. Horizontally set glass channels used as window

Details

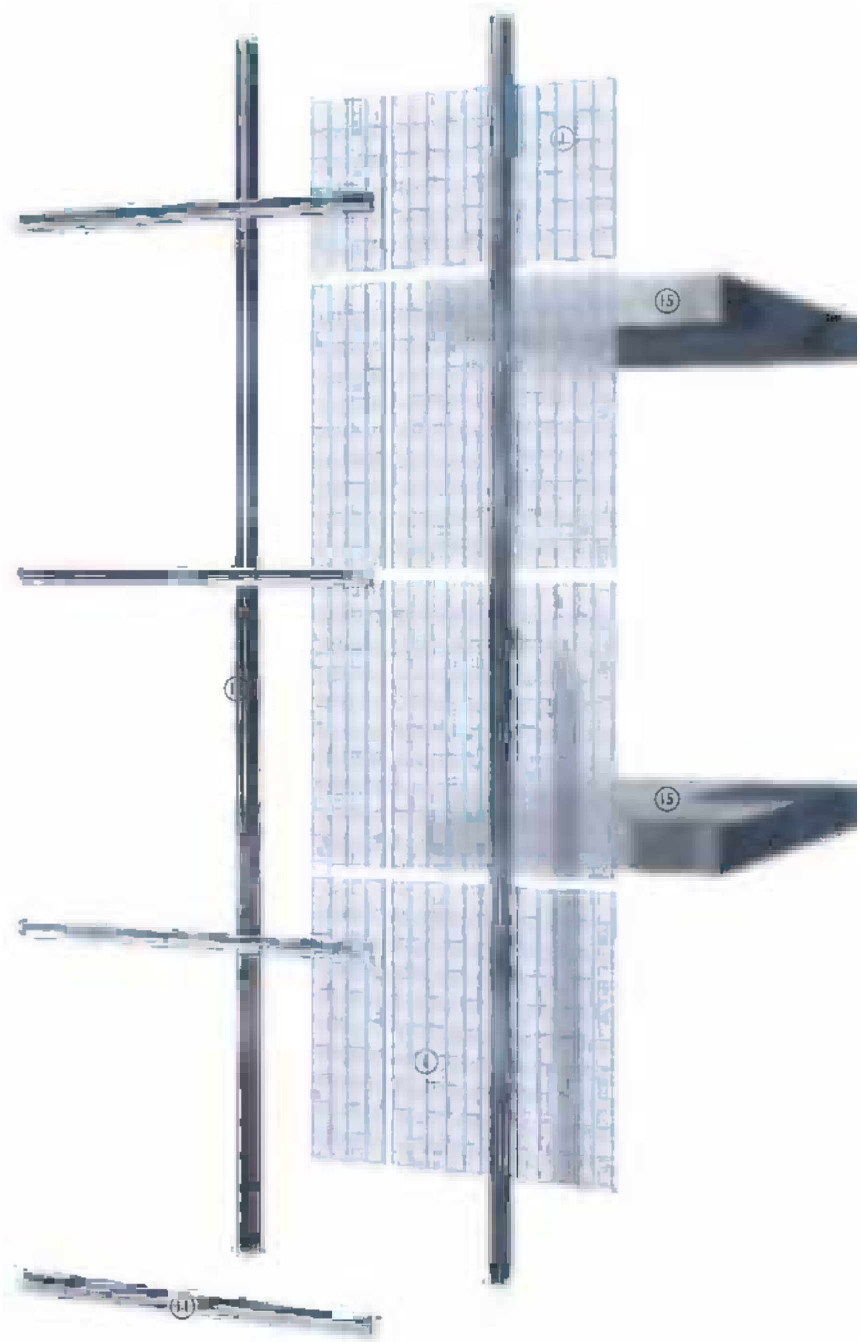
1. Glass block
2. Bedding reinforcement
3. Bedding compound, mortar or silicone-based bond.
4. Adjacent blockwork wall with rainscreen
5. Adjacent concrete wall
6. Adjacent light gauge steel framed wall
7. Reinforced concrete frame
8. Steel box section
9. 90° corner block
10. 45° corner block
11. Steel I-section, usually specially fabricated
12. Steel angle
13. Inside
14. Outside
15. Floor deck
16. Steel T-section
17. Adjacent brick cavity wall construction
18. Thermal insulation
19. Extruded aluminium sections providing support
20. Adjacent reinforced concrete wall



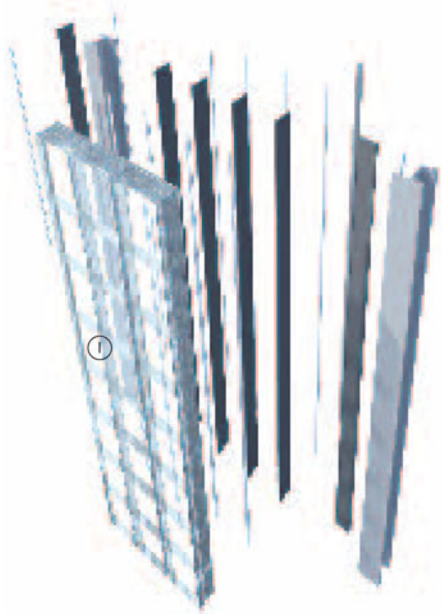
Horizontal section 1:10. Vertically set glass channels used as window



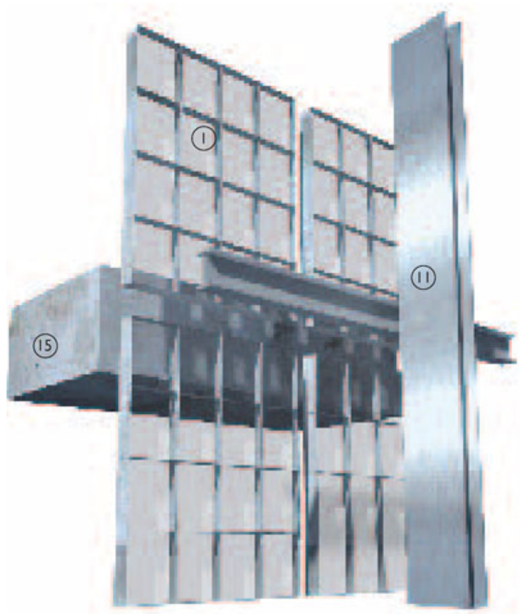
3-D view of opening set in glass channel facade



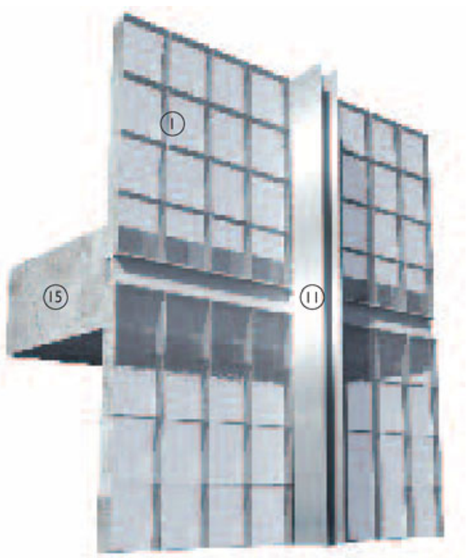
3-D exploded view of top of glass block facade system and floor slab connections



3-D exploded view of glass block system with supporting structure



3-D view of glass block facade system with supporting structure

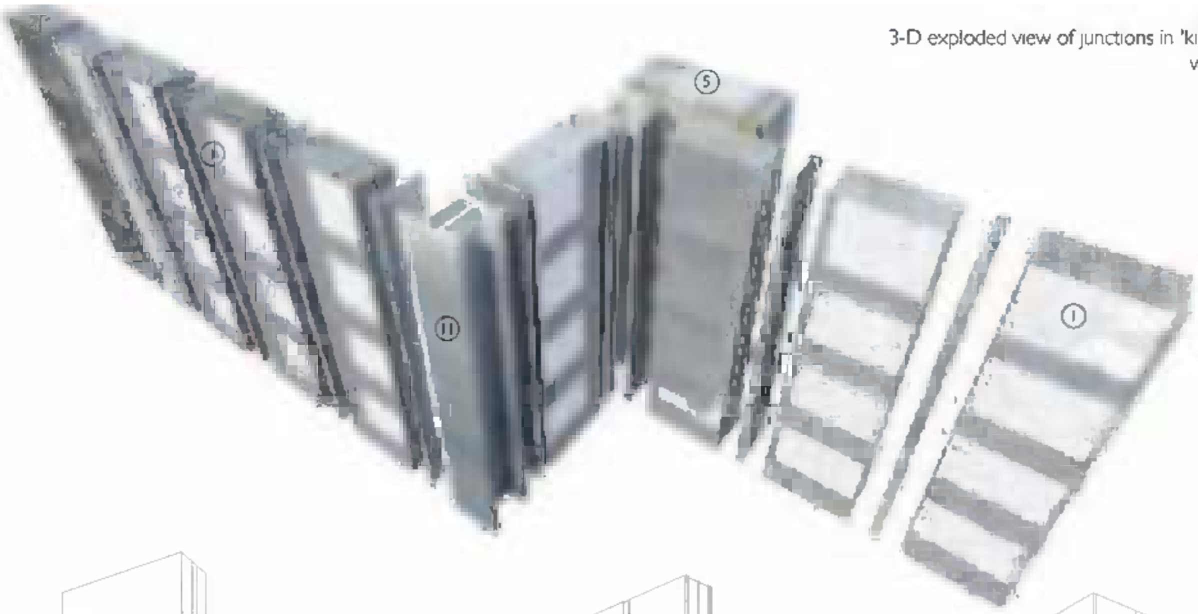


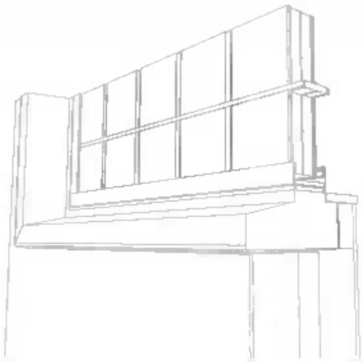
3-D exploded view of glass block facade system with supporting structure

Details

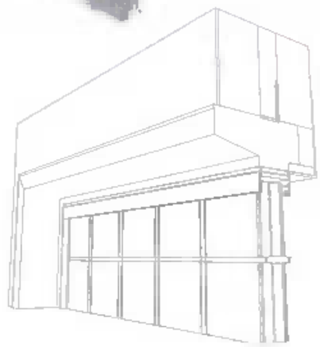
1. Glass block
2. Bedding reinforcement
3. Bedding compound, mortar or silicone-based bond
4. Adjacent blockwork wall with rainscreen
5. Adjacent concrete wall
6. Adjacent light gauge steel framed wall
7. Reinforced concrete frame
8. Steel box section
9. 90° corner block
10. 45° corner block
11. Steel I-section, usually specially fabricated
12. Steel angle
13. Inside
14. Outside
15. Floor deck
16. Steel T-section
17. Adjacent brick cavity wall construction
18. Thermal insulation
19. Extruded aluminium sections providing support
20. Adjacent reinforced concrete wall

3-D exploded view of junctions in 'kinked' glass bloc
wall configuratio

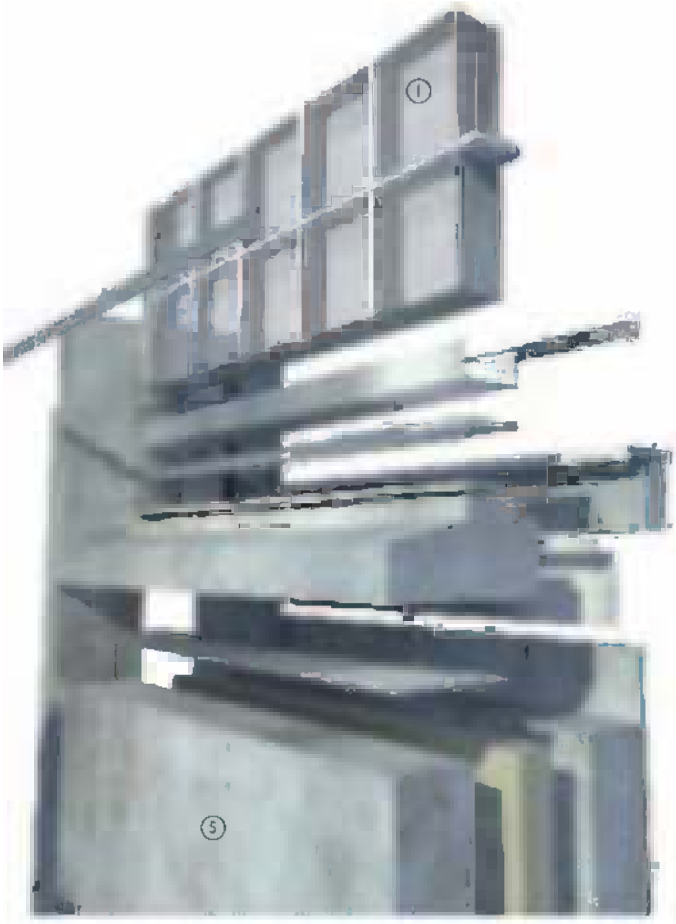




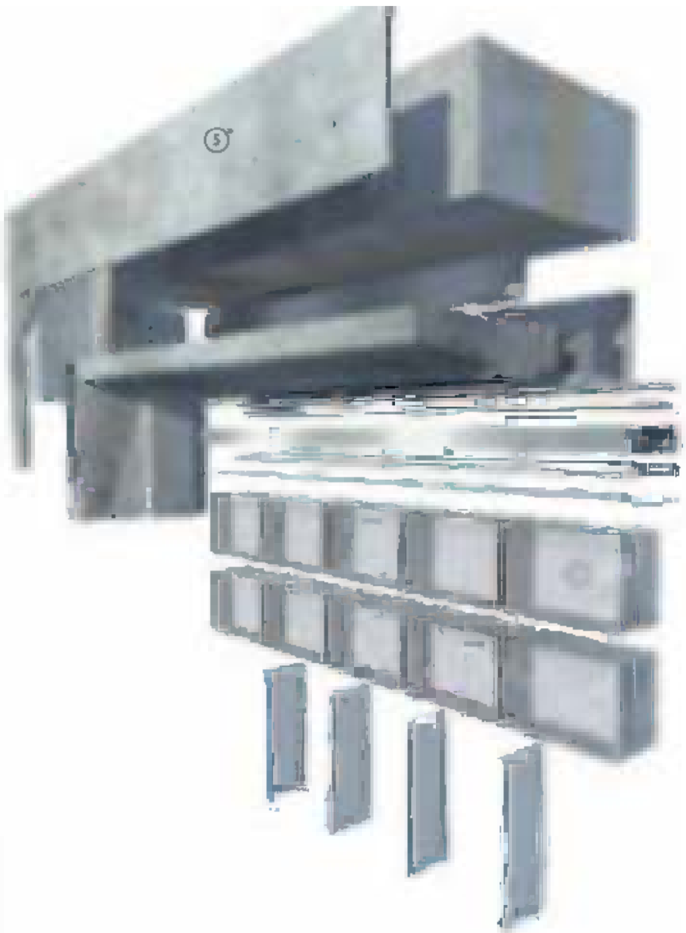
3-D view of bottom of glass block window set in cavity wall construction



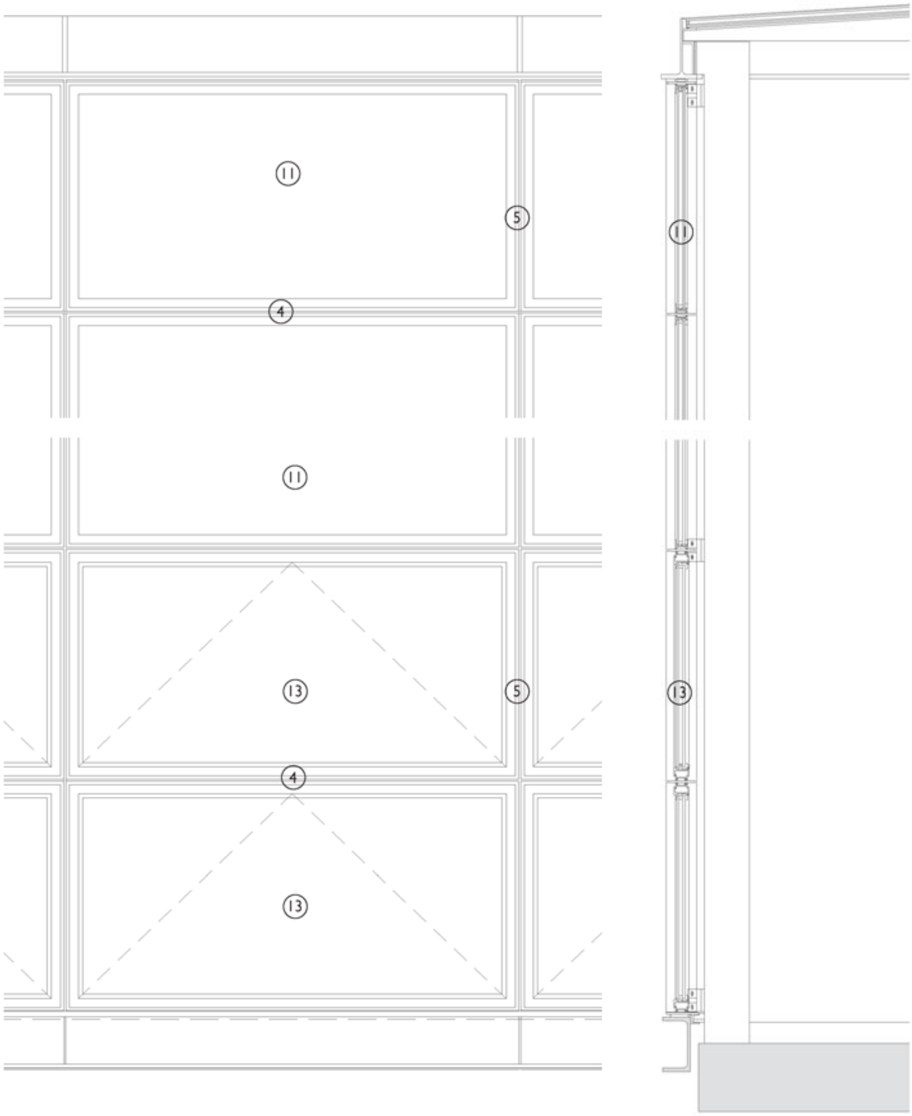
3-D view of top of glass block window set in cavity wall construction



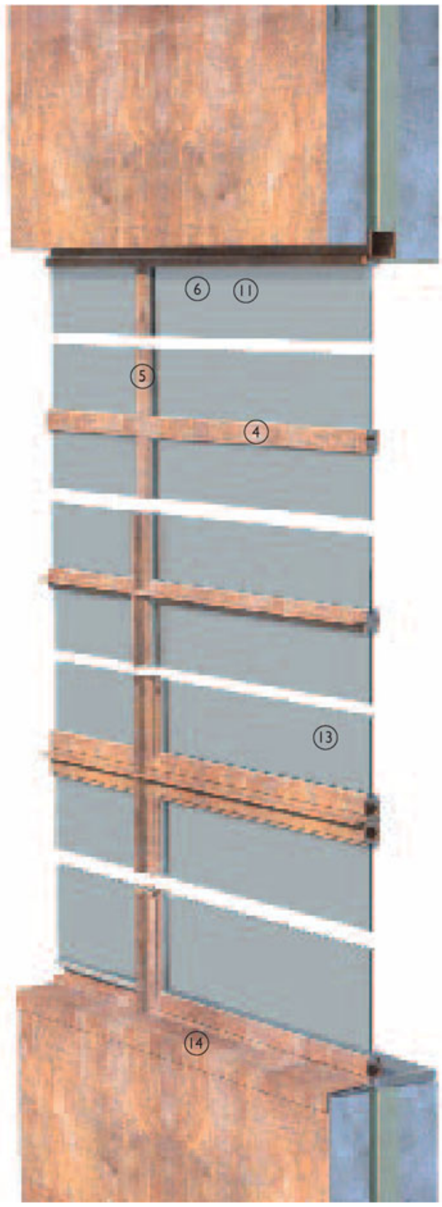
3-D exploded view of bottom of glass block window set in cavity wall construction



3-D exploded view of top of glass block window set in cavity wall construction



Elevation and section 1:25. Storey height steel window assembly



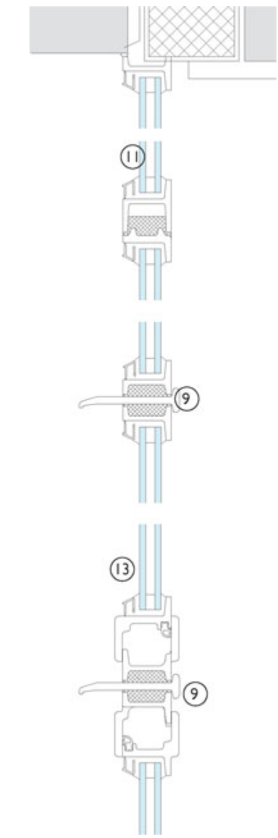
3-D view of rolled steel window details

Details

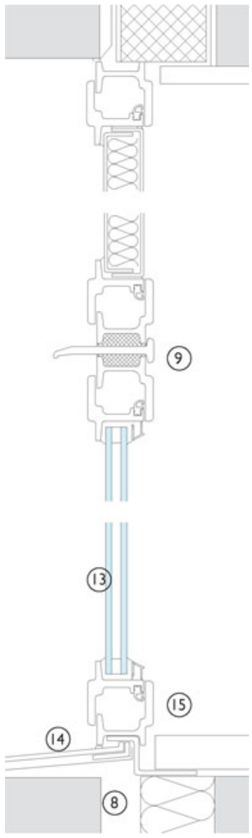
1. Outside
2. Inside
3. Steel supporting structure
4. Transom
5. Mullion
6. Single glazed or double glazed unit to suit application
7. Fixing bead
8. Fixing lug
9. Projecting transom
10. Rubber-based seal
11. Fixed light
12. Inward opening light
13. Outward opening light
14. Window cill
15. Condensation tray
16. Damp proof course (DPC)
17. Internal finish
18. Drip
19. Packing
20. Aluminium clip to secure double glazed unit
21. Steel cill
22. Meeting stile
23. Pressed steel frame

Steel framed windows are a robust window construction that is often used as a fire resistant glazing. Steel glazing was developed primarily for single glazing, where the main advantage was their thin sight lines when compared to those in aluminium. The thin, rigid, rolled steel sections were also more economic than their aluminium counterparts. The rolled sections can accommodate double glazed units of most thicknesses, but are not thermally broken. These rolled sections are used with small window sizes up to a maximum of around 3000 x 1800mm (10ft x 6ft) and a minimum of 250mm x 400mm (10in x 16in) with double glazed units. Fully glazed walls made from window sections can be made using this relatively small window size. The 'window wall' is stiffened with a frame formed from integral steel fins that pass through the window. These narrow window sections cannot incorporate a thermal break.

Window walls with larger panel sizes can be formed in larger pressed steel sections and rolled hollow sections rather than the smaller G-shaped or T-shaped sections. Their sight lines are very similar to those in aluminium, that is considerably wider than hot rolled sections. Pressed steel sections are wider and deeper in section than the rolled types but they have the advantage of being able to be formed into larger walls as well as being able to incorporate a thermal break. Thermal breaks are held in place by folding the material tightly over the ends of the polymer material, which is currently too difficult to do

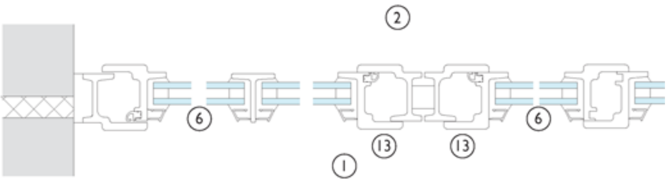


Vertical section 1:10. Internally glazed rolled steel frame

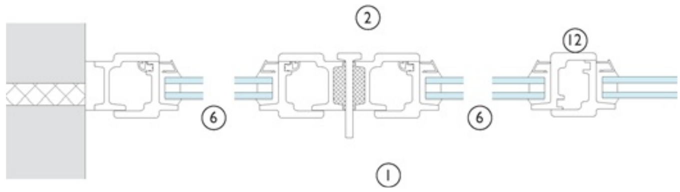


Vertical section 1:10. Internally glazed rolled steel frame

3-D view of rolled steel window details



Horizontal section 1:10. Internally glazed rolled steel frame



Horizontal section 1:10. Externally glazed rolled steel frame

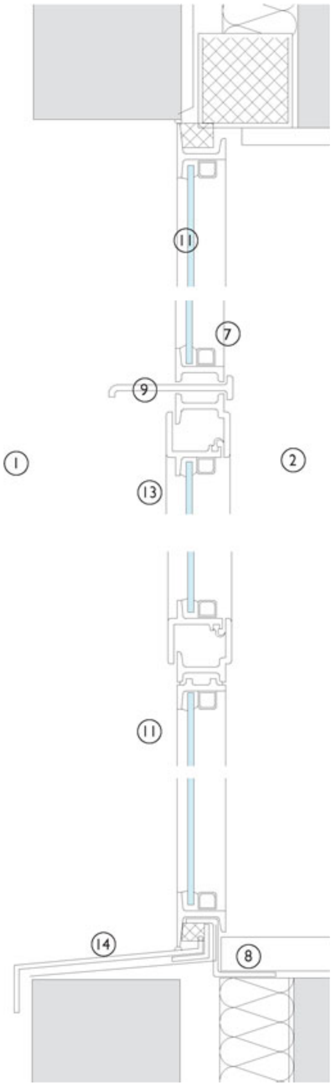
economically in thin hot rolled sections.

The most common use of steel windows is in fire resistant glazing, typically where glazed walls enclose a fire resisting compartment. The fire integrity is usually between 30 minutes and 1 hour, but 2 hour integrity can be achieved when used with fire resisting glasses. Although steel glazing provides structural integrity during a fire, it does not provide thermal insulation to counter the heat generated by fire. This is dealt with either by providing sprinklers that drench the wall to keep it cool or else the wall is positioned in a way that building users do not come into direct contact. Areas of fire resisting glazing can be combined with areas of unprotected glass without changing the outward appearance of the glazing. This is a big advantage where a consistency of appearance is required over a continuous facade with different requirements for fire protection in different areas of the same facade.

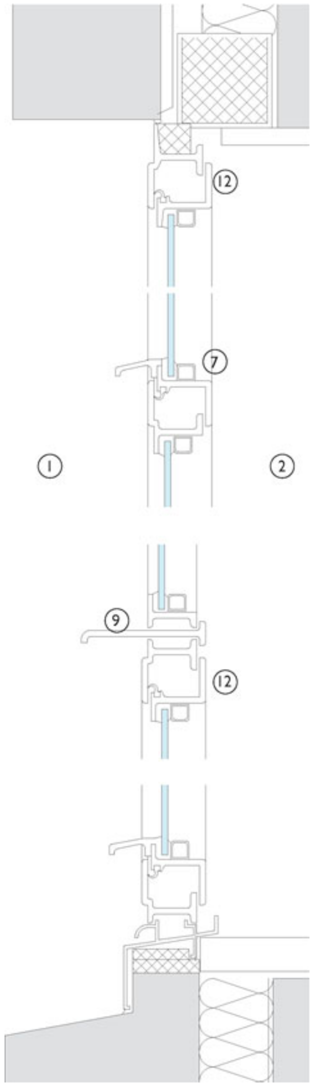
Small-scale glazing

Fixed and opening lights framed in sizes up to 3000mm x 1800mm (10ft x 6ft) use a standard single section which is used for both horizontal and vertical glazing sections as well as for opening lights. Where opening lights occur, the profile used for the window frame is different, as is the profile for the opening light itself. Also, profiles are different for inward and opening lights. Unlike aluminium framed glazed walling, where a single extrusion is used throughout, with opening lights glazed into the system, small-scale steel glaz-

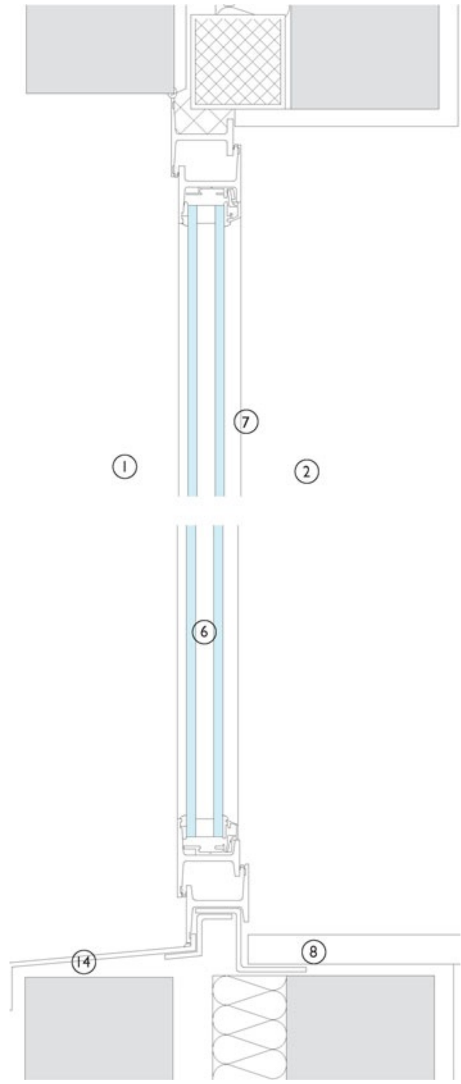
3-D view of junction with adjoining cavity wall



Vertical section 1:10. Rolled steel frame with single glazing



Vertical section 1:10. Rolled steel frame with single glazing



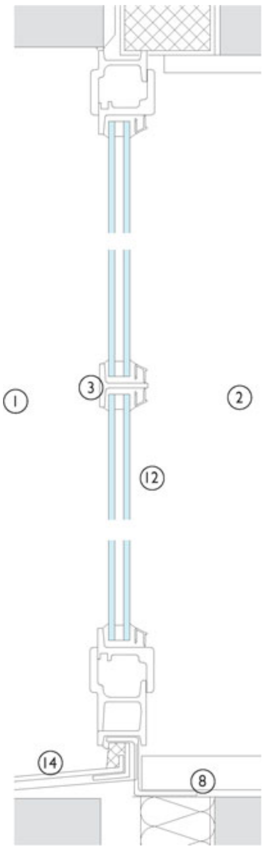
Vertical section 1:10. Rolled steel frame with double glazed unit

Details
1. Outside
2. Inside
3. Steel supporting structure
4. Transom
5. Mullion
6. Single glazed or double glazed unit to suit application
7. Fixing bead
8. Fixing lug
9. Projecting transom
10. Rubber-based seal
11. Fixed light
12. Inward opening light
13. Outward opening light
14. Window cill
15. Condensation tray
16. Damp proof course (DPC)
17. Internal finish
18. Drip
19. Packing
20. Aluminium clip to secure double glazed unit
21. Steel cill
22. Meeting stile
23. Pressed steel frame

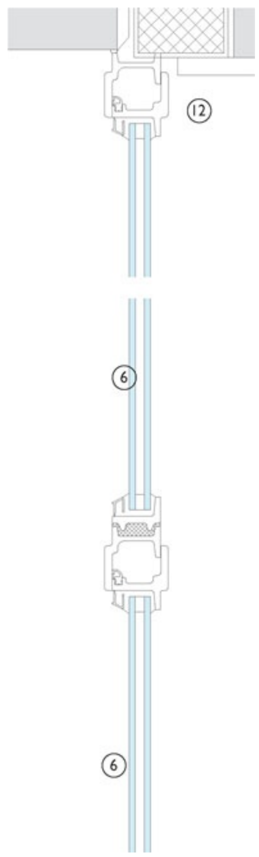
ing requires a family of different profiles to create a single glazed wall. For this reason, manufacturers offer a small range of steel window types in order to remain economic. Because sections are rolled rather than extruded, there is very little possibility of creating a new profile for a specific project. Single glazed panes of glass were traditionally fixed with steel pins and glazing putty like traditional window frames, but the practice has given way to thin steel channels and angles. More recently, aluminium extrusions are used, which are clipped into place. The extrusions are both more reliable in the long term and far easier to replace, particularly in large-scale glazed walls.

When windows, either fixed or opening lights, are joined together to form a glazed wall, mild steel T-section fins are set between the windows to form a stiffening frame. The adjacent frames are screwed to the fins in order to contribute to the overall stiffness of the frame. Unlike aluminium, the T-sections used are different from those set vertically in order to provide a projecting drip. Profiles are designed so that they are glazed from either the inside or the outside. The choice of system is usually dictated by the method of glass replacement, which may be from an internal floor or from an external ladder or cleaning and maintenance cradle.

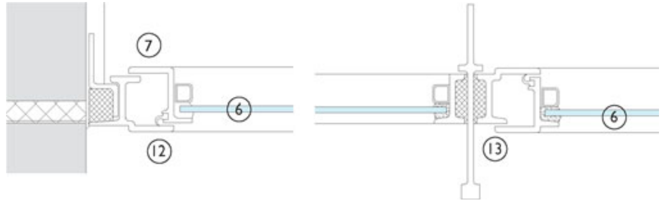
Outward opening lights have profiles with edges that project over the front of the supporting frame to exclude rainwater. A projecting drip is provided at the top to protect the vulnerable top joint. Any rainwater that



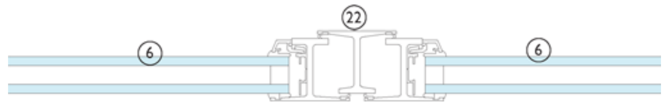
Vertical section 1:10. Inward opening rolled steel frame with double glazed unit



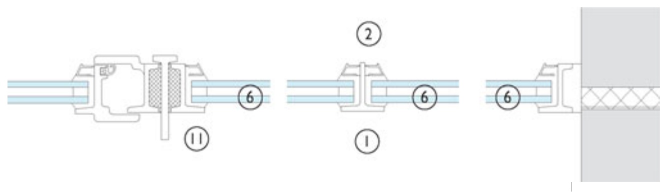
Vertical section 1:10. Outward opening rolled steel frame with double glazed unit



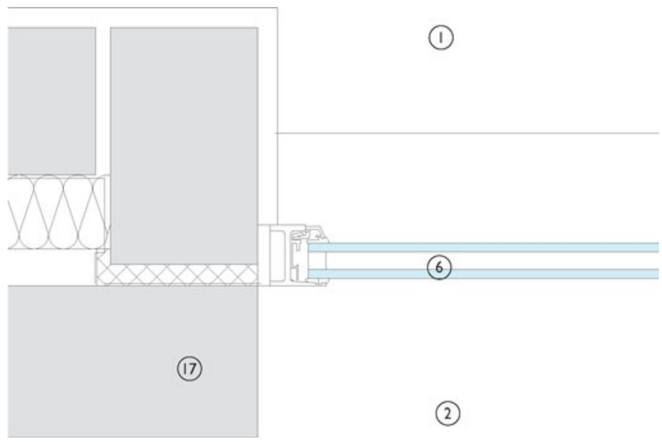
Horizontal section 1:10. Rolled steel frame with single glazing and outward opening light



Horizontal section 1:10. Meeting stile on rolled steel frame with double glazing



Horizontal section 1:10. Rolled steel frame glazed internally



Horizontal section 1:5. Junction between steel window and adjoining cavity wall construction

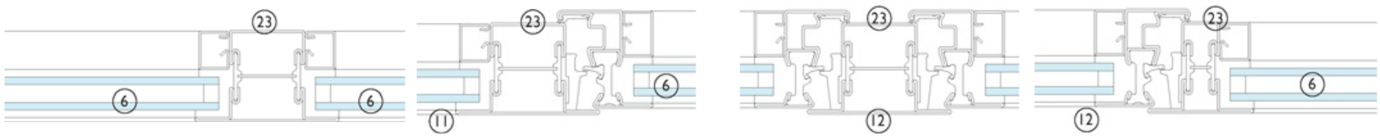
drips into the inner surface of the frame is drained away around the edge of the frame and out at the bottom of each frame. Rubber-based seals are now used to assist with reducing air infiltration through the window.

Inward opening lights use the same profiles with their projecting edges set against the frame in a similar way. At the window head, a projecting fin is not needed as a drip, since the outer frame is lapped over the inner light. Rubber-based seals are used to reduce air infiltration. Windows and glazed walls are fixed to adjacent masonry walls with steel lugs that allow them to be fixed away from the edge of the concrete or masonry. These lugs are concealed by internal finishes. When fixed into a timber or pressed steel edge frame, steel glazing can be fixed directly through the frame into the supporting material.

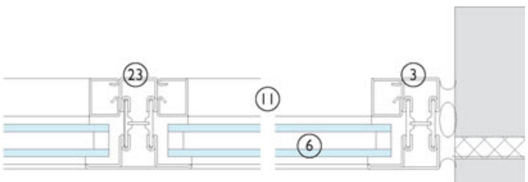
Additional stiffening for larger walls is provided by tube or box sections set away from the glazed wall. The glazing is fixed to the support frame with steel cleats and brackets. These provide a method of taking up tolerances and alignment adjustments between the windows and their supporting frame.

Doors are fixed to the supporting frame in the same way as windows, but their construction is more robust. They have thicker sections at the cill and have a horizontal rail at mid-height to provide stiffness. Some also have mild steel plates, glazed in at cill level as kicking plates. The plates have an internal insulation core if used in conjunction with

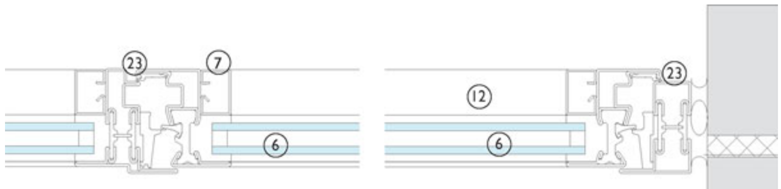
3-D view of steel glazing set in cavity wall construction



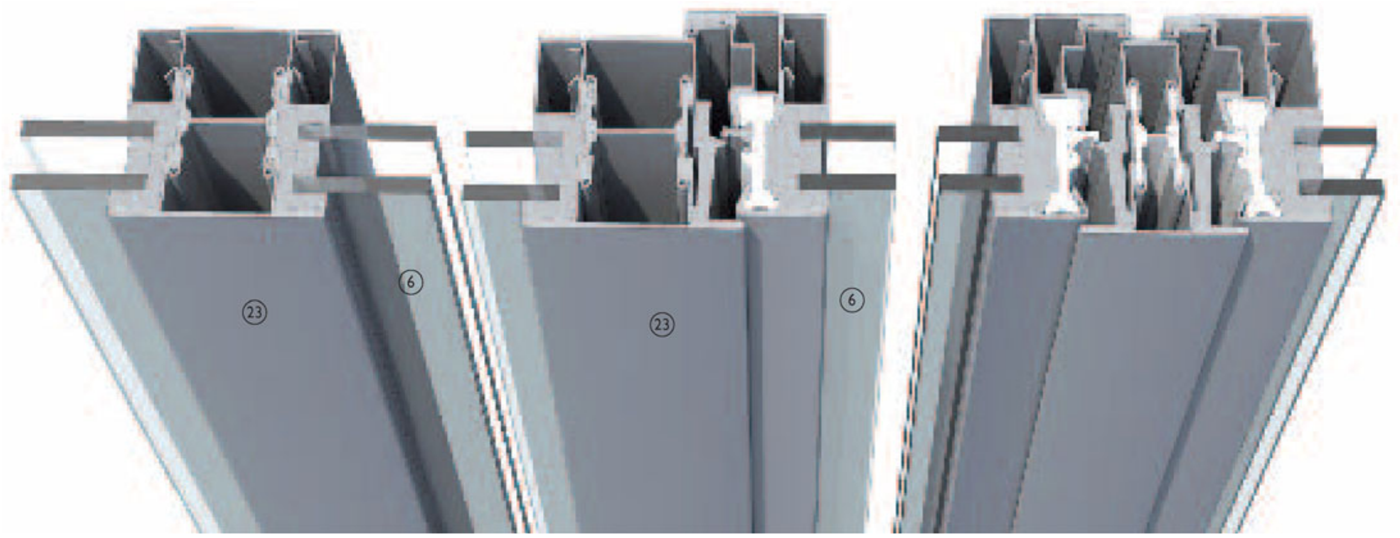
Horizontal sections 1:10. Various pressed steel window configurations with double glazing and thermally broken



Horizontal sections 1:10. Pressed steel frame windows with double glazing and thermally broken. Junction with cavity wall construction



Horizontal sections 1:10. Pressed steel frame windows with double glazing and thermally broken. Junction with cavity wall construction



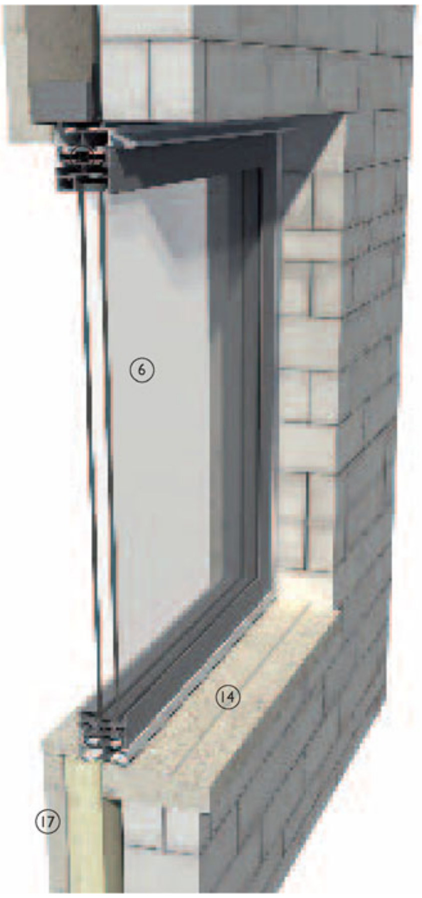
3-D view of various pressed steel frame window configurations with double glazing and thermally broken

Details
1. Outside
2. Inside
3. Steel supporting structure
4. Transom
5. Mullion
6. Single glazed or double glazed unit to suit application
7. Fixing bead
8. Fixing lug
9. Projecting transom
10. Rubber-based seal
11. Fixed light
12. Inward opening light
13. Outward opening light
14. Window cill
15. Condensation tray
16. Damp proof course (DPC)
17. Internal finish
18. Drip
19. Packing
20. Aluminium clip to secure double glazed unit
21. Steel cill
22. Meeting stile
23. Pressed steel frame

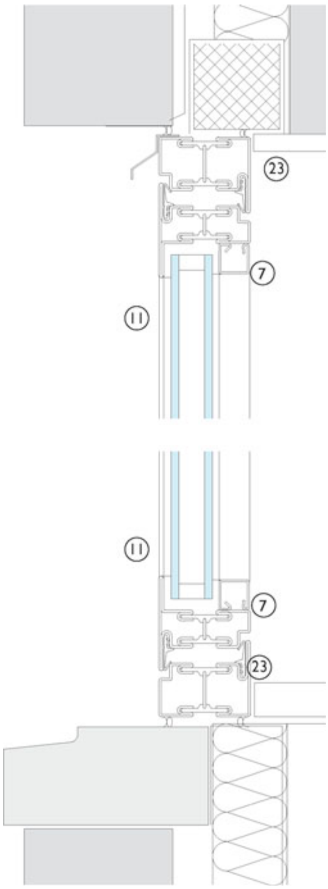
double glazing. The thinness of steel window frames in relation to aluminium allows door cills to be visually more discrete than those in aluminium, with a low upstand formed by the cill at floor level. Doors, in common with other cills, have a condensation channel which collects water at the bottom of the glazed wall and directs it to the outside. These channels are needed since the frame is not thermally broken and condensation can occur on the internal face in temperate climates.

Large-scale glazing

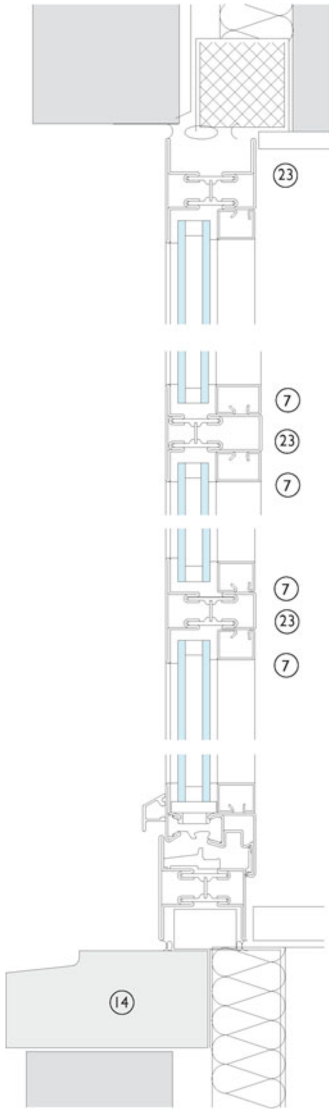
Large-scale glazing uses a carrier frame of mullions and transoms formed in steel box sections similar to that in aluminium. The carrier frame has an indented groove at the front to allow fixing toggles to be inserted into it. Rubber-based air seals are set against the carrier frame onto which the double glazed units are set. The glass is secured with pressure plates and integral rubber-based seals in the same way as aluminium glazed wall systems. The pressure plate is fixed with a bolt that is secured into the toggle. In aluminium construction, a projecting groove forms part of the extrusion to which the bolt is fixed. Rolled or pressed steel cannot incorporate such a complicated and rigid profile. The rubber-based air seals fixed to the box sections have an additional lip which tucks down over the top of the double glazed unit below. This provides a sealed inner chamber for drainage and pressure equalisation in the manner of aluminium glazed walls. Manufac-



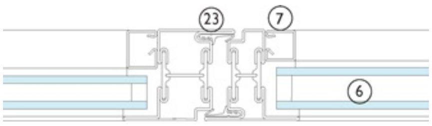
3-D view of double glazed steel frame window set in cavity wall construction



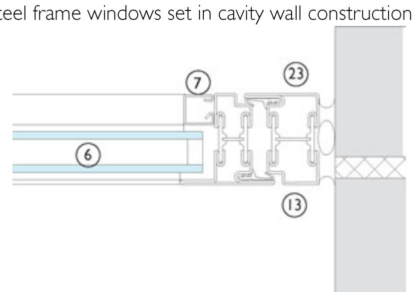
Vertical section 1:10. Outward opening double glazed steel frame windows set in cavity wall construction



Vertical section 1:10. Fixed light double glazed steel frame windows set in cavity wall construction



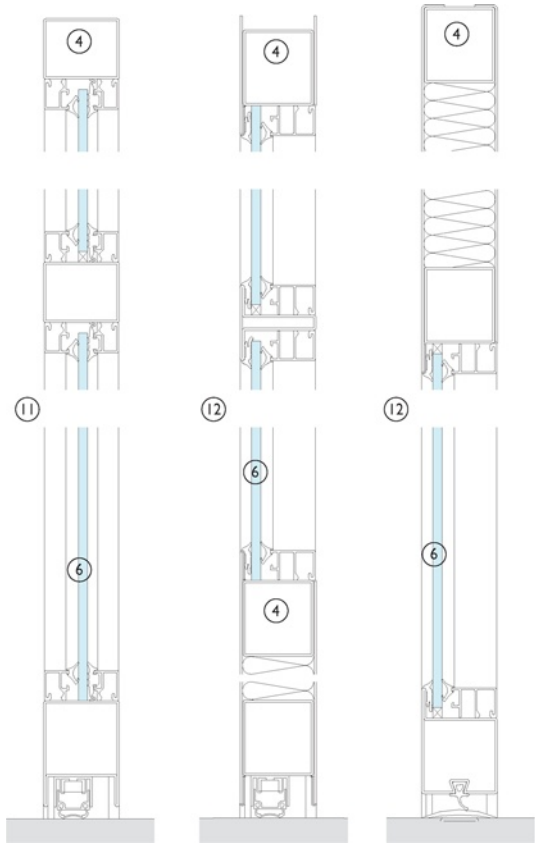
Horizontal section 1:10. Vertically set glass channels used as window



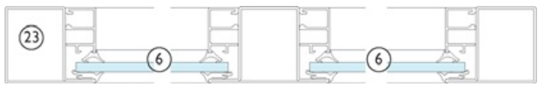
turers provide systems to suit different glazing layouts and spans. The shape of the box section can also vary, from thin long boxes, to a rectangular box, to a pointed aerofoil-type section. The overall sight lines are thinner than an equivalent in aluminium. Special corner pieces are made within manufacturers' systems which are similar to those in aluminium. These special profiles make corners more elegant than they would be by combining structural sections, which would necessitate the adding of sheet metal in corners.

Parapets are formed by glazing a metal flashing into the transom (horizontally) at the top of the wall and extending the flashing down the parapet wall behind which the roof build-up is retained. An advantage of steel glazed walls in box sections is that they can be combined with a glazed roof. In this detail a coping is glazed into the roof member adjacent to the wall at one end and glazed into the top transom of the wall at its other end. The coping profile is usually formed to project slightly forward of the top face of the pressure plate in order to provide protection from maintenance equipment and ladders that can damage the parapet coping. Cills at ground level have metal flashings glazed into them to project down over adjacent construction, such as an insulated concrete upstand. An aluminium or EPDM foil is also glazed in behind the flashing to provide a watertight seal against adjacent construction such as a floor slab. Slot drains at cill level are increasingly used to conceal the minimum 150mm (6in) upstand required between the lowest transom and the

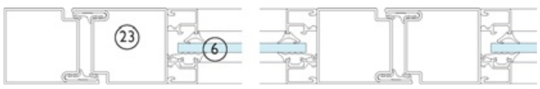
3-D view of double glazed steel framed window set in cavity wall construction



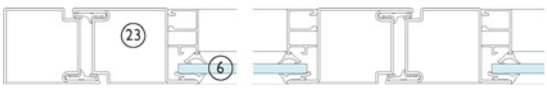
Vertical sections 1:10. Pressed steel single glazed fire resisting doors without thermal breaks



Horizontal section 1:10. Fixed pressed steel single glazed fire resisting doors without thermal breaks



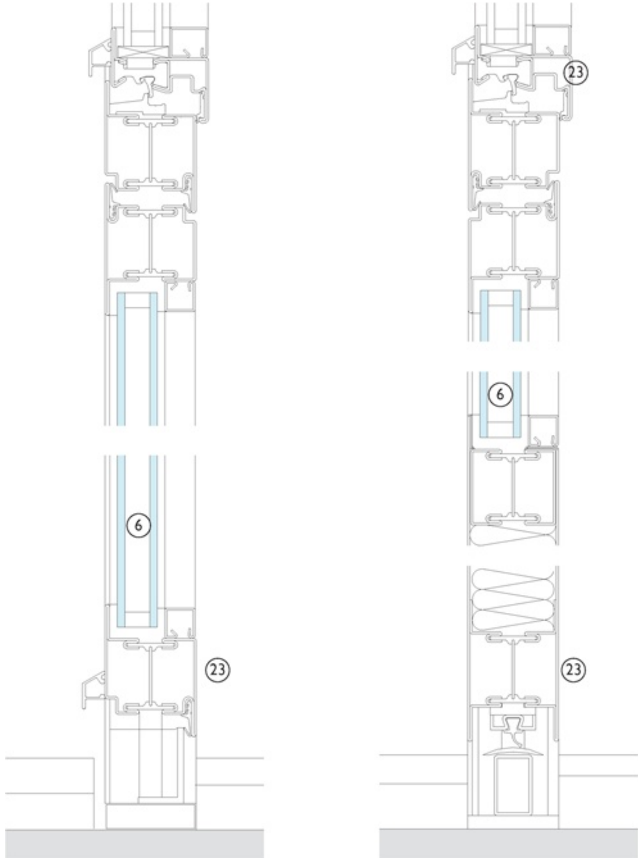
Horizontal section 1:10. Inward opening pressed steel single glazed fire resisting doors without thermal breaks



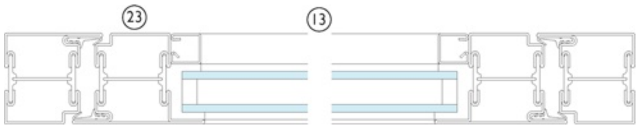
Horizontal section 1:10. Outward opening pressed steel single glazed fire resisting doors without thermal breaks

Details

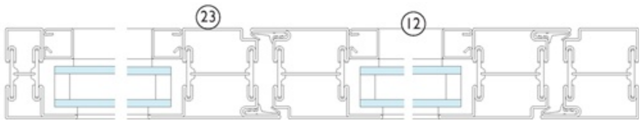
1. Outside
2. Inside
3. Steel supporting structure
4. Transom
5. Mullion
6. Single glazed or double glazed unit to suit application
7. Fixing bead
8. Fixing lug
9. Projecting transom
10. Rubber-based seal
11. Fixed light
12. Inward opening light
13. Outward opening light
14. Window cill
15. Condensation tray
16. Damp proof course (DPC)
17. Internal finish
18. Drip
19. Packing
20. Aluminium clip to secure double glazed unit
21. Steel cill
22. Meeting stile
23. Pressed Steel Frame



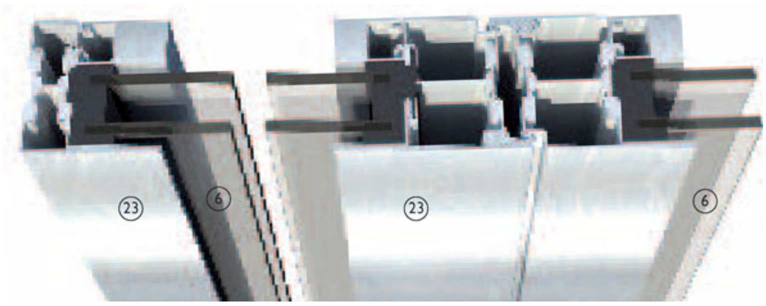
Vertical section 1:10. Pressed steel doors with thermal breaks. Outward opening (left) and inward opening (right)



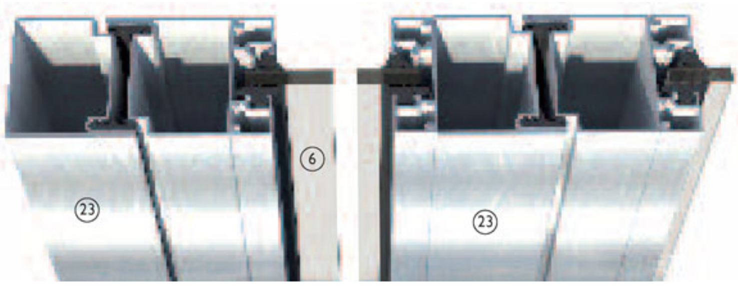
Horizontal section 1:10. Outward opening pressed steel door with thermal break



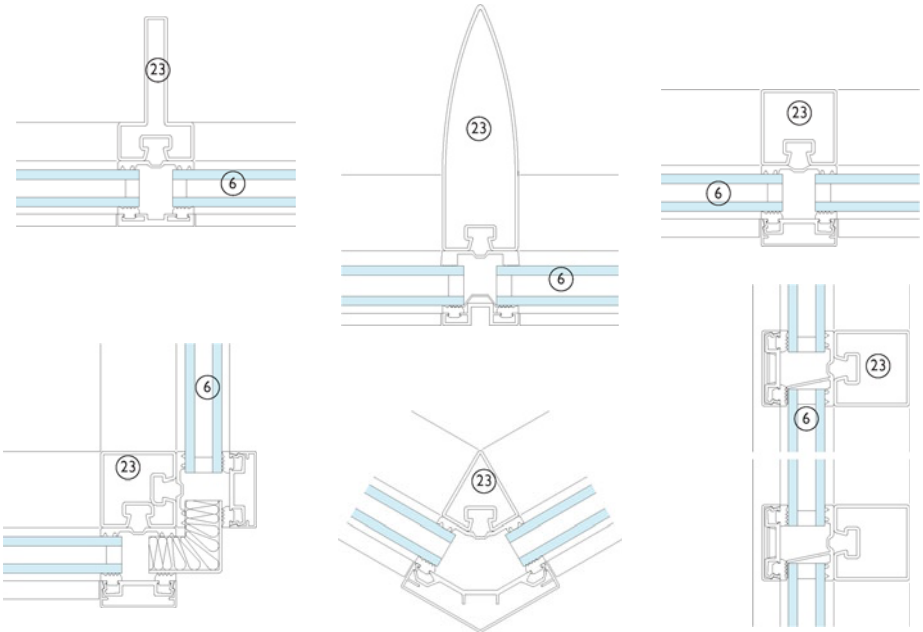
Horizontal section 1:10. Outward opening pressed steel door with thermal break



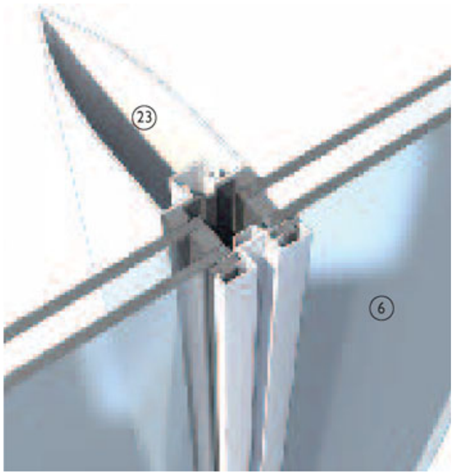
3-D view of outward opening pressed steel door with thermal break

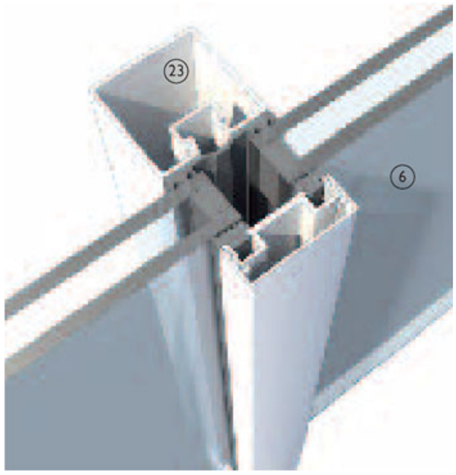


3-D view of outward opening pressed steel single glazed fire resisting door without thermal break



Horizontal section 1:10. Steel framed curtain walling details at various junctions





external ground level for waterproofing purposes. The use of an external slot drain also allows the external level to be the same as the internal floor level while providing a semi-concealed upstand.

Metal flashings and an EPDM foil behind it are also used to seal steel glazing against areas of adjacent construction such as masonry and concrete walls. Opening lights and doors are set into steel glazing as separate items glazed with an opening. As with aluminium glazed walls, the door or opening light has an additional frame which is visible from the outside. Door and window lights are formed from pressed steel sections which are folded together to form a family of profiles to suit different sizes and glass types. Steel framed windows and doors are also made as separate items for glazing into openings in masonry walls. In this instance they are fixed through the frame into the adjacent structural wall. An EPDM foil or silicone sealant is then used to seal the gap between the steel window/door and the adjacent concrete or masonry wall.

Steel glazing with box sections has a limited thermal break provided by the rubber-based seals. Similarly, doors can have a modest thermal break introduced that avoids condensation forming on the inside face of the door in temperate climates. Doors and opening lights have rubber-based seals between the light and the carrier frame to reduce air infiltration. Steel glazing is usually finished as either galvanised or polyester powder coated. PVDF is not used on steel. Sometimes a combination of galvanising and coating is used, but galvanising can distort small components, making it much less popular than polyester powder coating.

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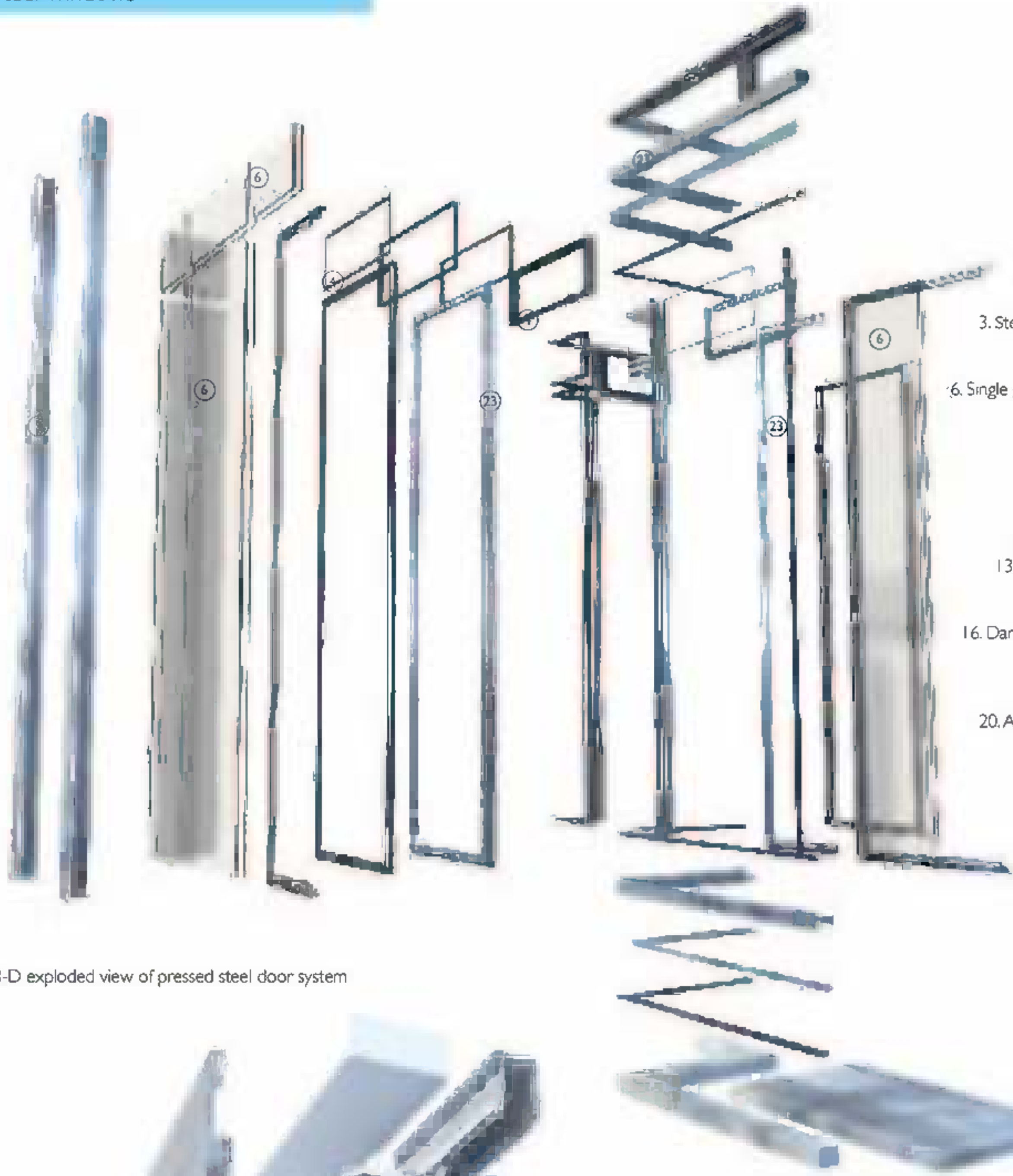
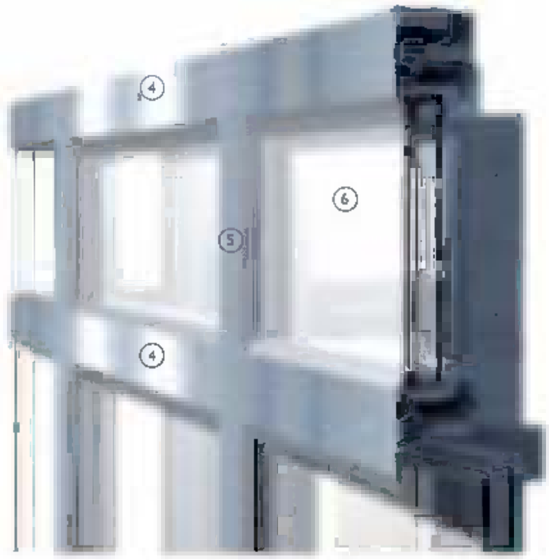


3-D exploded view of pressed steel door system

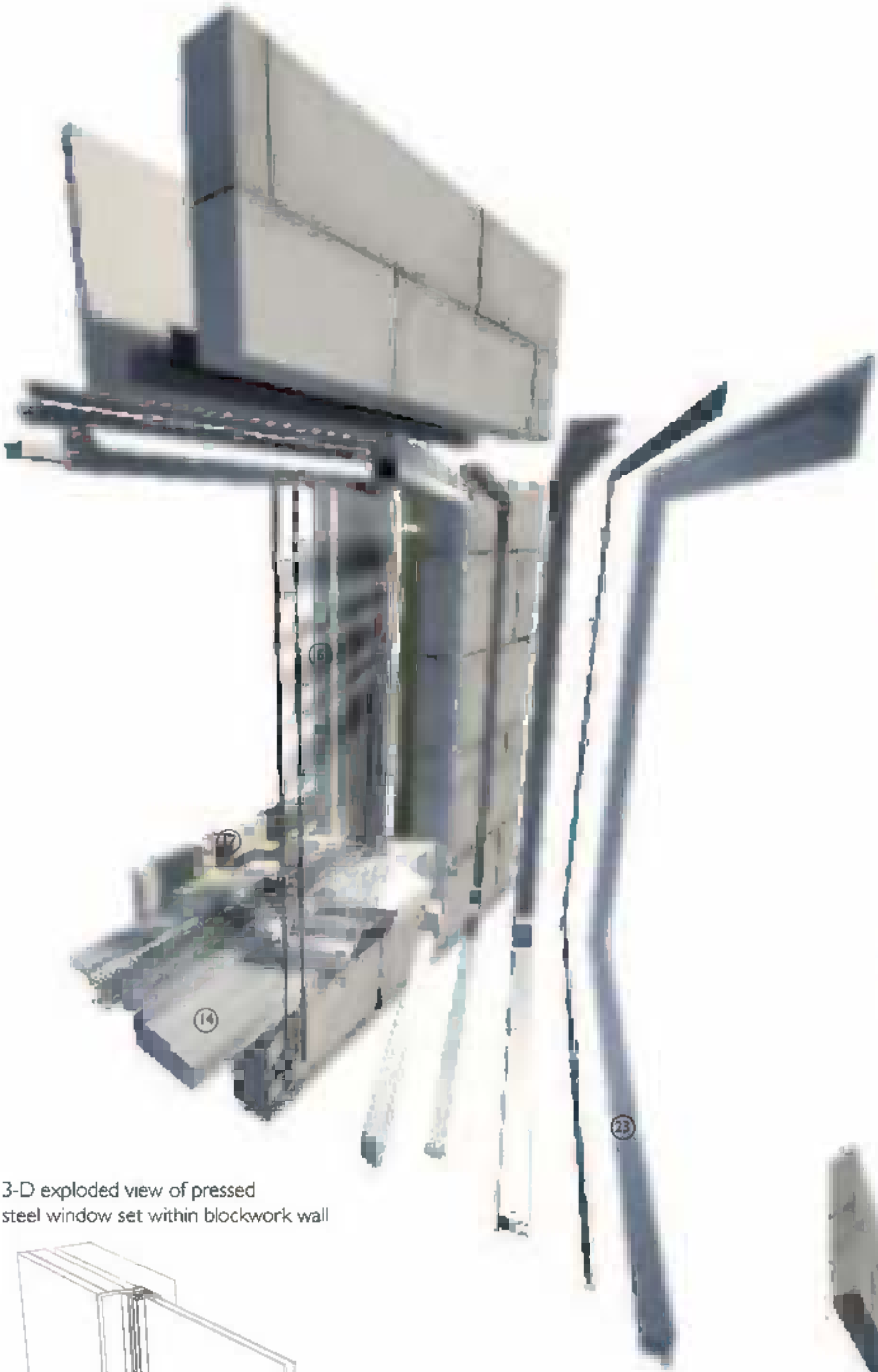
Details

1. Outside
2. Inside
3. Steel supporting structure
4. Transom
5. Mullion
6. Single glazed or double glazed unit to suit application
7. Fixing bead
8. Fixing lug
9. Projecting transom
10. Rubber-based seal
11. Fixed light
12. Inward opening light
13. Outward opening light
14. Window cill
15. Condensation tray
16. Damp proof course (DPC)
17. Internal finish
18. Drip
19. Packing
20. Aluminium clip to secure double glazed unit
21. Steel cill
22. Meeting stile
23. Pressed steel frame

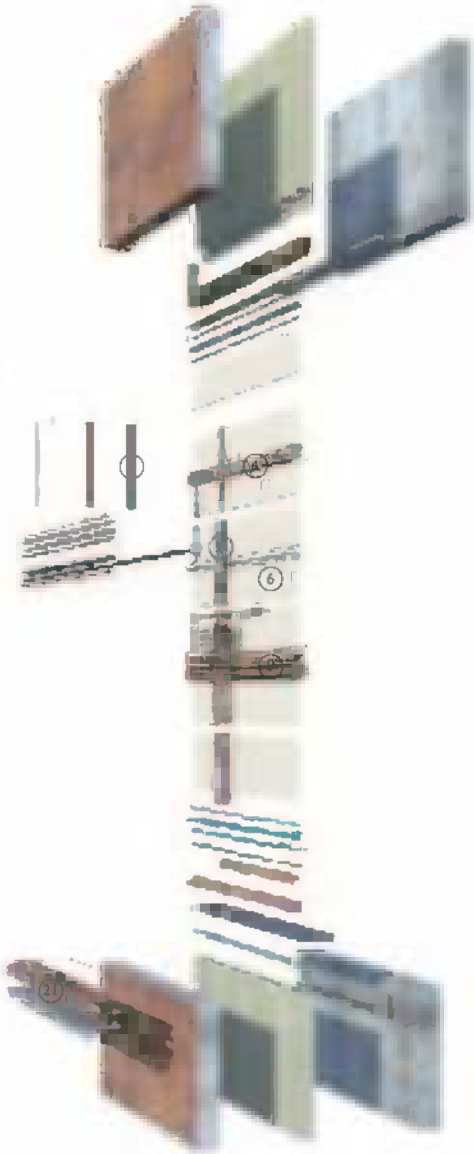
3-D exploded view of pressed steel door system assembly



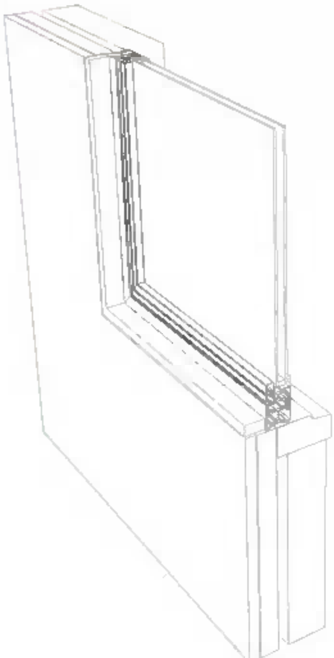
3-D sectional view of pressed steel door system assembly



3-D exploded view of pressed steel window set within blockwork wall

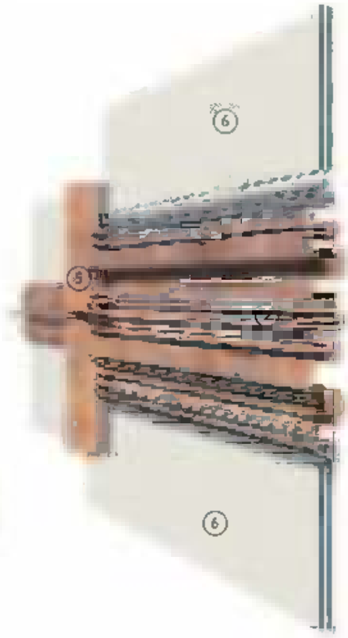


3-D exploded view of rolled steel facade

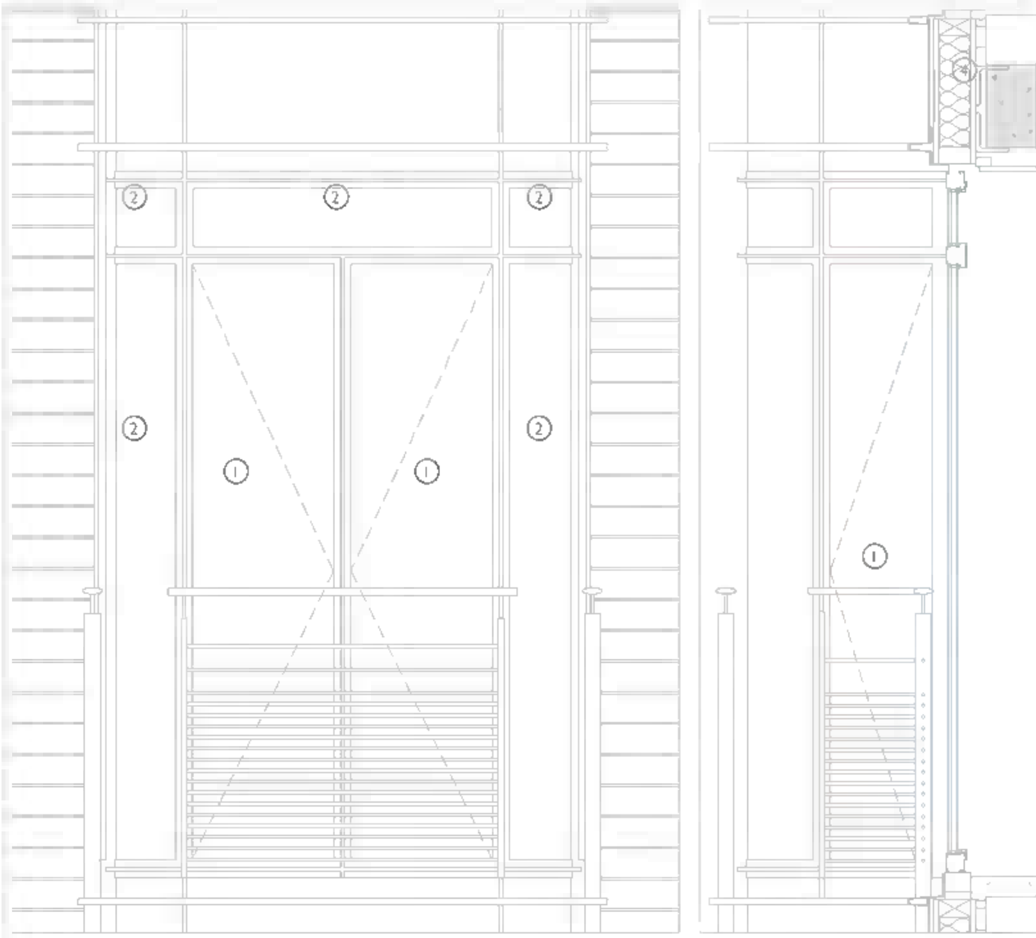


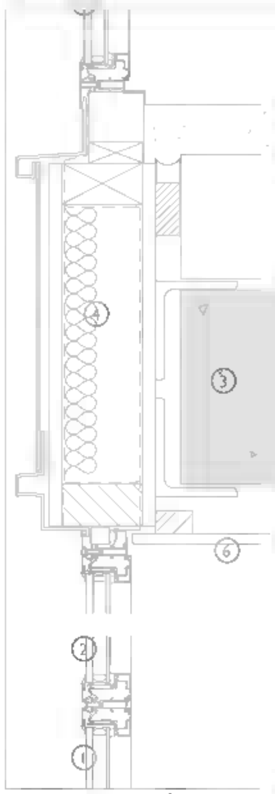
3-D view of pressed steel window detail in masonry cavity wall construction

3-D exploded view of pressed steel window set within blockwork wall

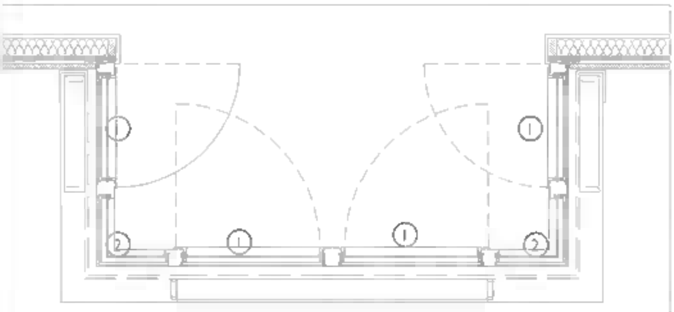


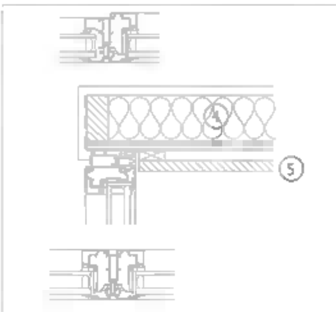
3-D exploded view of pressed steel window detail





Vertical section 1:10. Inward opening door





Vertical section 1:10. Meeting stile

Horizontal, vertical section and elevation 1:25. Inward opening aluminium doors

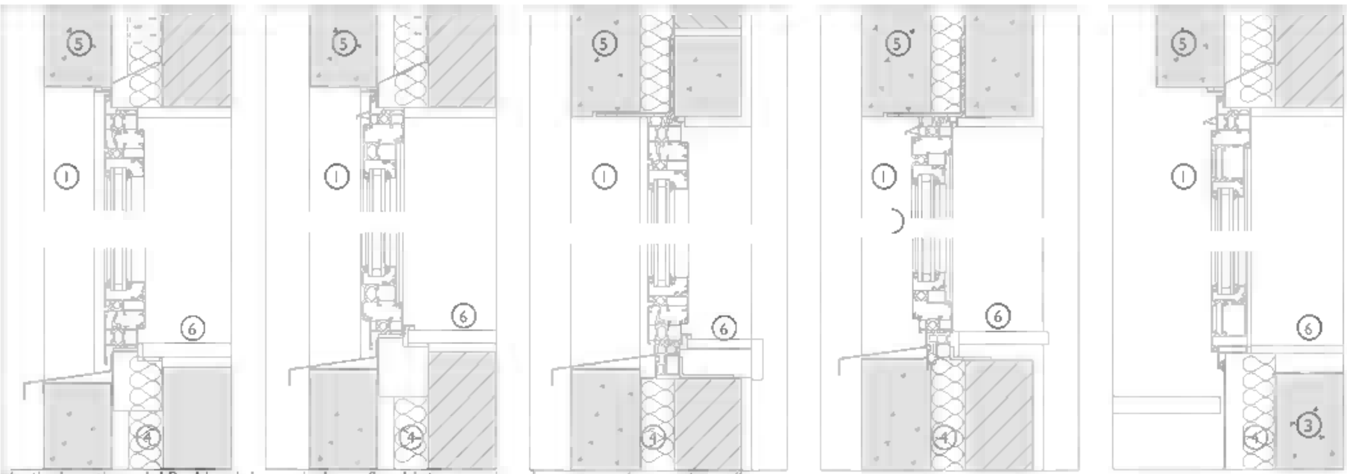
3-D view of aluminium opening doors and fixed lights

Aluminium windows are used either as individual lights set into a structural opening or as 'window walls' where windows are still set into openings, but are linked together with metal or opaque glass panels to give the appearance of a continuous glazed wall.

The essential difference between aluminium windows and aluminium glazed walls (or 'curtain walls') is that windows are set individually into structural openings, whereas curtain walling uses a continuous carrier frame fixed forward of the supporting structure. Windows are not technically inferior to curtain walling, but are a different method of glazing. Window systems are well suited to apartments, where the discontinuity of framing is preferred for acoustic reasons, avoiding flanking sound passing from apartment to apartment. 'Window walls' of windows linked by glass or metal panels is often preferred where a fire separation zone is needed between apartments, when combined with thermal and acoustic mass.

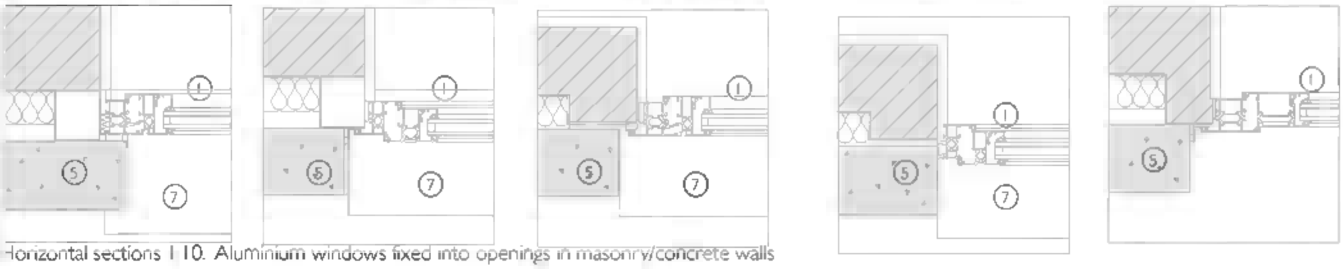
Windows in openings

When fixed into a structural opening in a wall formed in another material, aluminium windows have drips and flashings to seal against the adjacent material. Specific interface details of windows with adjacent materials are discussed elsewhere in this book, under the heading of each wall type. This section deals specifically with the issues of glazing aluminium windows and doors into any



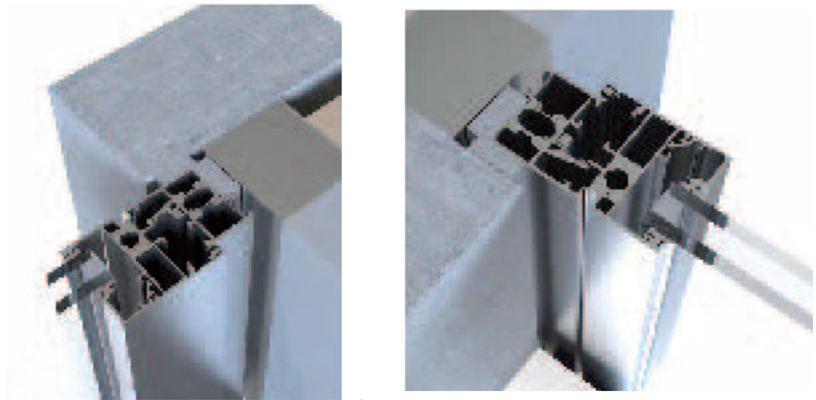
Vertical section 1:10 External opening door

ertical sections 1:10. Aluminium windows fixed into openings in masonry/concrete walls

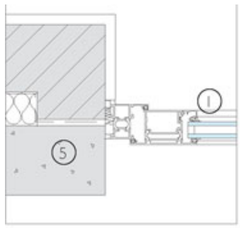


Horizontal section 1:10 Internal opening door

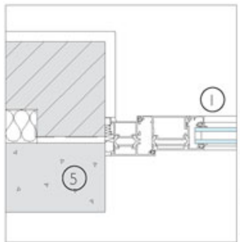
Horizontal sections 1:10. Aluminium windows fixed into openings in masonry/concrete walls



3-D views of aluminium windows fixed into openings in a concrete wall



Horizontal section 1:10. External opening door



Horizontal section 1:10. Internal opening door

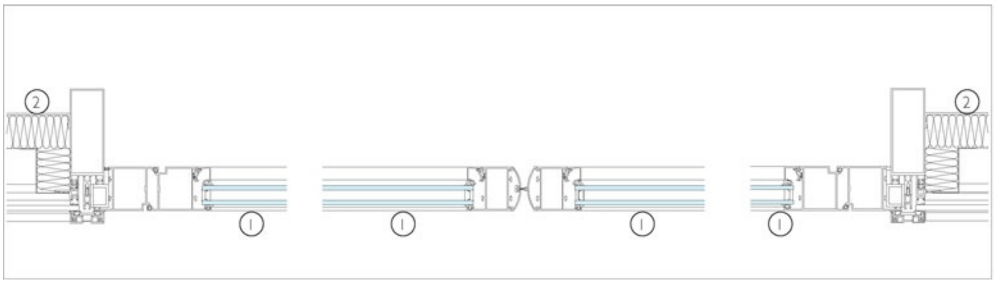
structural opening.

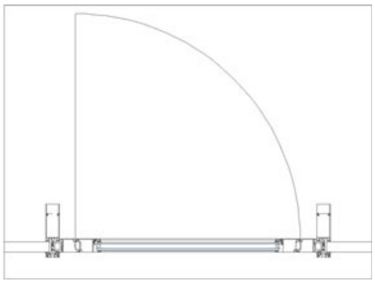
Aluminium windows and doors are often preferred for their thermal and acoustic insulation properties, together with low levels of air infiltration. They have a generally higher performance in these areas than steel or timber frames, and their durable finish gives them a consistent appearance over 20 years, depending on the type of finish used. Their main disadvantage is the wide sight lines required to accommodate smooth movement of the opening light in the frame as well as the seals and thermal breaks required. Manufacturers are ever-striving to make the sight lines thinner but this usually results in the depth of the window and door increasing substantially in order to maintain structural stability.

In common with aluminium curtain walls, aluminium windows are pressure equalised and internally drained, providing two lines of defence against rainwater ingress. The outer line of defence is provided by a rubber-based seal fixed to the window frame. Any rainwater penetrating this outer seal is drained away in a ventilated cavity within the window frame and is released back to the outside through the cill profile.

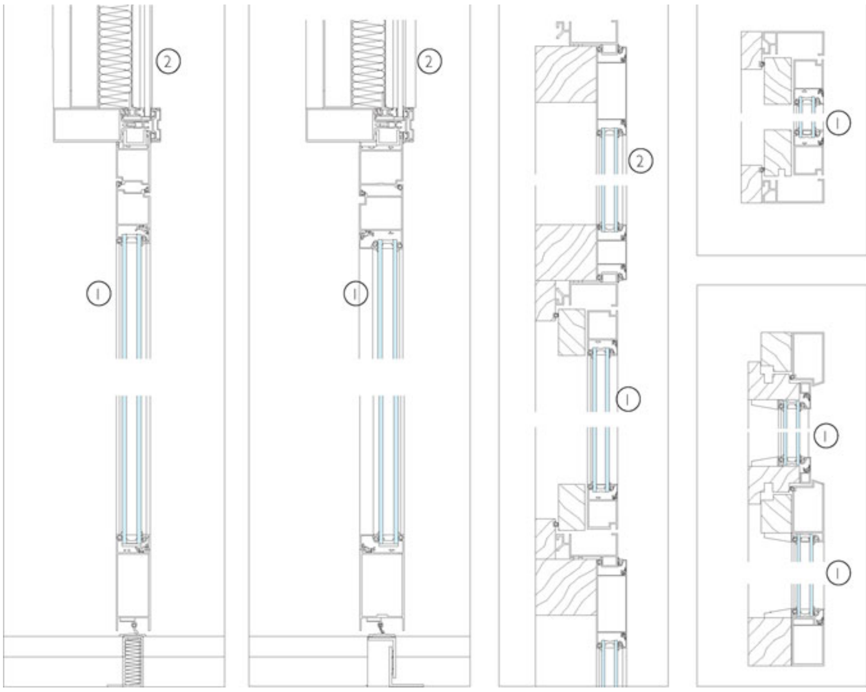
There is an increased use of 'flipper' seals within window frames to both keep any rainwater that penetrates the outer seal in a chamber at the front of the section (similar to unitised curtain walling) and to provide a thermal break in the void within the window

Details
1. Opening door or window
2. Fixed light
3. Floor slab
4. Thermal insulation
5. Surrounding wall
6. Internal finishes
7. Window cill



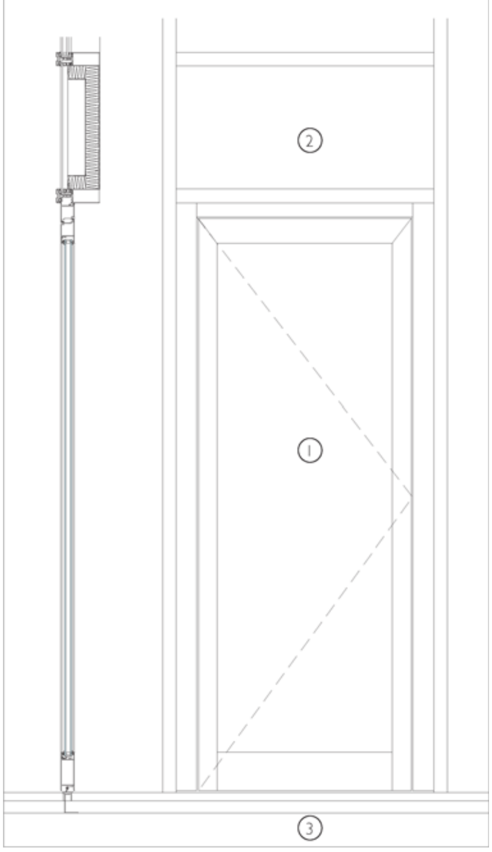


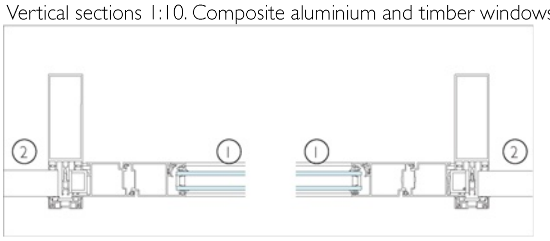
Plan. 1:10



Vertical sections 1:10. Composite aluminium and timber windows

Horizontal section and elevation 1:25.
Door fixed into a stick curtain wall system





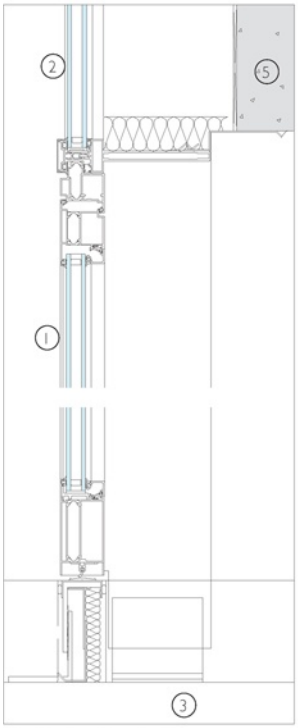
Horizontal section 1:25. Door fitted into a stick curtain wall system

3-D view of window fitted in to unitised glazing

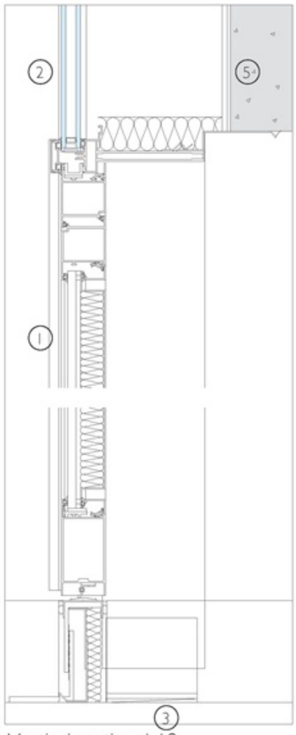
frame. This prevents air temperature and humidity levels in the outer chamber from passing all the way through the void in the frame and reaching the inner seal. The inner seal is then used only as an air seal rather than a full weathertight seal. This method is similar to that used in unitised curtain walling, where two air chambers are used at the joint between panels. There has been an increased use in recent years of thermal breaks in both the frame and the opening light in aluminium windows. The breaks are positioned to coincide with the rubber-based flipper seal to reduce the thermal bridge across the complete window section.

Aluminium frames for doors and windows differ substantially in that window frames are narrower but deeper than doors in order to provide much lower levels of air and water infiltration. Door frames are generally wider so as to provide stability for the infill panel of glass but are not usually thermally broken in order to provide a rigid frame to support the infill glass. Window frames are often used for doors where these lower levels of air and water infiltration are required, as in doors to balconies in apartments, for example. Doors using door profiles can reach 3.0 to 3.5 metres in height without wide sight lines whereas this is not the case for doors using window frame profiles which can reach a maximum of around 2.4 metres high (2400mm). Above this height, it is difficult to use the frame to support the glass. For doors exceeding 2.4 metres in height using window sections, it is visually

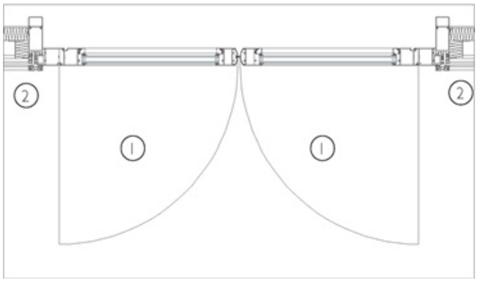
3-D view of alumnium window



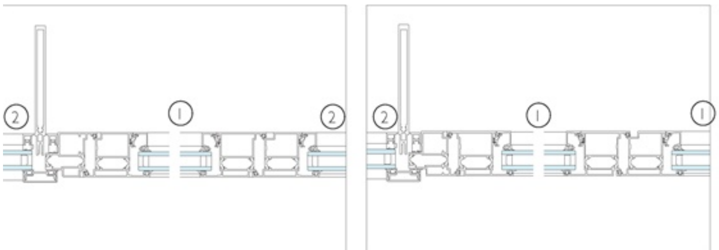
Vertical section 1:10.
Outward opening thermally broken door. Fixed into stick curtain walling



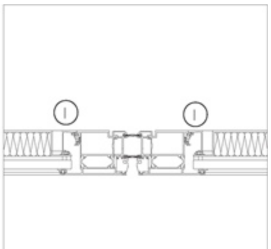
Vertical section 1:10.
Inward opening door with no thermal break. Fixed into stick curtain walling



Horizontal section 1:25. Aluminium doors fixed into a stick curtain wall system



Horizontal section 1:10. Junctions between fixed light and opening door and window



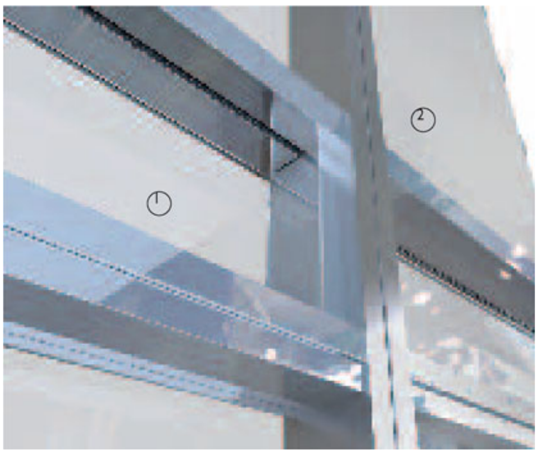
Meeting stile 1:10

Details

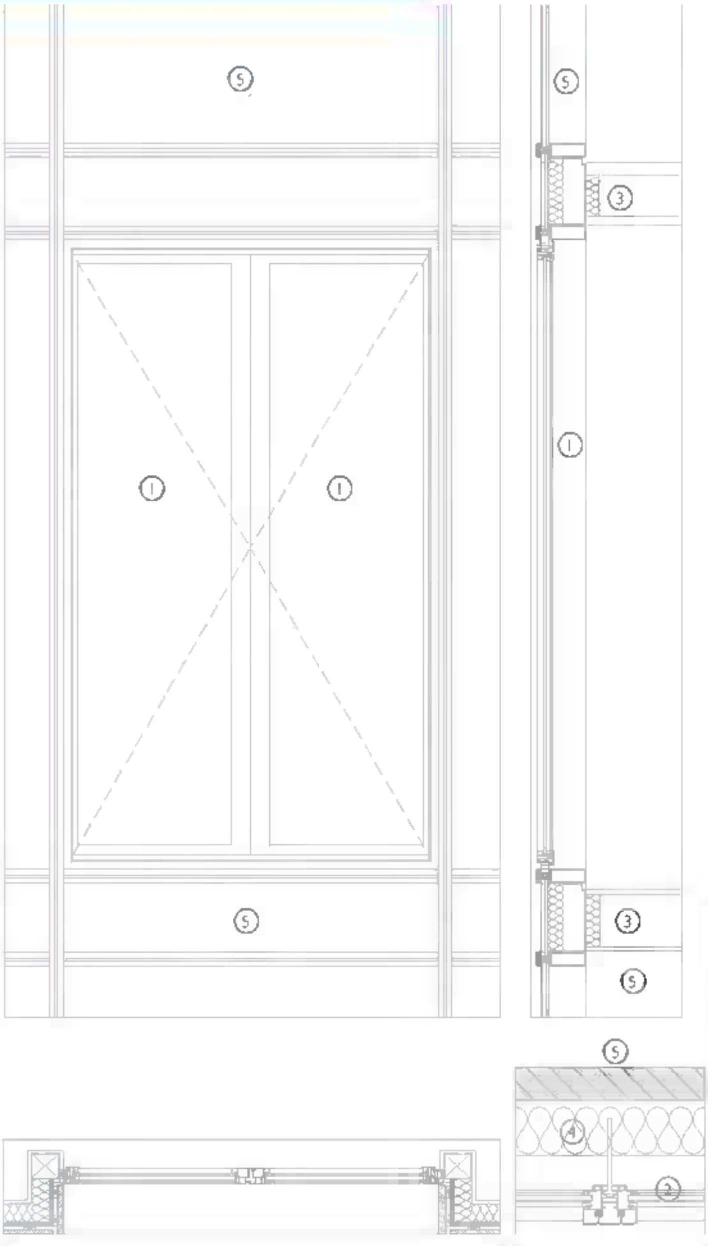
1. Opening door or window
2. Fixed light
3. Floor slab
4. Thermal insulation
5. Surrounding wall
6. Internal finishes
7. Window cill

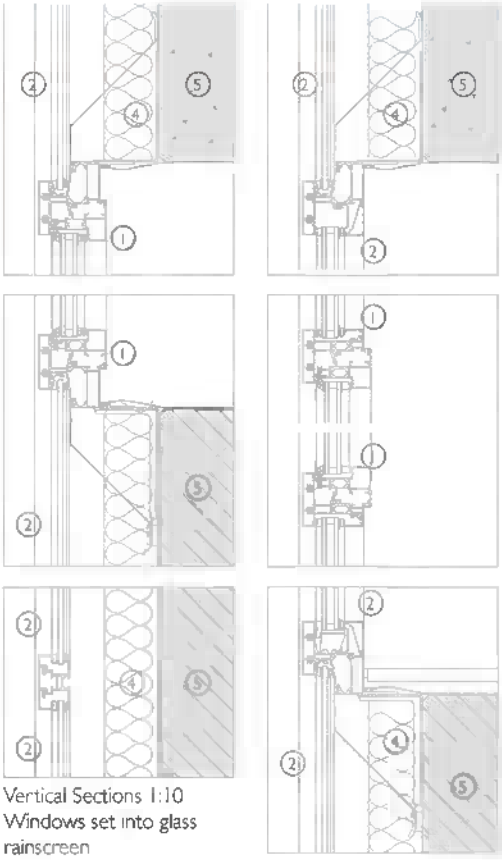
necessary to silicone bond the frame to the glass so that the frame and glass become a single structural component. The glass is then used to stiffen the frame rather than being a non-structural infill panel within the frame. This is more expensive and also difficult to replace the glass if broken without replacing the complete frame. If the frame is replaced then the colour of the replacement door may not match the surrounding framing. Maximum widths of aluminium glazed doors are a function of the height, in order to restrict the overall weight of the door leaf, but 850mm wide doors (for a 1700mm wide pair of doors) are common. The minimum width of the opening door is about 250mm to 300mm depending on door height and width. The minimum dimension is determined both by the minimum manufacturable size of double glazed unit and by the need to open the light smoothly.

Top hung lights, often set above fixed aluminium windows and opening doors to provide night time natural ventilation, have a minimum height of about 800mm to 900mm in order to accommodate the opening mechanism. Fixed lights above doors can be reduced to a height of around 200mm. Top hung, bottom hung and tilt/turn windows use similar sections to side hung windows. Tilt/turn windows have the advantage of combining the functions of side hung windows with their ability to open completely, and the ability of bottom hung windows to provide high level natural ventilation has led to their increased use.

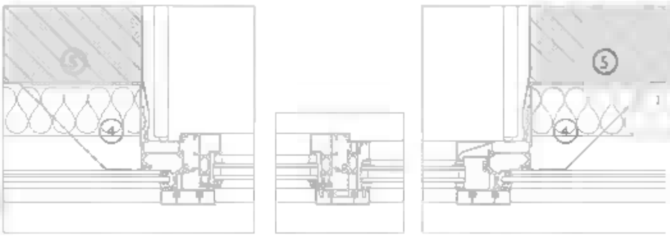


3-D view of alumnium window





Vertical Sections 1:10
Windows set into glass rainscreen

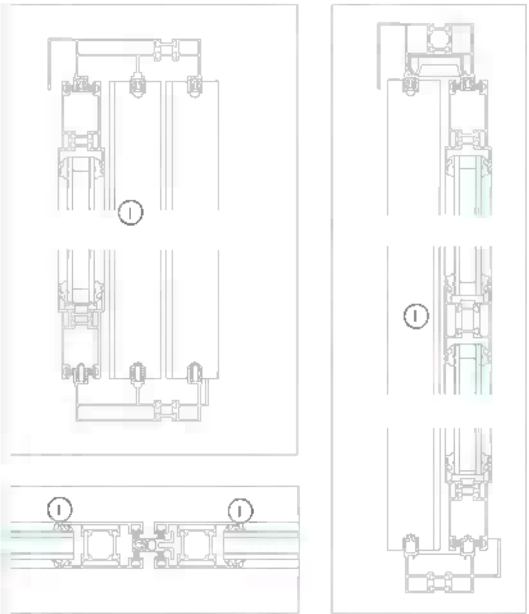


Horizontal section 1:10. Windows set into a glazed rainscreen

Horizontal & vertical section 1:25.
Aluminium windows set into a glazed rainscreeen

3-D view of top hung aluminium window

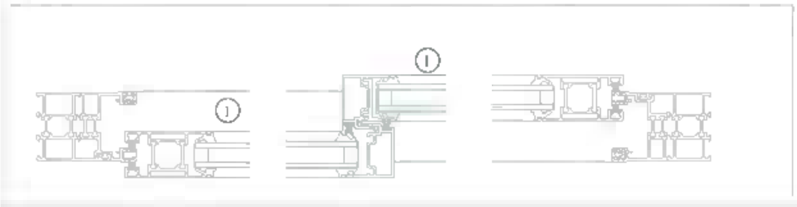
3D view of side hung aluminium window

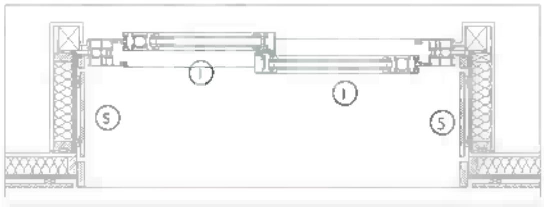


Horizontal & vertical section 1:10.
Aluminium windows set into masonry openings

Details

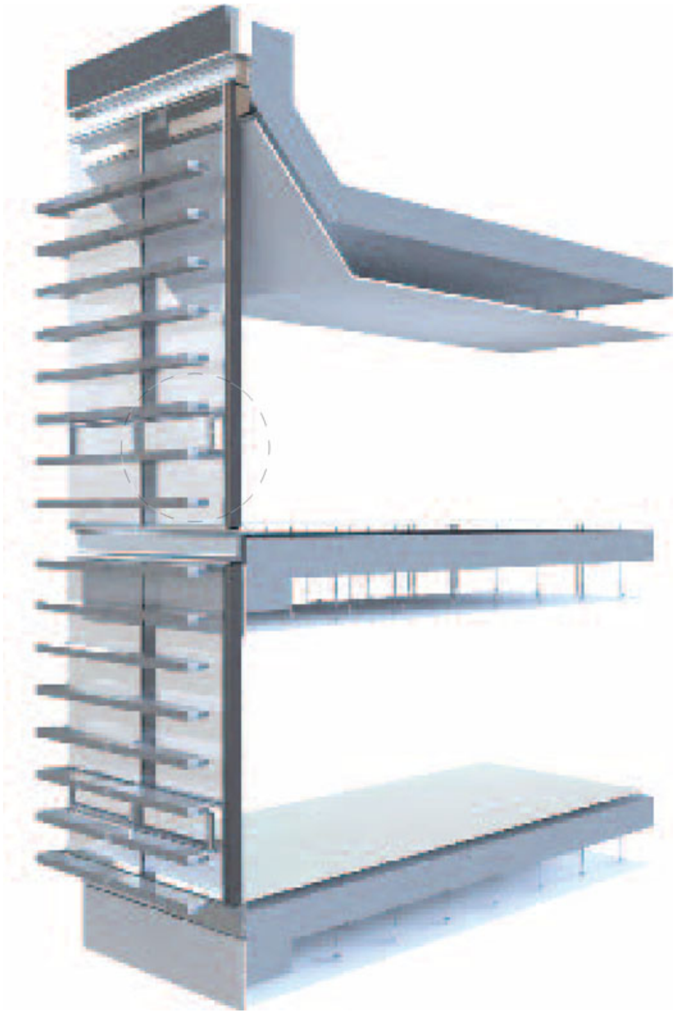
1. Opening door or window
2. Fixed light
3. Floor slab
4. Thermal insulation
5. Surrounding wall
6. Internal finishes
7. Window cill





Sliding doors are usually top hung, sliding on rollers set at the door head. The bottom of the door is restrained by guides that both hold the door in place and allow it to move without being obstructed by dirt and grit accumulating in the bottom of the cill profile. Bottom rolling doors, which are supported on the cill profile and are restrained at their head, are much less commonly used for external doors since dirt and grit can hinder their movement. There are two types of sliding door: those that roll in a constant plane and those which lift out and then slide. The first type has higher levels of air infiltration associated with side hung door profiles. The second type has much lower levels of air infiltration but has wider sections, creating wider sight lines.

When aluminium windows are glazed into a structural opening, the joint between window and adjacent wall is made either with a sealant, such as silicone, or with an EPDM foil glazed into the window frame and sealed against the face of the surrounding wall. The choice of seal is dependent upon the material used in the surrounding wall, but silicone seals are generally used where the adjacent wall is of sealed construction, such as an open jointed wall, sheet metal or render on concrete. EPDM foil is used where the adjacent wall has an open jointed finish in front of the structural wall, as in rainscreen construction, in metal or stone, for example. The EPDM foil is sealed against the waterproof backing wall used in this type of construction. This method makes it necessary to fix the windows and seal them to the backing wall before the external cladding is fixed. This is often an advantage, where aluminium windows and backing walls provide a weathertight enclosure at an earlier stage than would be achieved with more traditional methods where the windows are glazed in afterwards. The early date for weathertight enclosure allows construction work internally to commence at the same time as the external cladding is being installed. Forming a seal with sealant, with silicone or a polysulphide for example, rather than EPDM, allows the window to be installed afterwards. Since the joints are visible, and are formed with a tool



3-D view of aluminium window as part of a unitised glazing system

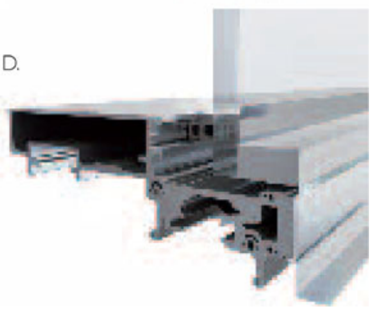
3-D view of aluminium window as part of a unitised glazing system

3-D detail view of aluminium glazing

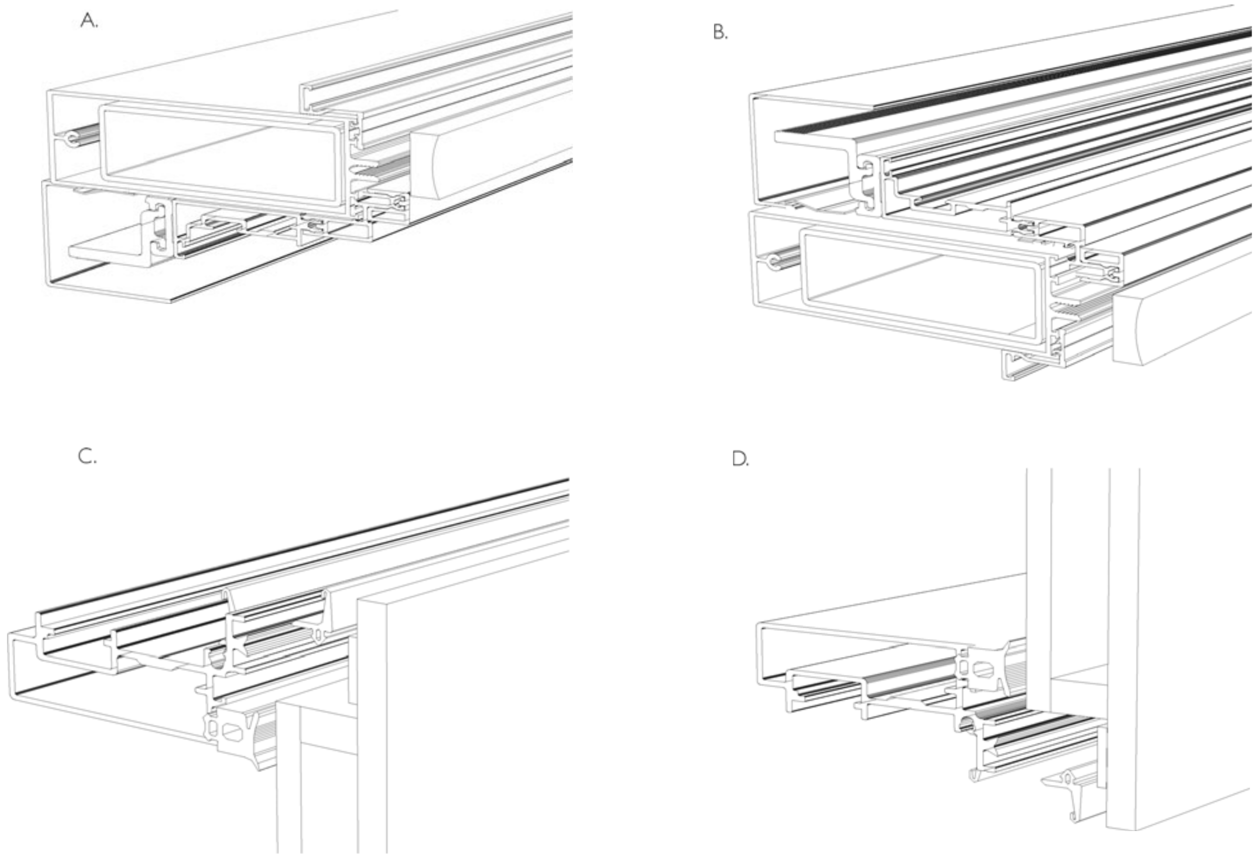
3-D views of frame details

B.

D.



Details
1. Opening door or window
2. Fixed light
3. Floor slab
4. Thermal insulation
5. Surrounding wall
6. Internal finishes
7. Window cill



from outside, care should be taken to choose a colour which is compatible with both the window and the adjacent construction.

Window walls

This system is particularly useful where a discontinuity is required, usually for fire or acoustic reasons, while maintaining an overall modular facade. They are usually less expensive than glazed curtain walling. The opaque areas are usually filled with either an aluminium sheet (coated to match the colour of the adjacent window frames) or with opacified glass. These infill panels are supported by the window frames and do not have a support frame behind as would be used in curtain walling systems.

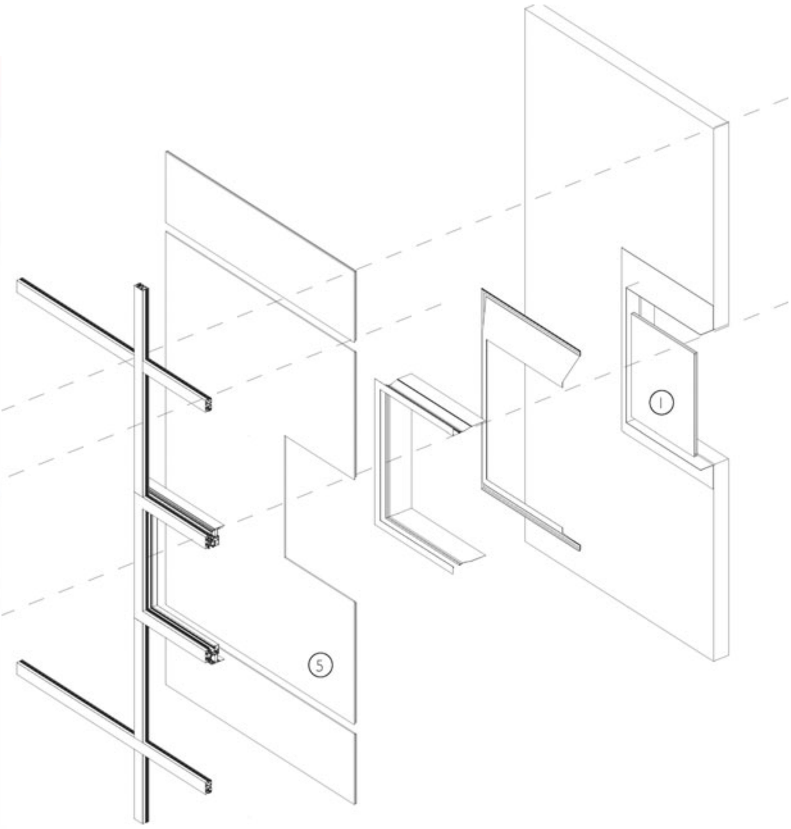
In a window wall, the aluminium profile visible from outside is adapted to give the same appearance as the junction between opaque spandrel panels. This gives the external framing an overall consistent appearance associated with other modular glazed wall types. Windows are supported either directly onto a floor slab or concrete/ block upstand, or alternatively are set forward of them on brackets. If the window is sitting on a support, then the opaque panel adjacent to it is usually set forward of the window in order to accommodate its thermal insulation. When the window is set forward of the opening, then the glazing in the aluminium window can be aligned with the opaque glazing. This glazing type is commonly used with both ribbon windows and rows of individual windows.

An advantage of window walling is that the opaque spandrel panels can be made in a different form of construction from the windows. Insulated composite panels can be used for example as metal rainscreen panels, or open jointed opaque glazing. This can make the system very economic when compared to curtain walling. If the spandrel panels are not set into a framing system that is internally drained and ventilated like the windows, then the void behind the opaque panels must be drained at the head of the window below. In addition, the thermal insulation behind the spandrel panel forms a continuity with the double glazed unit of the window.

Composite windows

A recent development has been in the use of aluminium windows with an inner frame in timber to support the outer aluminium profile. This is effectively an aluminium window wall with a timber carrier frame. From the interior, the framing has an all-wood appearance. However, the glazing sections used are those from windows rather than curtain walling. Some manufacturers make windows with timber frames behind them to form a timber framed unitised system. The outer joint is an open jointed rainscreen. This protects the inner seals between timber frames from the worst effects of windblown rain. The timber frames are screwed or bolted together. The complete carrier frame is fixed back to floor slabs with steel or aluminium brackets in the manner of glazed curtain walling. These brackets are described in the section on stick glazing and unitised glazing.

3-D exploded view of wall with aluminium window



Exploded axonometric view of wall with aluminium window

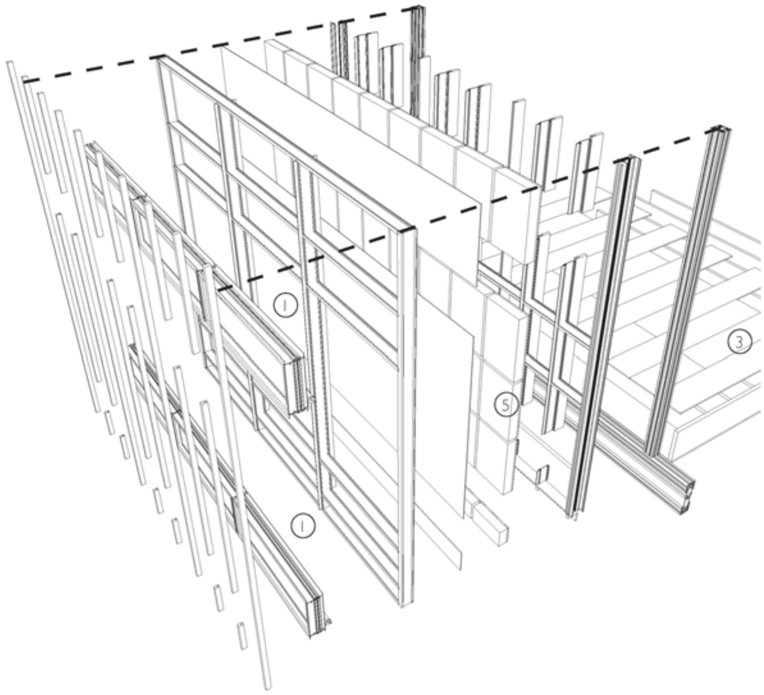
3-D view of top hung aluminium window open

3-D frame detail of top hung aluminium window open

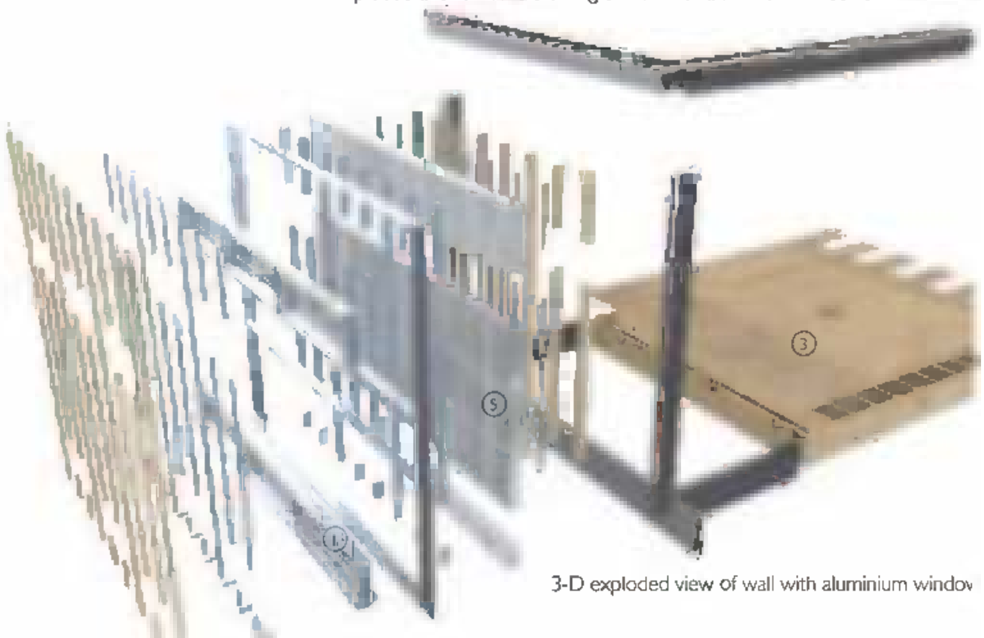
3-D view of side hung aluminium window open

3-D detail of side hung aluminium window frame open

3-D view of wall with aluminium windows

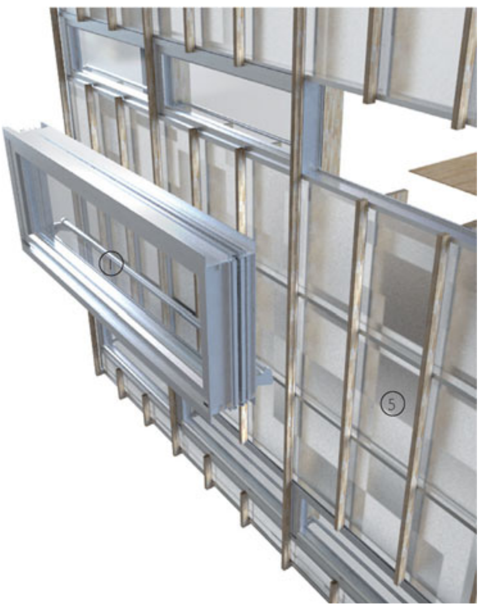


Exploded axonometric drawing of wall with aluminium windows



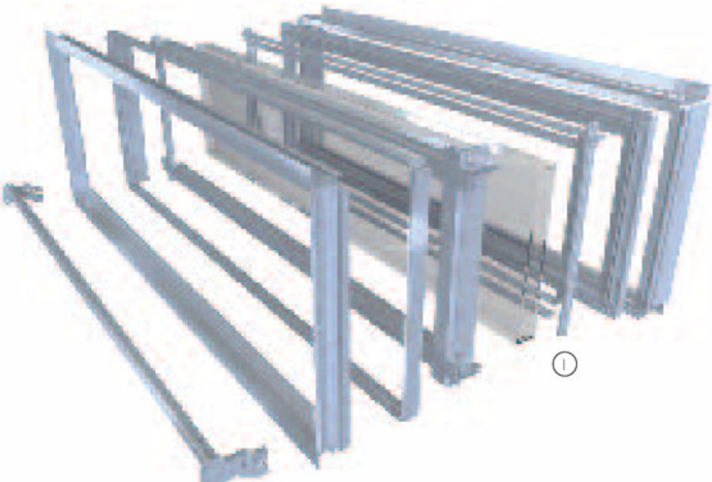
Details
- Opening door or window
- Fixed light
- Floor slab
- Thermal insulation
- Surrounding wall
- Internal finishes
- Window cill

3-D exploded view of wall with aluminium window

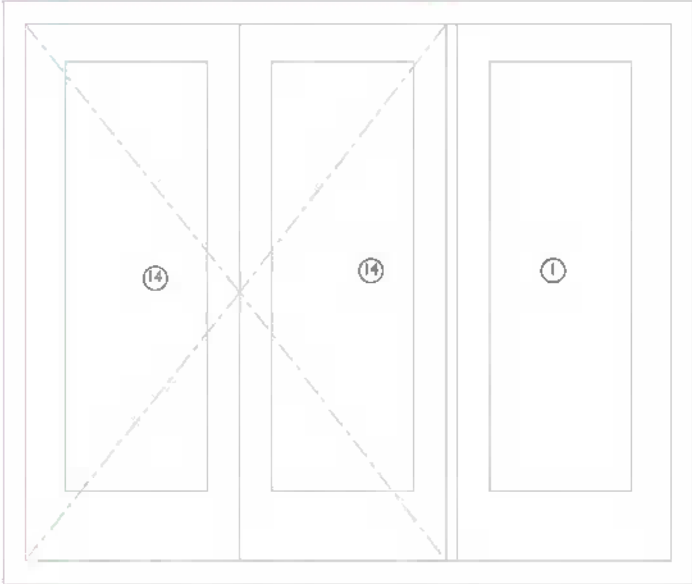


3-D view of aluminium window exploded from wall

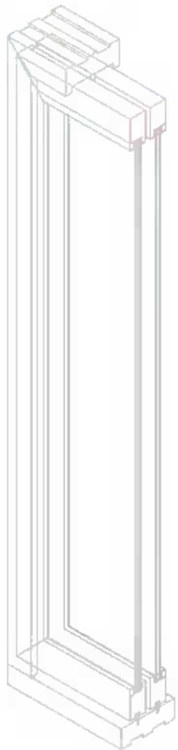
3-D view of aluminium window

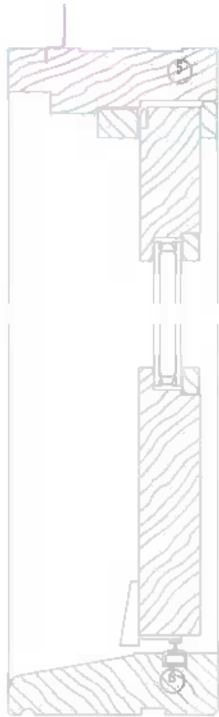


3-D exploded view of aluminium window

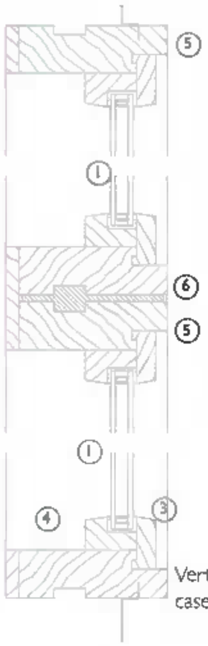


Elevation 1:25. Opening casement doors with fixed sidelight

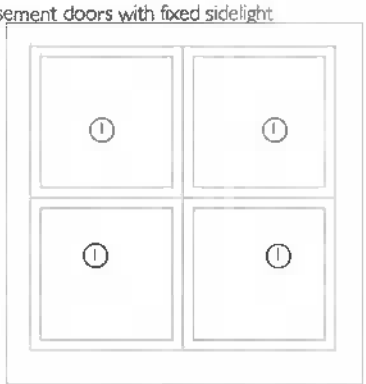




Vertical section 1:5. Inward opening casement doors

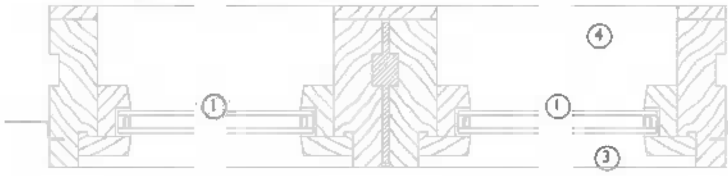


Vertical section 1:5. Fixed casement window

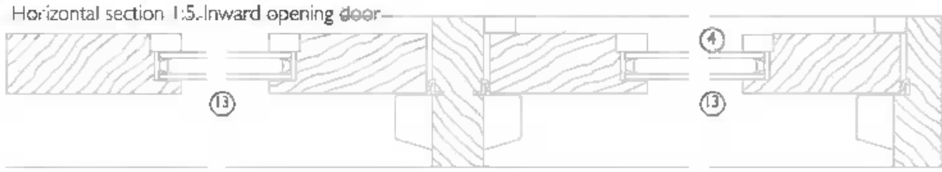


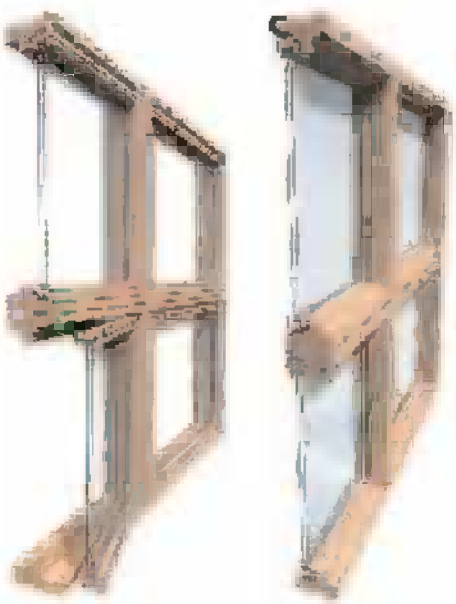
Elevation 1:25. Fixed casement window

Horizontal section 1:5 Fixed casement window



Horizontal section 1:5. Inward opening door



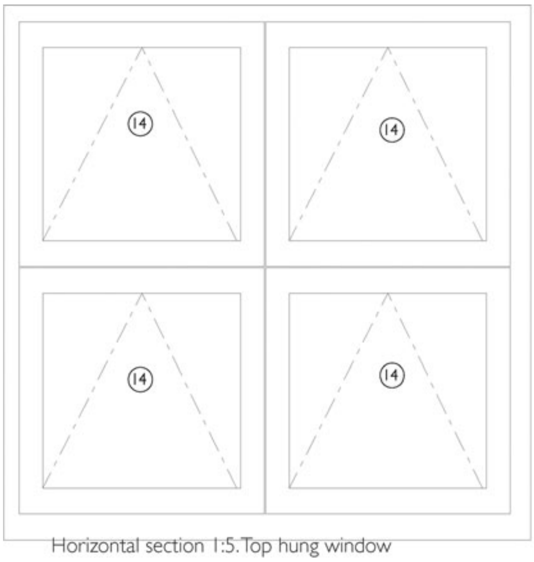


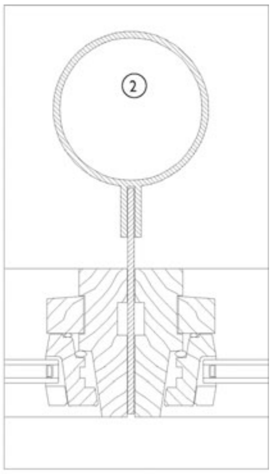
3-D views showing side hung and fixed light windows

Like aluminium windows, timber windows are used either as individual components or as assemblies of 'window walls' of opening windows and fixed lights which are linked together.

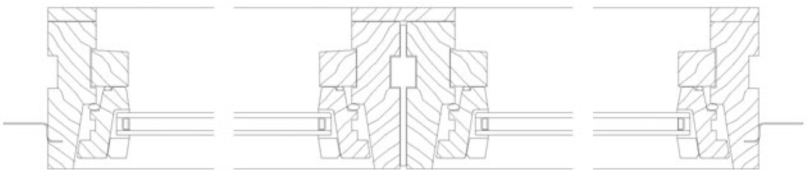
Window walls

These are formed either as individual windows linked together and reinforced by a secondary frame, usually steel flats, or are formed as full curtain walling systems. Where timber sections form the full structural support for the glazing, the glazing is secured with timber glazing beads. Where individual windows are linked together with steel reinforcement, additional support may be needed from a secondary structure. Steel tubes, T-sections or box sections are typically used to avoid much larger equivalent sections in timber. In common with other framed glazing systems, timber windows are required to be held in a rigid frame, with only small structural deflections allowed under wind load. For this reason, cable-assisted structures are seldom used, since they are associated with higher deflections than framed supporting structures. These reinforcements or additional supports are usually set inside the building to avoid penetrating the exterior seal of the timber frames. Whereas aluminium glazing systems can accommodate support brackets penetrating the outer seals with rubber-based gaskets and silicone seals, the high moisture movement associated with wood makes this much less practical with timber windows.



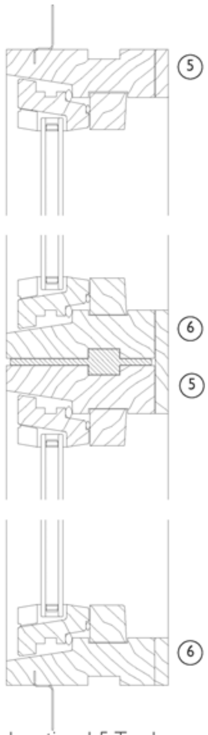


Horizontal section 1:5. Top hung window

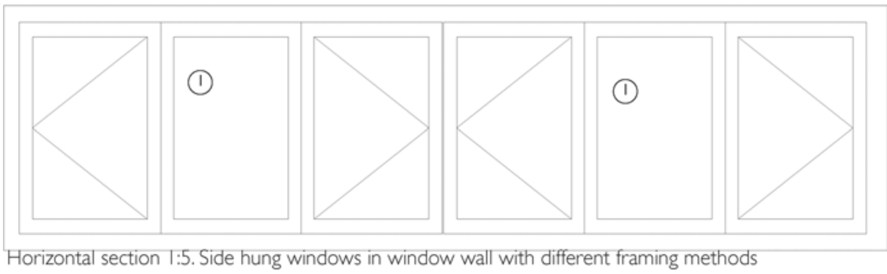


Elevation 1:25. Side hung window

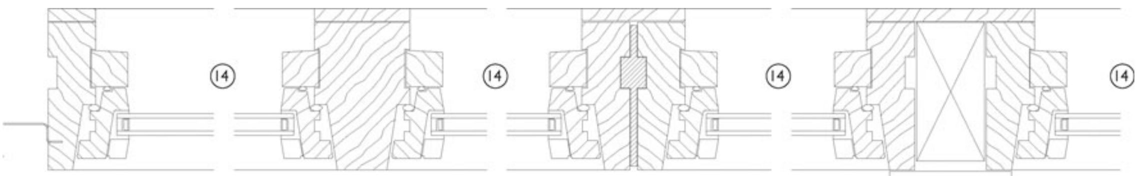
Details
1. Fixed light
2. Supporting structure
3. Outside
4. Inside
5. Head
6. Cill
7. Metal stiffening insert
8. Timber infill panel
9. Thermal insulation
10. Single glazed or double glazed unit to suit application
11. Fixing bead
12. Rubber-based seal
13. Inward opening light
14. Outward opening light
15. Damp proof course (DPC)
16. Internal finish
17. Flashing to seal against adjacent wall
18. Vertically sliding sash
19. Sliding door frame top hung or bottom rolling
20. Window or door jamb

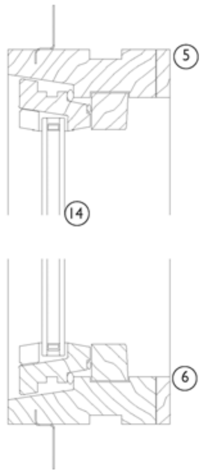


Vertical section 1:5. Top hung window



Horizontal section 1:5. Side hung windows in window wall with different framing methods

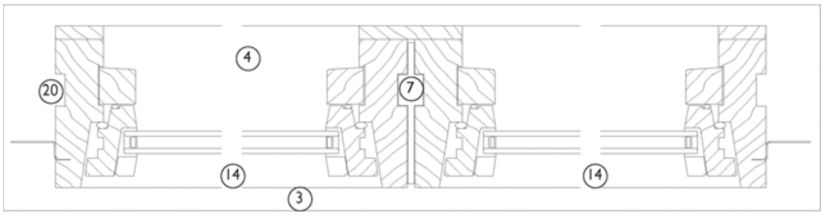




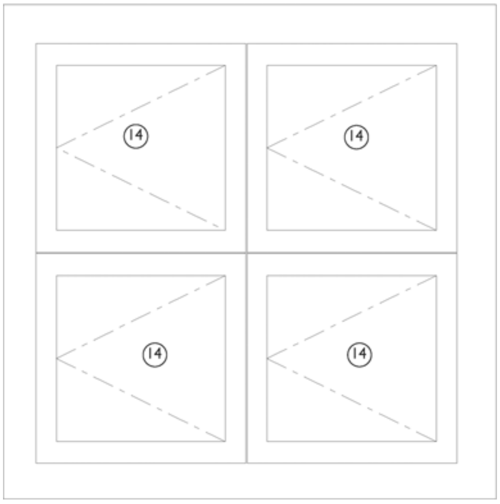
Where windows are linked together and reinforced with a mild steel flat, a drainage groove is cut into the outside of the frame as part of a standard window frame. Any water that passes through the outer seal is drained away in the groove which is used on all four sides of a typical frame. Water is drained away to the outside at the cill. The reinforcement does not extend forward of the drainage groove to allow water to be drained away unimpeded. All-timber frames, in the manner of glazed curtain walling, may have mullions and transoms of different depths, reflecting their different structural requirements, and each may be in a different wood type. Hardwoods and softwoods can be mixed, but moisture movement needs to be taken into account. An advantage of solid timber sections over aluminium extrusions is the ability of timber to be routed to form a variety of junctions between mullion (vertical) and transom (horizontal). Slots and continuous grooves can be cut into the sections to give them a visual richness that is often lacking in metal glazed walls. Support brackets fixed to the inside face are formed in aluminium or mild steel.

Timber framed window walls typically span up to two floors, due to the self weight of the panels. This is due to the need to bind the frame into large single units to avoid the effects of thermal movement from shrinking of the sections. If timber sections are not tied together, they tend to warp and twist when exposed to outside elements. Even if the surfaces are painted or sealed with varnish, any

3-D view showing side hung window

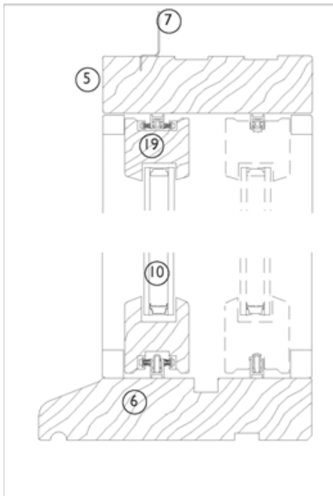


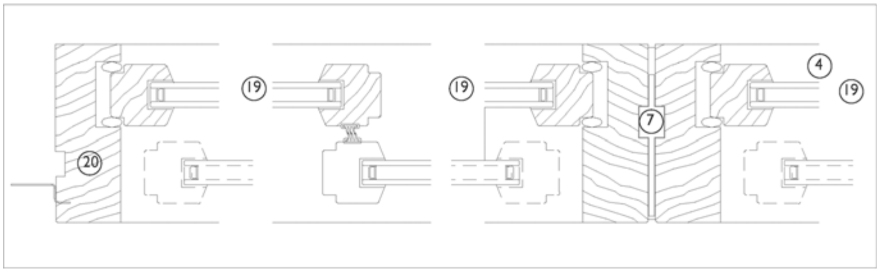
Horizontal section 1:5. Side hung window



Elevation 1:25. Side hung windows

Elevation 1:25. Horizontal sliding window





Horizontal section 1:5. Horizontal sliding window

Vertical section 1:5. Sliding window

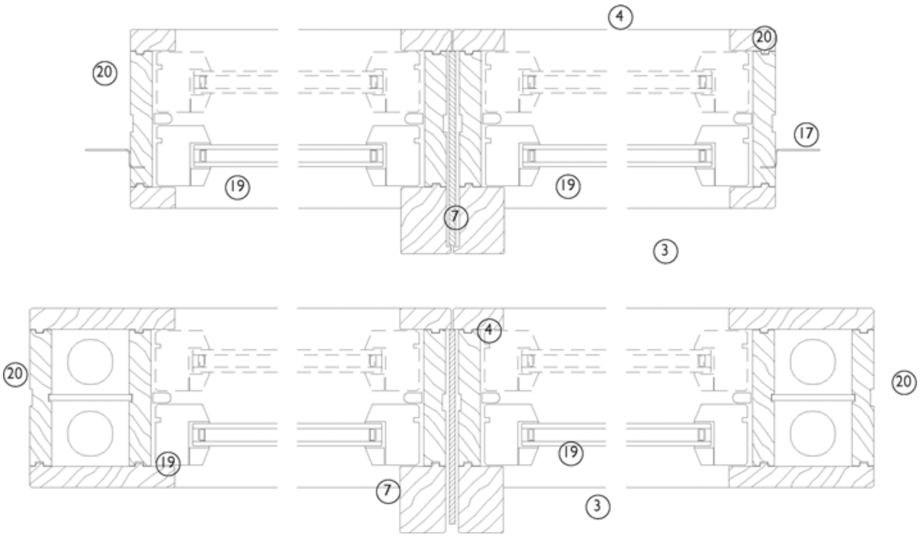
movement due to moisture will crack the outer finish and allow further movement to occur. Timber sections are jointed with either tongue-and-groove or rebated joints. Where tongue-and-groove joints are used, the linking material can be a durable hardwood or aluminium. Sections can also be bolted together if the sections are of sufficient size, such as around 75 x 50mm (3in x 2in).

Glazed walls can be joined relatively easily to adjacent wall construction with seals and lapped edges associated with traditional windows. Corners are straightforward to form as either a structural corner or as a fully glazed corner. Structural corners have two glazing sections brought together, which are reinforced with an additional corner post. This post is set into routed grooves in the edges of the two window frames to provide additional stiffness at the corner, binding the three timber sections into a single structural component.

Window design

Windows in recent years have developed by providing better airtight and better watertight barriers in their design. Air infiltration in opening lights has been reduced, when the window is closed by the addition of rubber-based seals, often held in place by aluminium clips so that they can be replaced when worn-out. Watertightness of opening lights has been improved by the use of pressure equalised rebates in the window section so that any water entering the profiles at the sides is drained away from an outer cavity without being drawn into the inner seal by capillary action (pressure differential)

3-D section through side hung window details showing different framing methods



Horizontal sections 1:5. Sliding sash window

between inside and outside the framing.

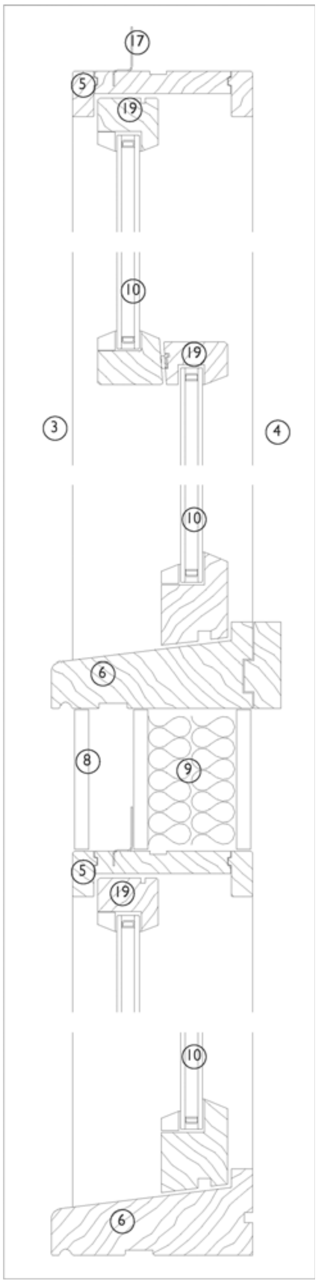
An outer seal prevents excessive water infiltration while the inner air seal also serves as an acoustic barrier, providing better sound insulation than traditional windows without those seals. The inner rubber-based air seal is usually 'vulcanised' or fused at the corners of the frame to maintain performance around the complete perimeter of the window. The drainage groove or channel around the frame of opening lights sometimes has an aluminium profile attached to allow the timber profile to be simpler. Holes are drilled into the aluminium profile at cill level to allow water to drain to the outside of the frame. This metal profile is painted to reduce the visibility when the window is open.

Seals between the window and the opening into which the window is fixed have also been improved by the use of folded aluminium and UPVC profiles. These profiles are set fixed on all edges of the window by setting them into a groove in the window frame and projecting them over the face of the surrounding wall. This makes the sealing of the gap between window and surrounding wall much easier by avoiding the need to seal the butt joint created by setting the window directly into the opening. This projecting profile is more reliable than the traditional weather bar used in the cill with sealed butt joints on the jambs and head.

There has been an increased control of moisture movement of the timber used. When timber is kiln-dried to reduce its water content prior to manufacture, the process is now better controlled to avoid excessive shrinkage afterwards. Timbers are dried to

Details

1. Fixed light
2. Supporting structure
3. Outside
4. Inside
5. Head
6. Cill
7. Metal stiffening insert
8. Timber infill panel
9. Thermal insulation
10. Single glazed or double glazed unit to suit application
11. Fixing bead
12. Rubber-based seal
13. Inward opening light
14. Outward opening light
15. Damp proof course (DPC)
16. Internal finish
17. Flashing to seal against adjacent wall
18. Vertically sliding sash
19. Sliding door frame top hung or bottom rolling
20. Sliding window or door jamb



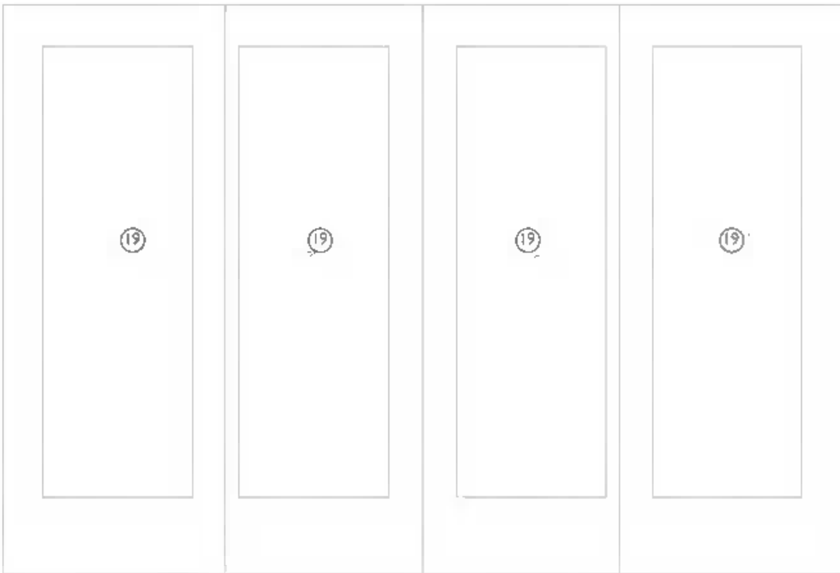
Vertical section 1:5. Vertical sliding sash window

3-D view of vertical sliding sash window

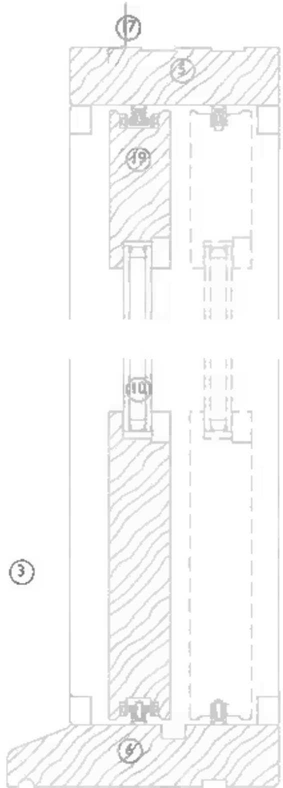
Details
1. Fixed light
2. Supporting structure
3. Outside
4. Inside
5. Head
6. Cill
7. Metal stiffening insert
8. Timber infill panel
9. Thermal insulation
10. Single glazed or double glazed unit to suit application
11. Fixing bead
12. Rubber-based seal
13. Inward opening light
14. Outward opening light
15. Damp proof course (DPC)
16. Internal finish
17. Flashing to seal against adjacent wall
18. Vertically sliding sash
19. Sliding door frame top hung or bottom rolling
20. Window or door jamb

around 15% moisture content, depending on the species used. Treatments to timbers are also changing to avoid toxic runoff while providing some protection against colour fading from UV radiation from sunlight. Timber still requires re-coating and cleaning to avoid the surface visually fading and causing damage to the timber itself. Some more economic timber windows have traditionally suffered from poor jointing at the corners of the frame. These have been improved across all window types in recent years with the use of double mortice and tenon joints and wood glues with better resistance to heat and moisture.

With the improvement in protective coatings for timber windows, particularly those on the outside face, has come the use of rounded edges to profiles. As is the case with coatings to aluminium profiles, it is very difficult to coat the edge of a sharp corner. A radiused edge allows the protective coating to maintain a better constant thickness at the vulnerable corners. Typically, rounded edges allow an 80% layer thickness of coating (with 100% on adjacent flat surfaces) compared with around 5% coating thickness for a sharp angle. With the increased use of double glazed units in timber windows, rubber-based gaskets are also increasingly being used to allow the moisture movement of the window frame and timber glazing beads to move without reducing the water tightness of the seal between the frame and double glazed unit. Soft seals, including those made from wet-applied silicone, or silicone extrusions, perform much better in this respect than the

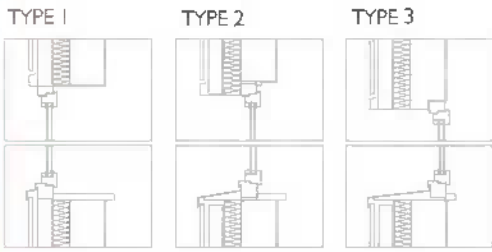


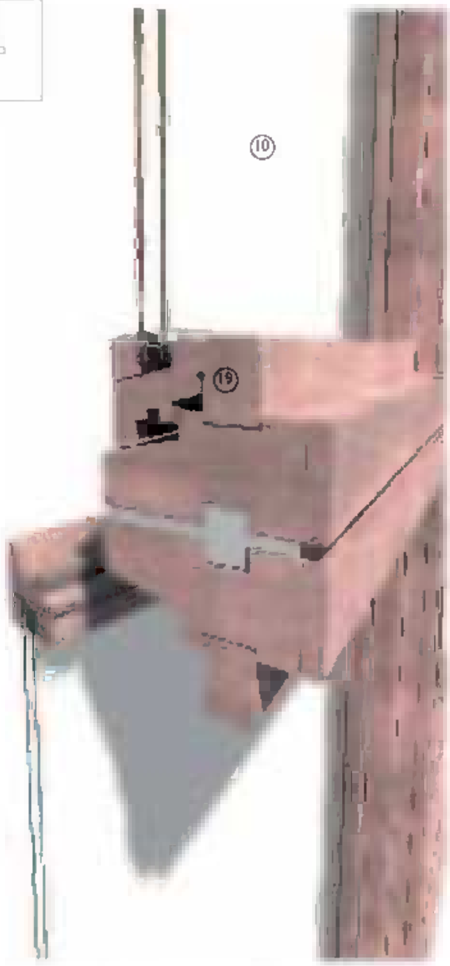
Elevation 1:50. Sliding doors



Horizontal section 1:5. Sliding doors

3-D view of vertical sliding sash window





3-D view of side hung timber window

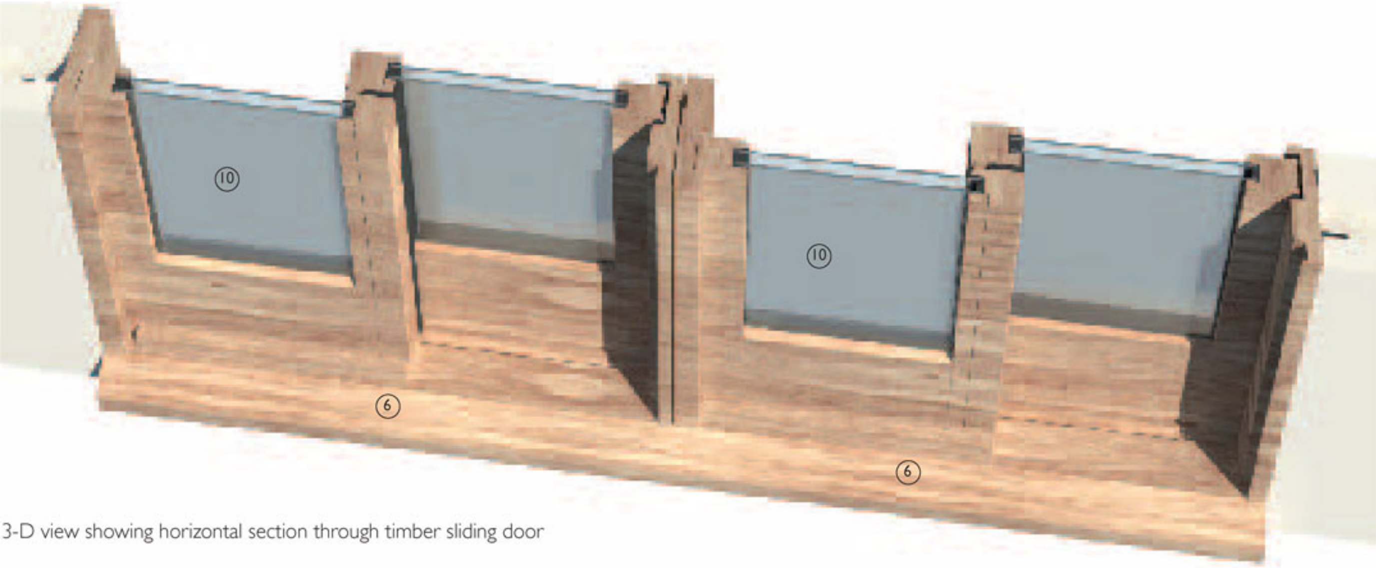
harder and more brittle putties and sealants used previously.

Aluminium trims are also used to secure the glass, but the appearance from outside is obviously a mixture of timber and aluminium rather than all-timber, making the window more of a composite design associated with timber window walls. This trend will probably continue due to the greater reliability of aluminium for glazing beads and trims.

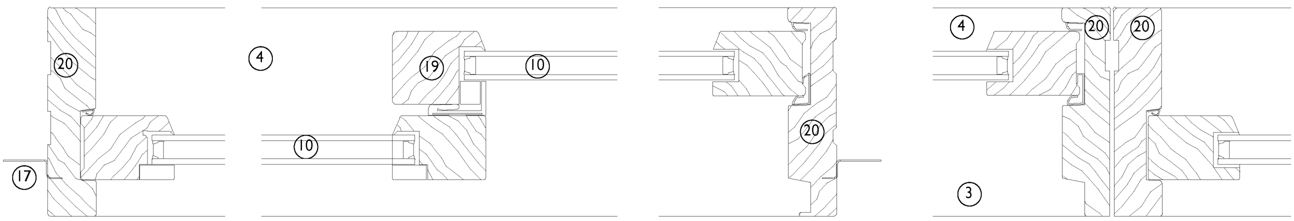
Windows in openings

Where timber windows are set into an opening rather than being part of a window wall, the most common materials used are masonry block, brick or timber boarding. With all these materials, timber windows are fixed either into the reveals of the opening or are fixed onto the face of the opening. The position of the window in the opening has more influence over the junction with the surrounding wall than the choice of material for the wall.

In generic examples, the window is fixed to the outside face of the wall, which would typically be reinforced concrete or concrete block. This would be used where a massive, sound insulating structure, such as an apartment building, is clad in a different material such as timber rainscreen panels or terracotta, which are often used in a smooth continuous plane without reveals. This construction is ideal for rainscreen construction. It allows the window to be sealed to the structural wall, or backing wall, with a lapped joint around the opening and allowing it to be fitted inde-



3-D view showing horizontal section through timber sliding door



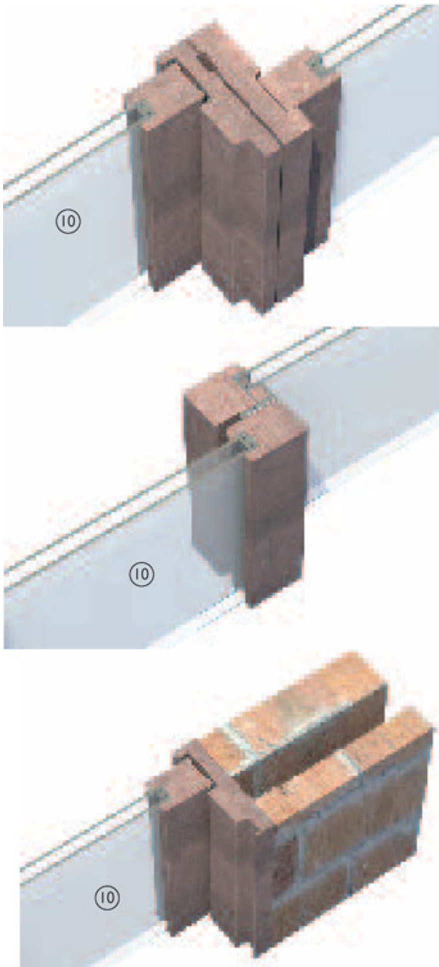
Horizontal sections 1:5. Sliding doors

pendently of that opening. This permits the wall to be set out on a precise grid that would be difficult to achieve by setting the window into the opening. This is because the construction tolerances associated with concrete frame construction are considerably higher than those used for timber windows. Windows would typically be sealed against the concrete wall with projecting profiles that would lap under a waterproof layer on the surrounding wall. This creates a deep reveal on the inside face of the wall which has finishes applied to create a tidy junction with the internal face of the window.

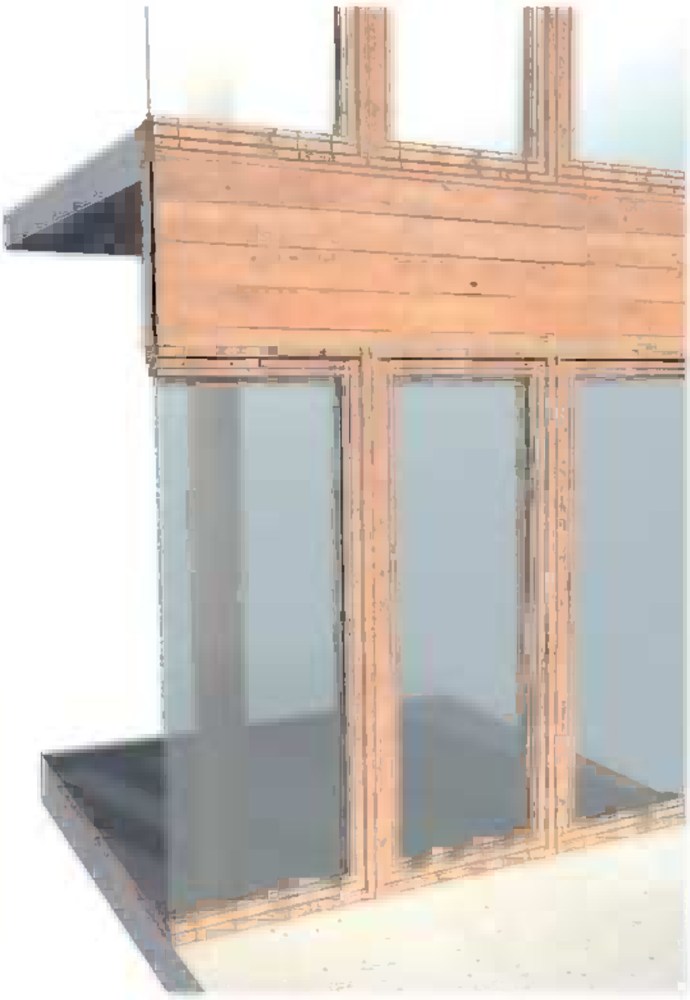
In some cases, the window is set into the reveal of the opening. Because the window has to be smaller than the opening size in order to install it, the joint width has to be accurately formed around the window. Sometimes the window frame is built in to the wall as the surrounding wall is constructed, or else a template is used to avoid accidental damage to the window during construction.

Alternatively, the window could be set into the outer wall construction and in this case needs to allow water to drain the top of the opening to the sides, as in masonry cavity wall construction. In the previous case, the window does not have this additional requirement, and so is protected from water penetration by the wall itself. However, rainwater needs to be drained at the bottom of the opening, where a cill is provided. The window is lapped over the cill, often with an additional weather bar for protection against water ingress through capillary action.

The window can also be set into a stepped reveal. This has the advantage of giving greater construction tolerance when fitting the window as well as creating a lapped joint between the structural opening and the window, which is easier to seal than an equivalent butt joint, where a backing strip is needed to give a surface to which the sealant can adhere.



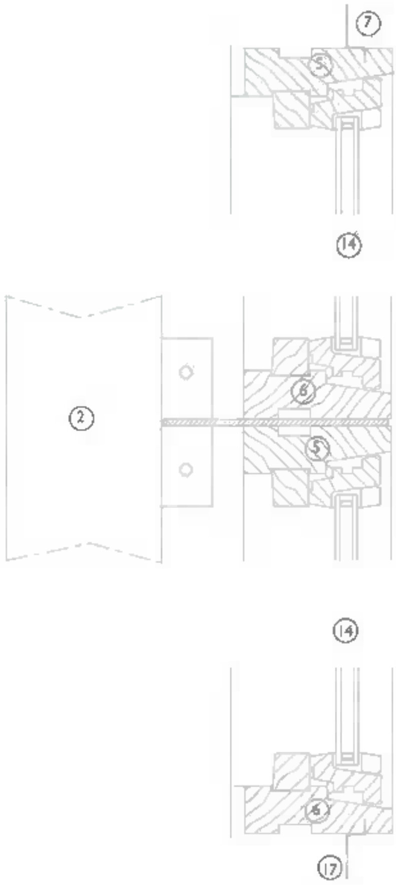
3-D views of sliding door junctions



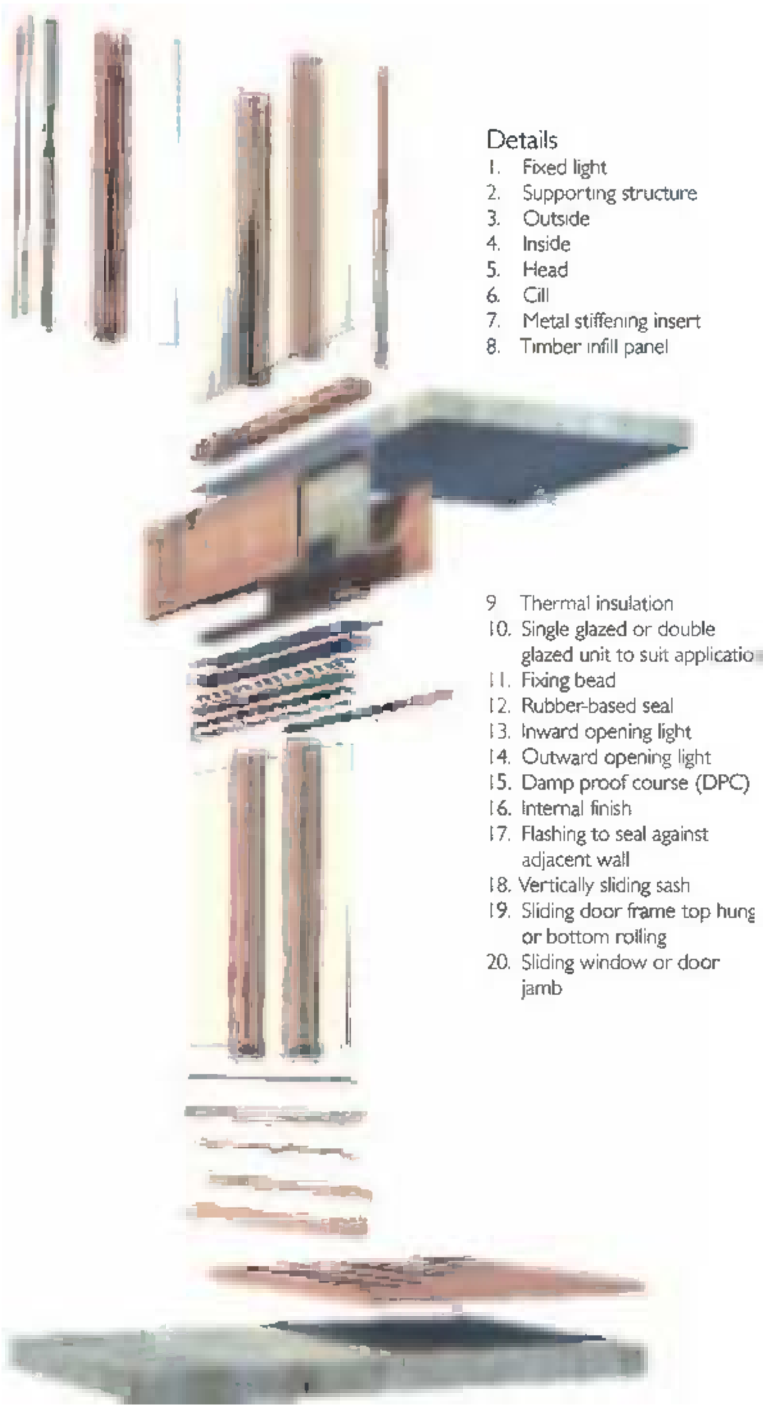
3-D views of timber windows and doors in wall system

Details

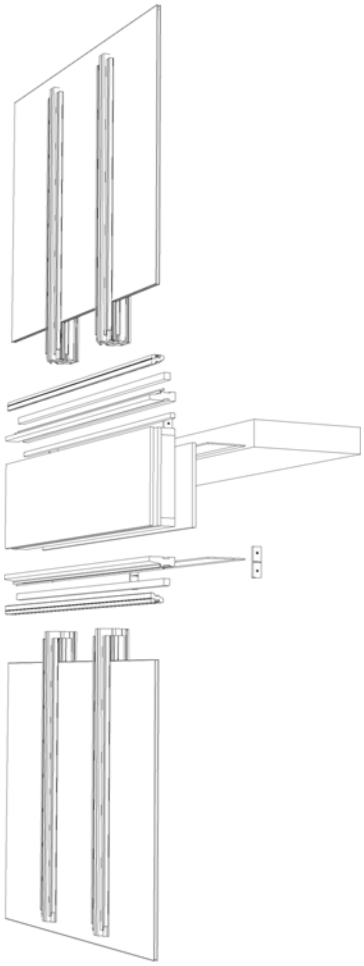
1. Fixed light
2. Supporting structure
3. Outside
4. Inside
5. Head
6. Cill
7. Metal stiffening insert
8. Timber infill panel
9. Thermal insulation
10. Single glazed or double glazed unit to suit application
11. Fixing bead
12. Rubber-based seal
13. Inward opening light
14. Outward opening light
15. Damp proof course (DPC)
16. Internal finish
17. Flashing to seal against adjacent wall
18. Vertically sliding sash
19. Sliding door frame top hung or bottom rolling
20. Sliding window or door jamb



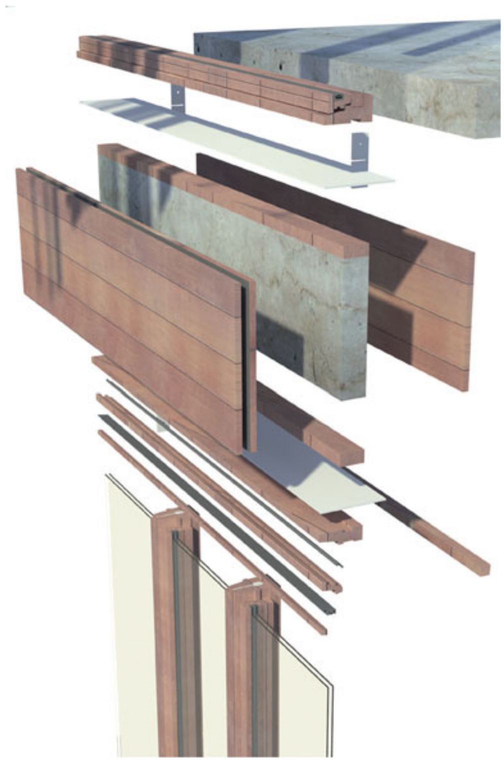
Vertical section 1:5. Outward opening casement doors

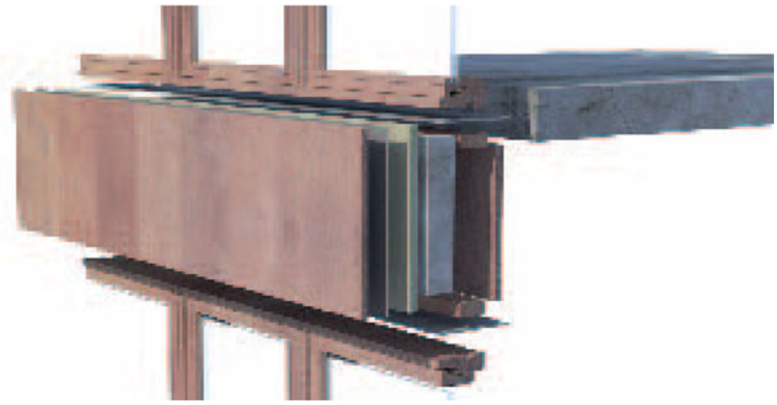


3-D exploded view of storey-height timber window construction



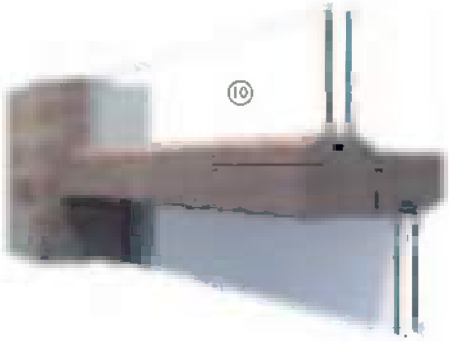
3-D view of storey-height timber window construction

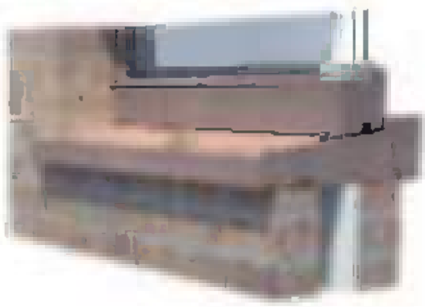




3-D exploded detail view of storey-height timber window construction at upper floor level

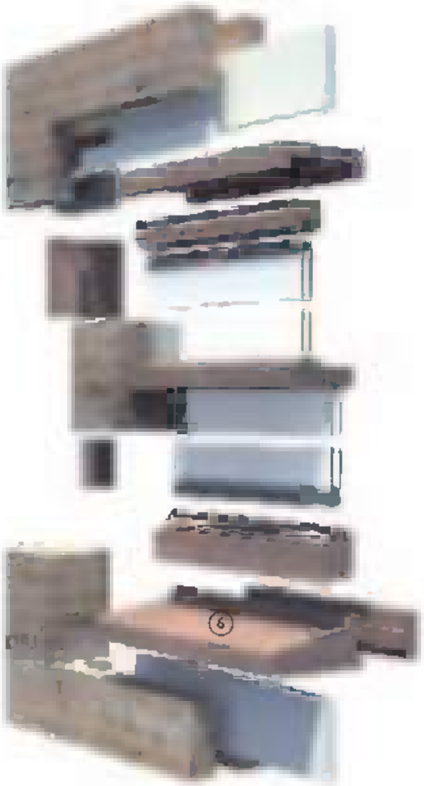
3-D exploded detail view of storey-height timber window construction at upper floor level



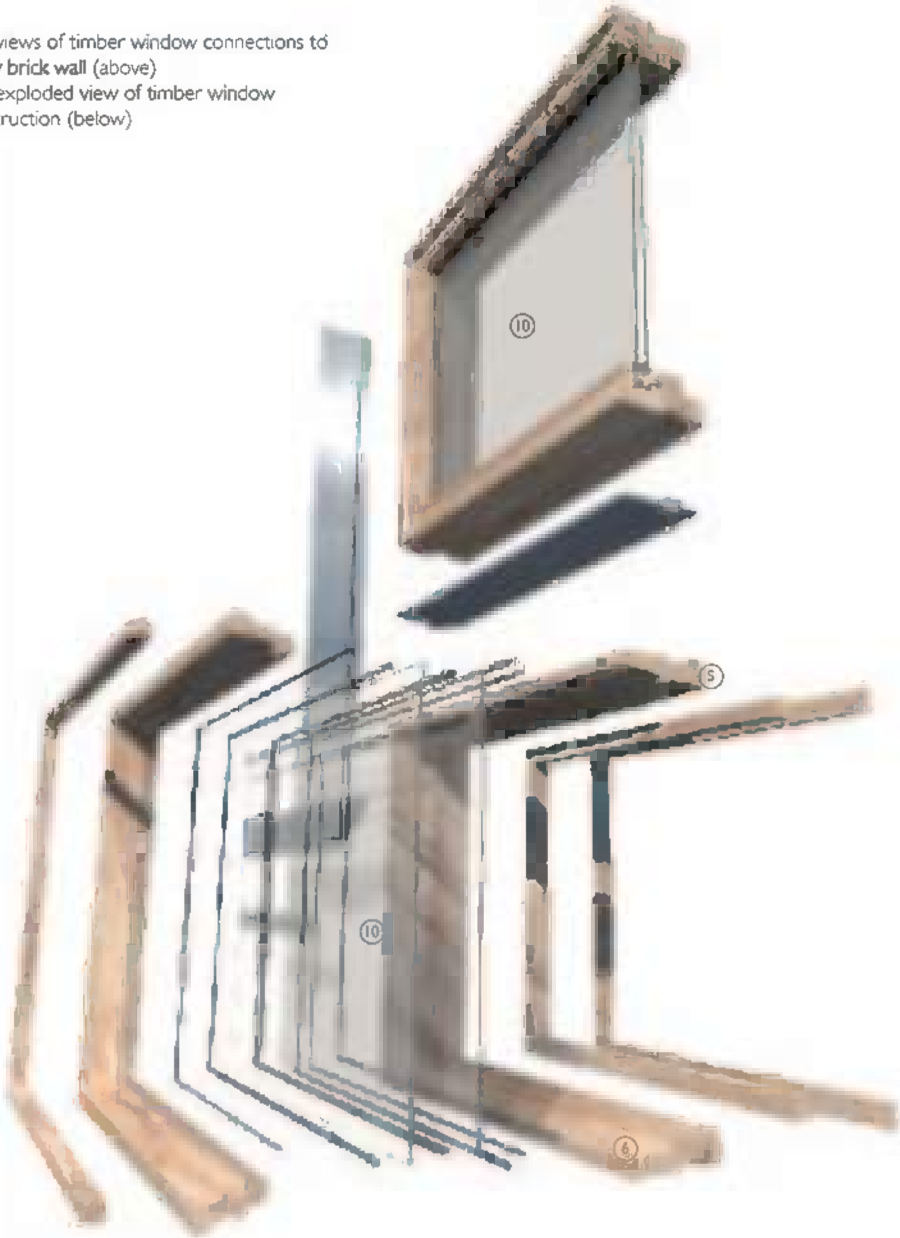


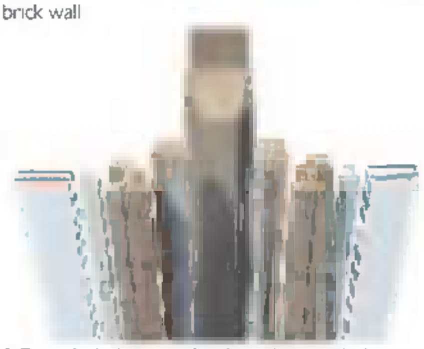
3-D views of timber window connections to cavity brick wall (above)
3-D exploded view of timber window construction (below)

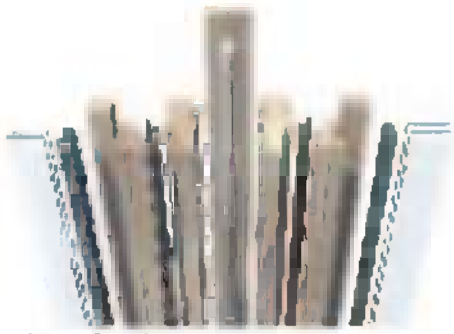
3-D view of timber window set in cavity brick wall

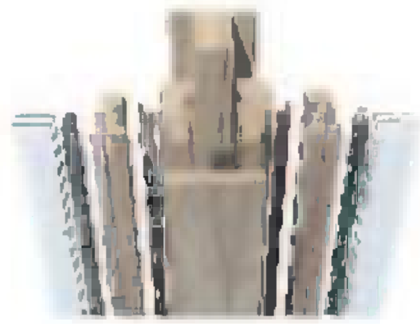


3-D exploded view of timber window set in cavity brick wall









3-D exploded views of various timber window construction configurations

3

CONCRETE WALLS

(1) **Cast in situ / cast-in-place:**

Parapets, drips and cills
Finishes
As-cast finish
Washed finish
Polished finish

(2) **Storey height precast panels:**

Panel types
Thermal Insulation
Joints
Acid etched finish

(3) **Small precast/GRC cladding panels**

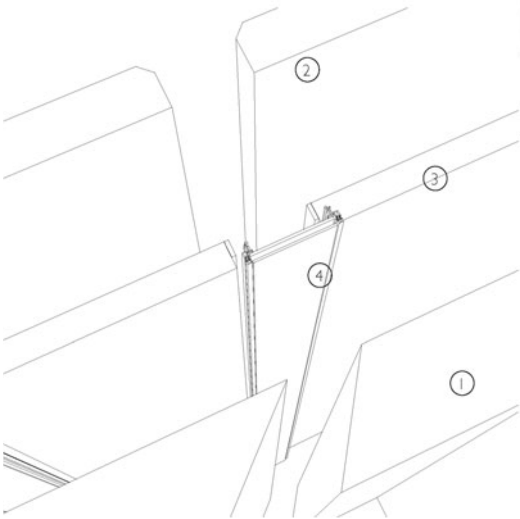
Individually supported panels
Self supporting stacked panels
Parapets and cills
Openings
Sand blasted finish and tooled finish


Setting reinforcement

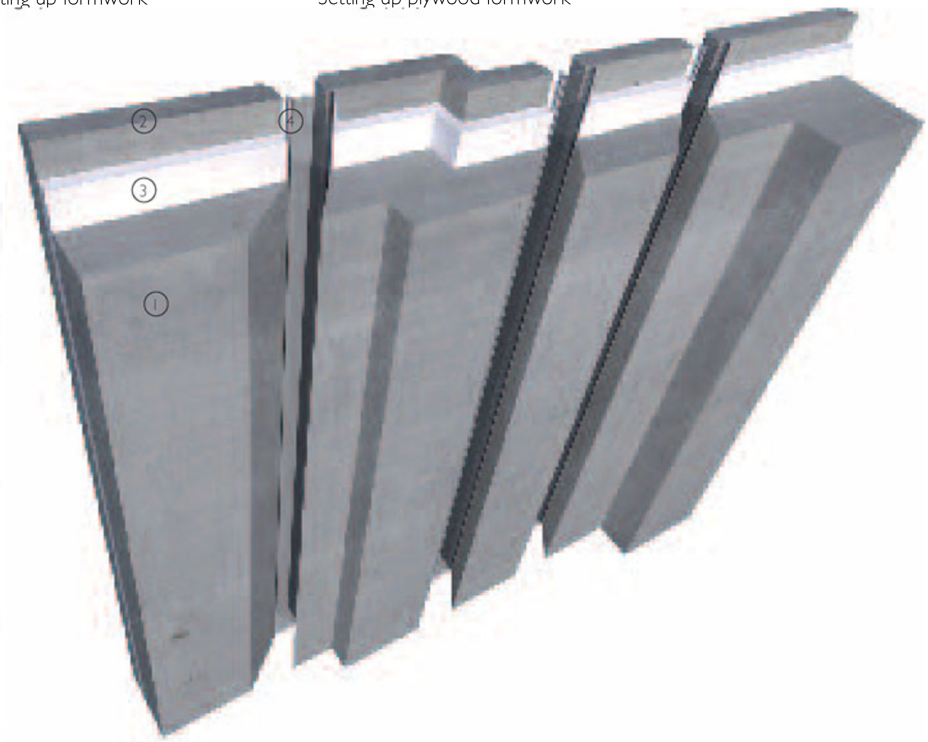

Setting up formwork



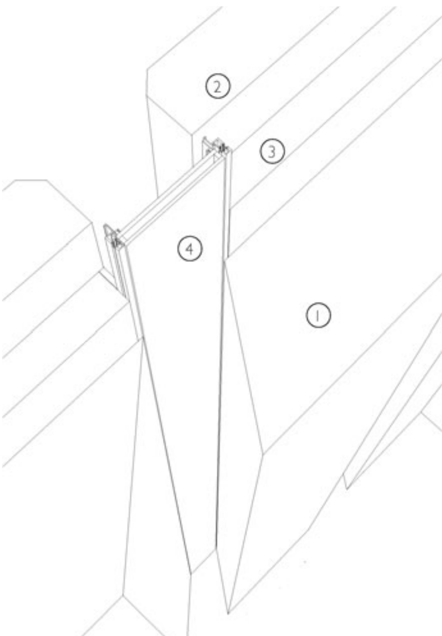
Setting up plywood formwork



3-D exploded view of window set in precast concrete wall



3-D view of precast concrete wall with vertical windows



3-D view of window set in precast concrete wall

An essential difference between concrete and other materials used in facade construction is that concrete is poured in place into moulds, or into formwork, rather than being manufactured as a standard size component in a factory. Whereas metal, glass, masonry, plastics and timber are made to standard dimensions in the form of sheets or sections, concrete is cast, either on site or in a factory as precast panels. Although there are few constraints on the size of a single cast element in concrete, in practice an essential determinant of concrete panel size is the amount of concrete that can be poured at one time. With precast concrete the essential constraint on panel size is the weight that can be lifted by a crane on site.

In-situ concrete is dependent on the formwork in which the concrete is cast. An understanding of formwork is important to appreciate how to control the appearance of joints and of bolt holes through the concrete, since the formwork is the negative impression, or mirror image, of the final concrete.

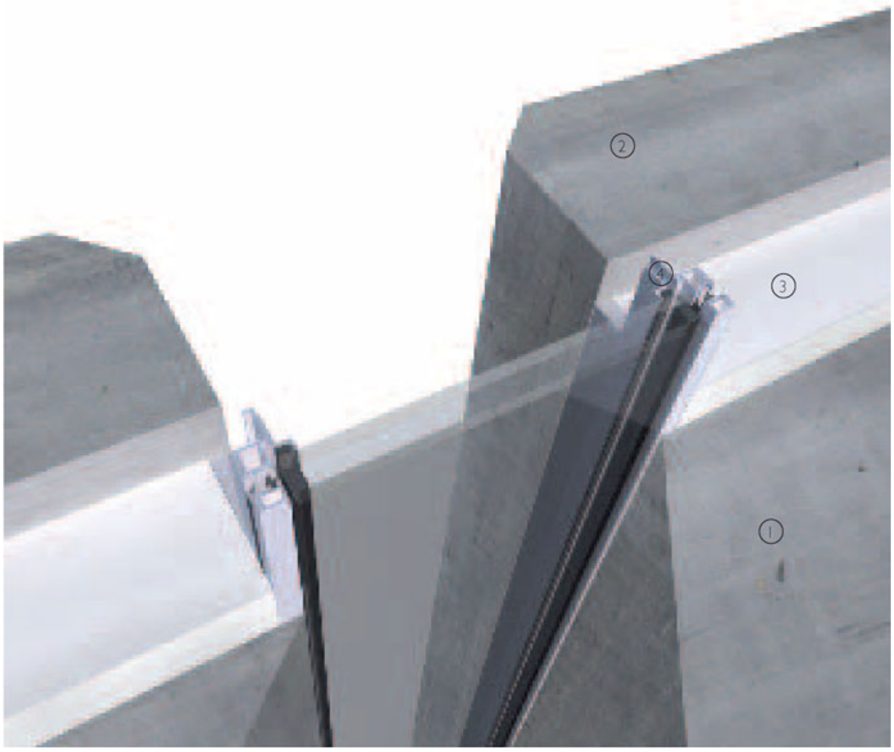
The design of in-situ concrete walls has changed in recent years to include thermal insulation, either set within the concrete during pouring, or fixed on the internal face or external face after the wall has been cast. The position of the insulation within the construction affects the use of the thermal mass of concrete and its ability to contribute to night-time cooling as part of an overall reinforced concrete structure. Continuity of thermal insulation is increasingly important in the interface with glazed openings and doors to avoid thermal bridging. Continuity of double glazing and thermal insulation in the concrete

Setting up plywood formwork

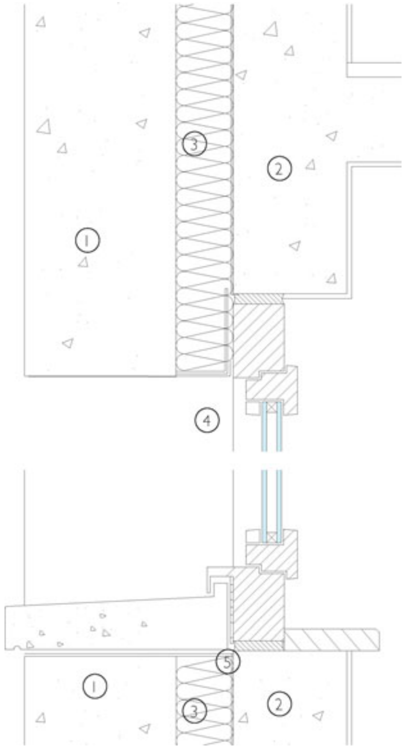
Setting up formwork

Securing formwork

Concrete pouring



3-D view of window set in precast concrete wall



Vertical section 1:10. Connection between in-situ wall and window

wall is probably the biggest recent change in this form of construction in recent years. In-situ concrete walls are formed as either a structural concrete wall with thermal insulation on the inside face with an internal dry lining, or as a diaphragm/double wall of concrete with thermal insulation set between the two skins of concrete.

The first method has the benefit of economy, particularly where the thermal mass of the concrete wall is not required for use in night-time cooling. The wall zone for the insulation can also be used to fit windows, so that the opening lights and doors do not have to be set into specially cast recesses in the concrete, which makes it more expensive. Drips are cast into the tops of window reveals to reduce staining to the adjacent wall beneath caused by rainwater runoff from dust that accumulates on flat surfaces. Parapets have metal copings that prevent staining on the wall beneath by directing rainwater towards a gutter immediately behind the parapet.

With the second method, in-situ concrete walls are formed as 'sandwich' walls with internal insulation. These have either insulation broken by strips of concrete that link across the two skins (forming limited thermal bridges) or are formed as two separate concrete skins linked only by stainless steel brackets and ties. The second type is increasingly popular as it avoids thermal bridging with its associated risk of condensation forming on the inside of the wall, in temperate climates.

Details

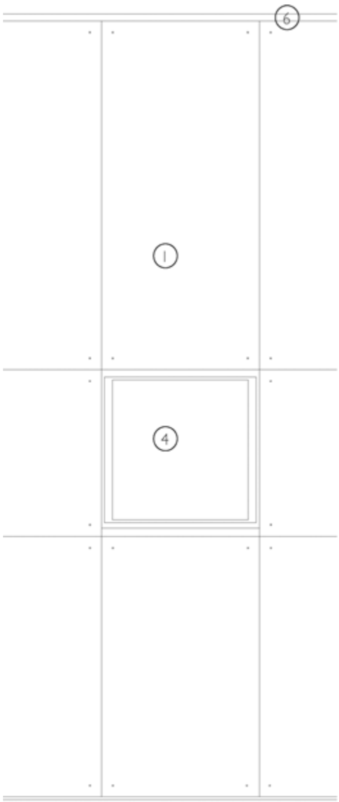
1. Concrete external wall
2. Concrete internal wall
3. Thermal insulation
4. Window frame
5. Waterproof membrane
6. Metal parapet flashing
7. Internal finish
8. Metal cill
9. Drip
10. Metal lined gutter

Concrete curing

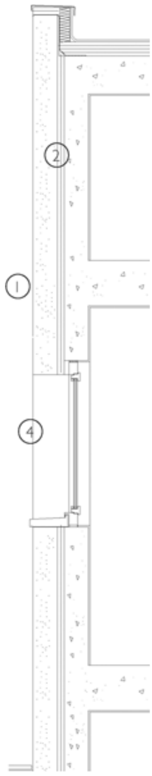
Concrete curing

Setting up formwork

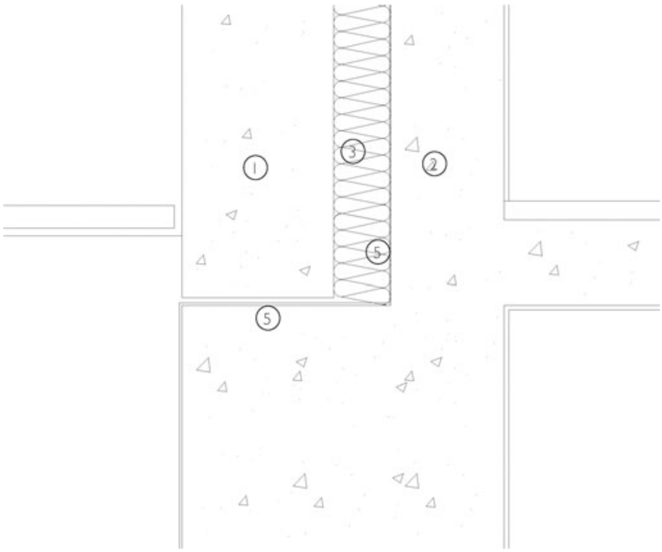
Concrete poured



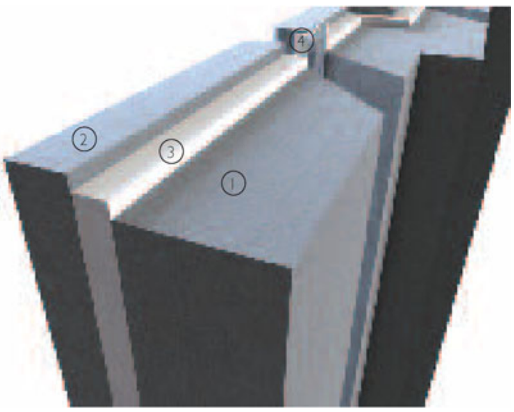
Elevation 1:50. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



Vertical section 1:50. In-situ concrete wall cast in two skins with rigid closed cell insulation between skins



Vertical section 1:10. In-situ concrete wall construction, junction at ground level. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



3-D view of In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins

Parapets, drips and cills

The detailing of openings, parapets and cills follows the same principles for a single wall of structural concrete with internal thermal insulation. When concrete is used as an exposed external finish, cills, parapets and drips are detailed to ensure that rainwater is thrown as clear as possible from the external wall surface. When an additional outer material is used, typically a rainscreen in a wide range of materials, the concrete wall can be formed economically with no regard for visual appearance, since the material is not visible.

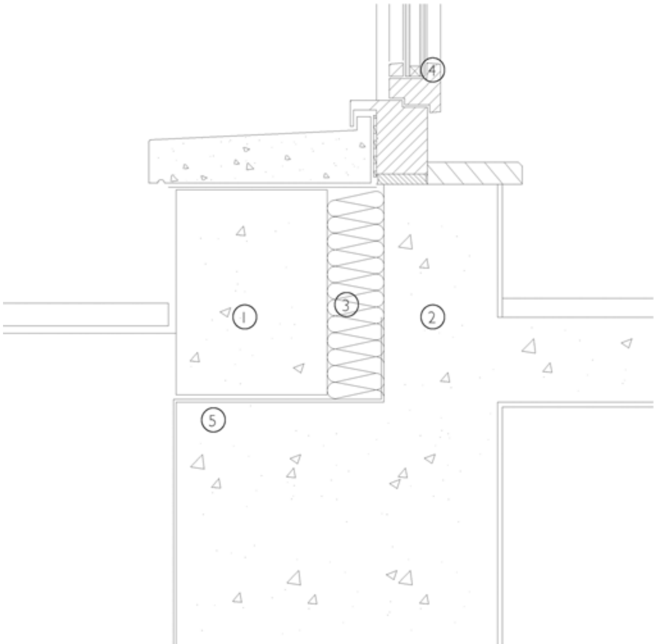
Since horizontal or slightly sloping surfaces catch dust, roof overhangs and deep eaves are often incorporated into the design to avoid wash-off from rain. Dust washed away by rainwater causes the deposit of dirt and dust in adjacent areas of wall. If overhangs are not a part of the design, then water from horizontal or slightly sloping surfaces is thrown clear of the wall by projecting cills and flashings. In highly polluted environments, dust-catching wall textures are usually avoided, and smooth finishes are often preferred. However, where protective treatments are applied to the concrete to reduce porosity, this can lead to greater run-off across the facade which can increase staining, and must be taken into account in the design of the external wall.

Finishes

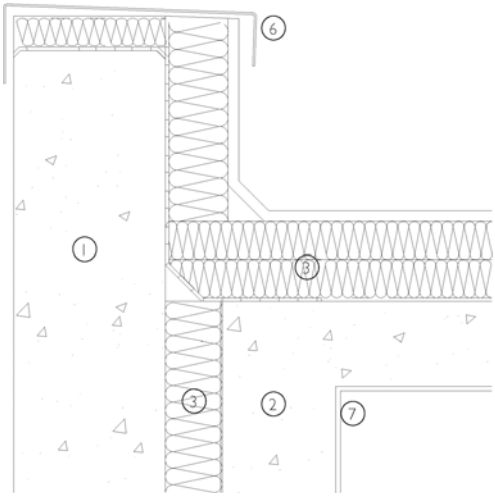
The main influence in the base colour of concrete used for wall construction is in the choice of cement, with fair-faced visible con-

Moving formwork up to higher floors

Details
1. Concrete external wall
2. Concrete internal wall
3. Thermal insulation
4. Window frame
5. Waterproof membrane
6. Metal parapet flashing
7. Internal finish
8. Metal cill
9. Drip
10. Metal lined gutter



Vertical section 1:10. In-situ concrete wall window/door condition. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



Vertical section 1:10. Junction at parapet level for typical wall condition. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins

crete walls using either a grey cement base or a white cement base. The physical properties of these two cement types are very similar.

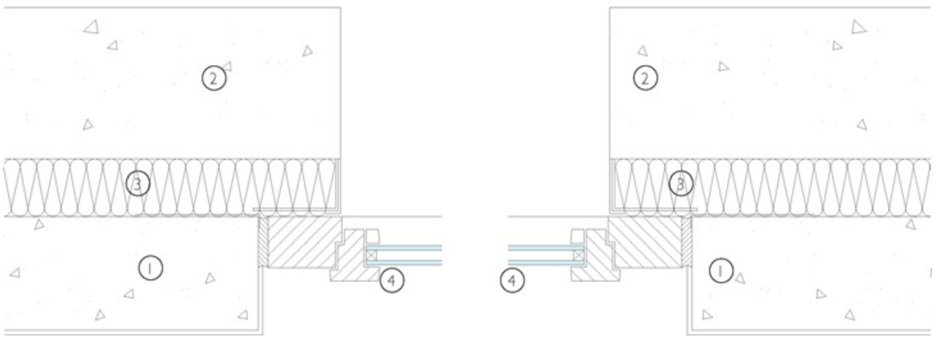
The colour of finished concrete from a grey cement base is also grey, as expected, but this can vary with the water/cement ratio, the porosity of the shuttering, vibration conditions, formwork stripping time and weather conditions. The grey type can also blacken with rain due to the presence of iron oxide. However, grey cement based architectural quality concrete can achieve an even colour when pouring methods and conditions are kept consistent. When grey cement is used with a moderate to high level of pigment content, as-cast or treated concretes are much less prone to colour variations due to the strong covering capacity of the pigments. White cement is much more expensive than grey cement but it is not subject to the colour variations of grey cement, nor is it subject to rain darkening.

The most common finishes used for in-situ cast concretes are an as-cast finish, a washed finish and a polished finish. The less common types are described in the following sections on precast panels, but can also be used for in-situ cast concrete walls, depending on the ability to work on large areas of completed wall surface.

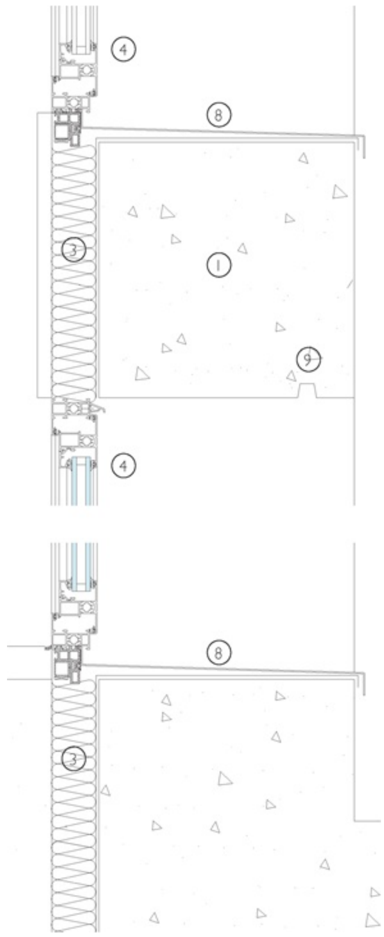
As-cast finish

Smooth concrete finishes can have their surfaces broken by small air bubbles of entrained air, but these hardly affect the sur-

3-D view of metal flashing on in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



Horizontal section 1:10. In-situ concrete wall condition at window jamb. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skin

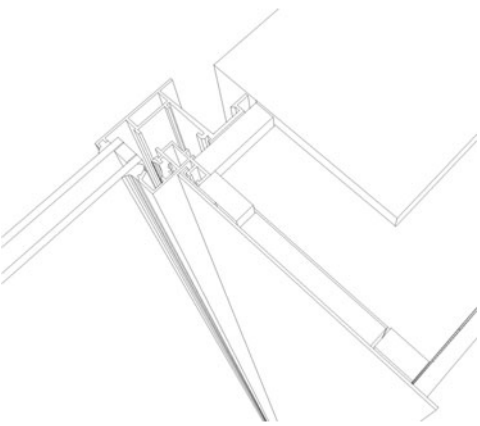


Vertical section 1:10. In-situ concrete wall junction at window. In-situ cast concrete wall cast as a monolithic construction with internal thermal insulation

3-D view of window in an in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skin

Details

1. Concrete external wall
2. Concrete internal wall
3. Thermal insulation
4. Window frame
5. Waterproof membrane
6. Metal parapet flashing
7. Internal finish
8. Metal cill
9. Drip
10. Metal lined gutter



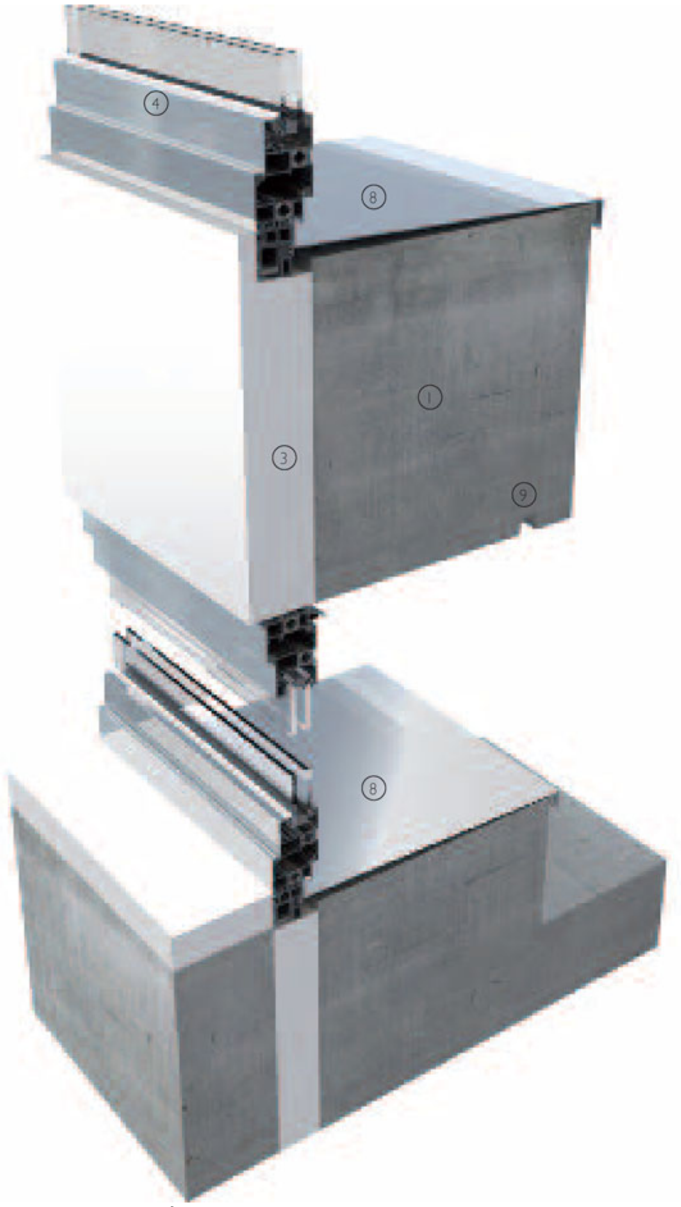
Axonometric view of window jamb in an in-situ concrete wall

face any more than would be found in natural sandstones and limestones. Colour variations from the use of grey cement result not from its natural colour, but its colour after pouring, and from fine particles of sand becoming segregated in certain areas as a result of vibration. If these fine particles appear in the face of the wall, a marbling effect similar to that of natural stone will occur. If the particles are different from the shade of the facing, staining will occur. As a result, the tinting of clear mixtures with fine particles of dark sand is avoided. Smooth concrete is usually self-coloured, at least in large areas, to avoid colour variations associated with using pigment additives. Smooth and visually consistent natural finishes are achieved largely by both the accuracy of the proportions of the materials in the concrete mix, including water, and the care in preparing and setting the formwork.

Textured surfaces with either a shallow or deeper contoured profile can be formed either with specially fabricated shuttering boards or with an additional lining that is set on the inside face of the shuttering boards, against which the concrete is poured. An additional lining is usually flexible and is made of either polystyrene board, which can be used only once, or polyurethane sheet or silicone rubber sheet which can be used several times. Silicone rubber moulds are made by pouring the material into a positive-shaped mould made from a non-cohesive material such as sand, making its use expensive, but capable of forming complex forms in the surface of as-cast concrete. Joints between these specially-made shuttering boards are usually

3-D view of window and external cill

3-D view of window junction in an in-situ concrete wall cast as a monolithic construction with internal thermal insulation



3-D view of window junction in an in-situ concrete wall cast as a monolithic construction with internal thermal insulation

formed as grooves to avoid uneven and blurred lines resulting from attempting to bond their edges.

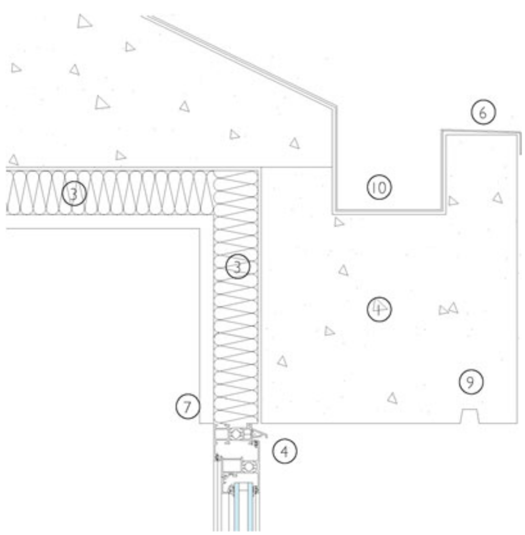
Washed finish

The washing-out or deactivation of fresh concrete is carried out in two ways, either with 'faces shuttered' or with 'faces not shuttered'. The faces shuttered method involves the application of a product on the shutter panels that deactivates, retards or eliminates hydration of the cement. The product is applied with either a brush or by spraying. After stripping the shuttering, the external faces are washed with a water jet which removes the hydrated skin and, depending on how deep the effect of the deactivator is, reveals either the grains of sand or, more commonly, the coarse aggregate.

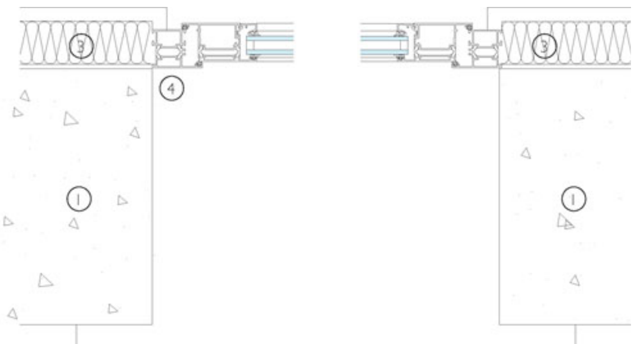
The faces not shuttered method is done either by spraying deactivator on the green (fresh) concrete and washing it as just described, or by direct washing before the cement has fully set. Usually the method is completed with a last wash using an aqueous acid solution in order to remove traces of hydrated cement soiling the exposed aggregate, leaving stains on the outside face. When this is completed, the mineralogical nature of the coarse aggregate is exposed, which gives a textured appearance. Some aggregates, such as limestone, can become dulled or change colour on contact with the acid. In deep washing, this method is particularly suitable for bringing out the visual characteristics of coarse aggregate. It leads to a very different finish depending on the shape, either crushed or rolled, the mineralogical type (sili-

3-D view of window junction in an in-situ concrete wall cast as a monolithic construction with internal thermal insulation

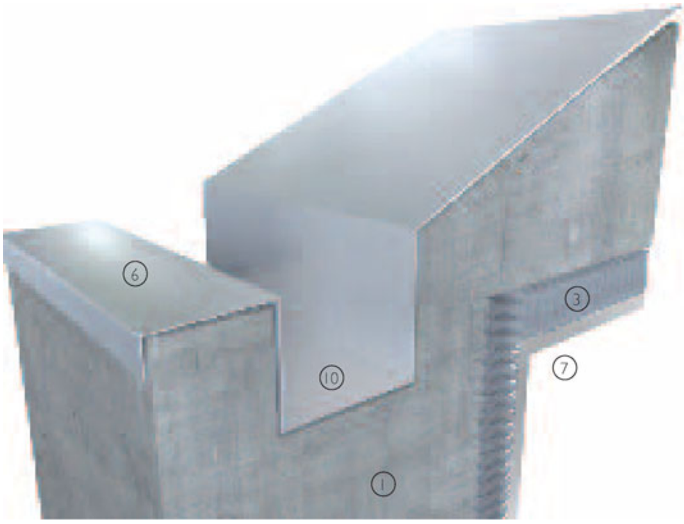
3-D view of parapet junction of an in-situ cast concrete wall cast as a monolithic construction with internal thermal insulation



Vertical section 1:10. Junction at parapet level for typical wall condition. In-situ cast concrete wall cast as a monolithic construction with internal thermal insulation



Horizontal section 1:10. Junction at window jamb. In-situ cast concrete wall cast as a monolithic construction with internal thermal insulation



3-D view of parapet junction of an in-situ cast concrete wall cast as a monolithic construction with internal thermal insulation

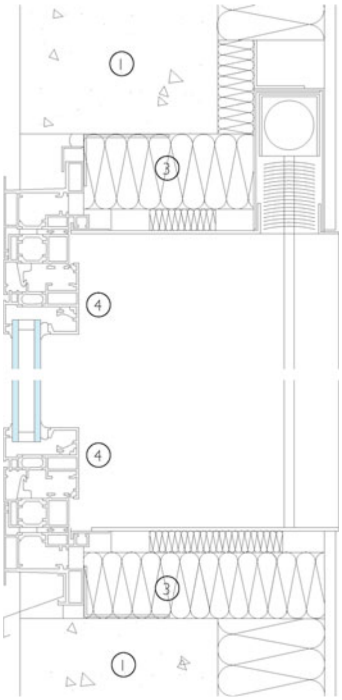
3-D detail view of window jamb in an in-situ cast concrete wall cast as a monolithic construction with internal thermal insulation

ca or limestone), particle size, but also the mix composition in terms of the density of stones revealed on the surface.

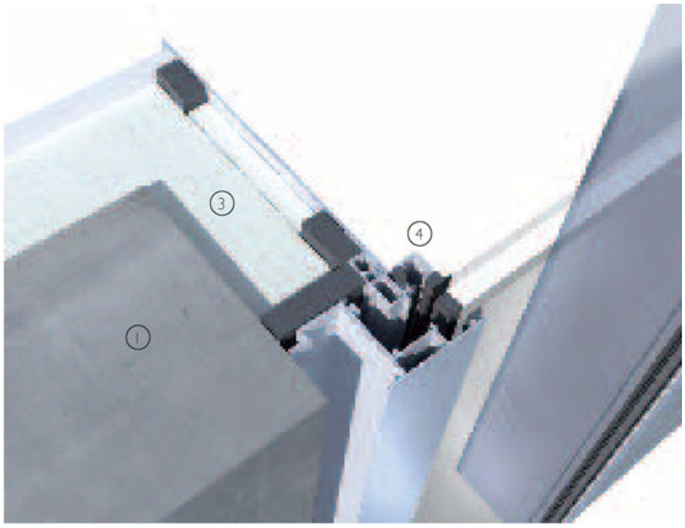
Polished finish

Concrete walls can be polished to varying amounts of smoothness by abrasive grinding, using a grinding wheel which is lubricated by water. The outer skin of the concrete is removed by abrasion to a depth of between 1mm and 2mm, with one pass of a grinding wheel which exposes some of the fine and coarse aggregate behind the surface. A second pass with a finer abrasion disc removes the big scratches left by the first pass, which are particularly visible on darker surfaces. With polishing by disc, a filler is applied to the surface to fill the air bubble pockets and small honeycombing. After this filler has hardened, the surface is again polished with successively finer grains. As the scratches are removed, the colours of aggregate reveal themselves, but the surface does not shine naturally. The concrete wall surface can, however, be made shiny by the application of a varnish. Concrete walls can be polished further to create a satin finish and even further to provide a gloss finish. A protective clear coating can also be applied at this point.

Polishing is easier to apply on flat surfaces than on roughened or curved areas of concrete. Polishing exposes the colour of the minerals within the concrete, giving rich colour effects from the cement, the sand, and the coarse aggregate materials in the mix. This method provides a self-coloured finish

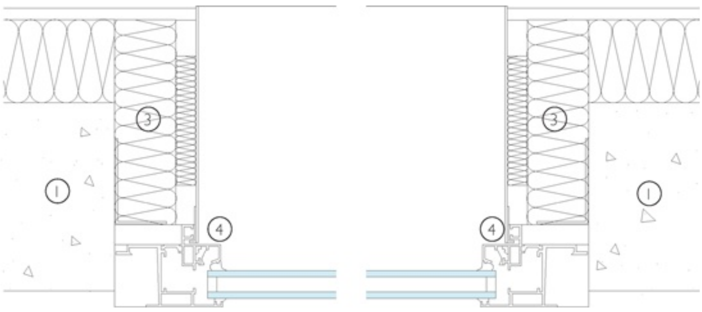


Vertical section 1:10. In-situ loadbearing concrete wall with window flush to external face



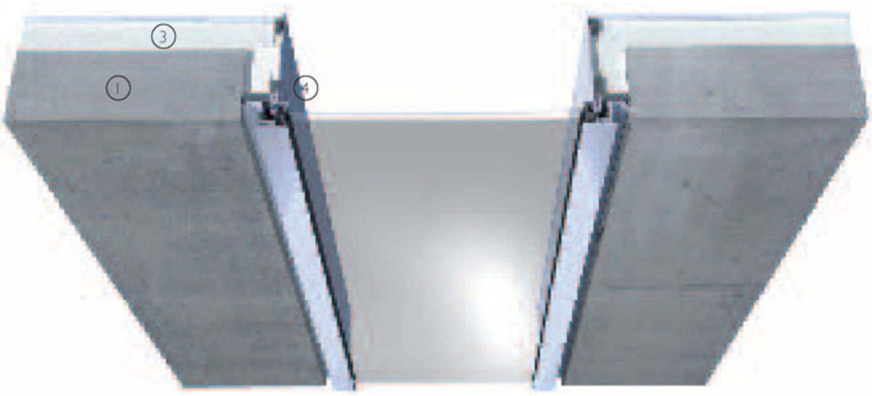
3-D detail view of concrete wall construction and junction with window flush to exterior face

Details
1. Concrete external wall
2. Concrete internal wall
3. Thermal insulation
4. Window frame
5. Waterproof membrane
6. Metal parapet flashing
7. Internal finish
8. Metal cill
9. Drip
10. Metal lined gutter



Horizontal section 1:10. In-situ loadbearing concrete wall with window flush to external face

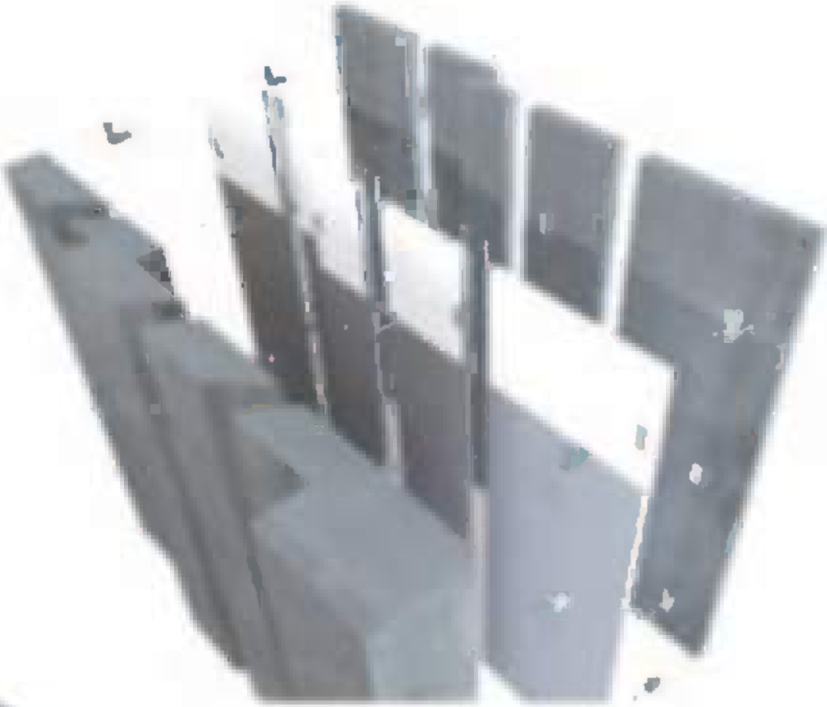
with a surface that is less prone to retain dust, which washes off, causing staining, and is easy to maintain by simple washing, undertaken using the same methods of maintenance access used for glazed walls.



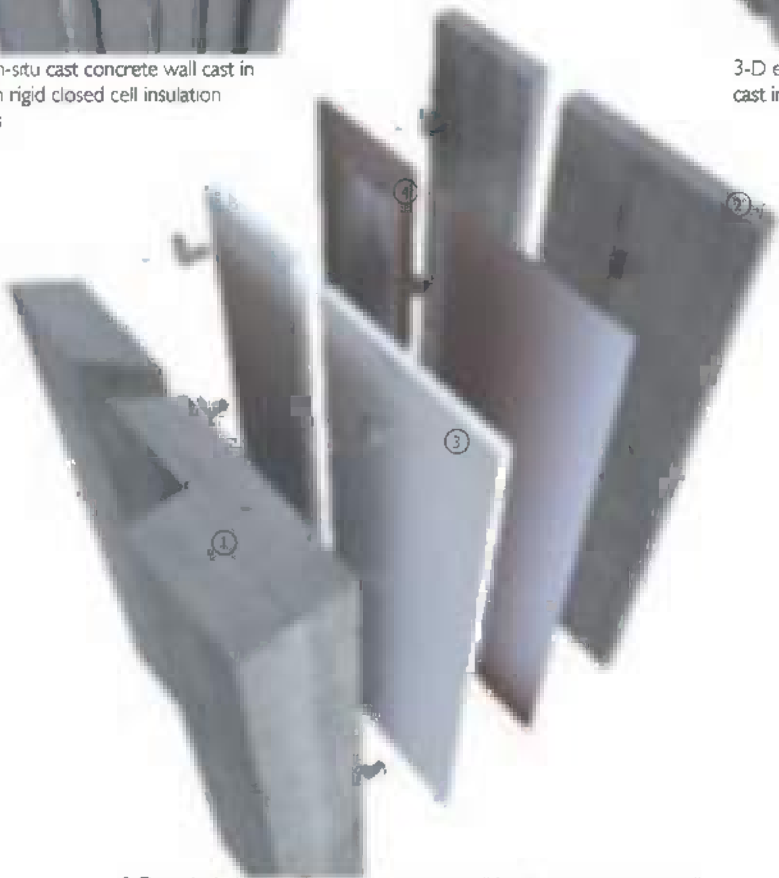
3-D view of in-situ loadbearing concrete wall junction with window flush to exterior face

3-D section view of in-situ loadbearing concrete wall junction with window flush to internal face

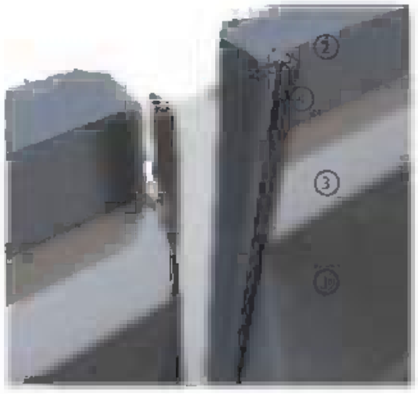
3-D view of in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



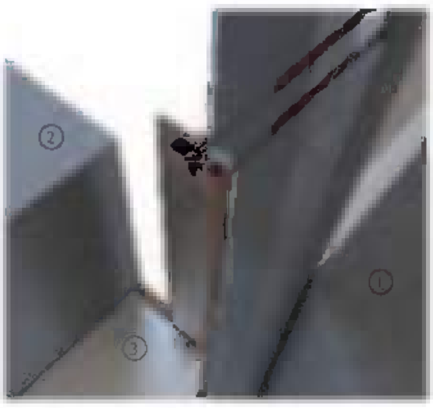
3-D exploded view of concrete wall in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



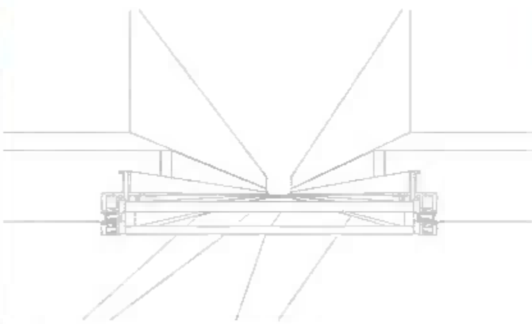
3-D exploded view of precast concrete wall in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



3-D view of in-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



3-D view of concrete wall frame detail

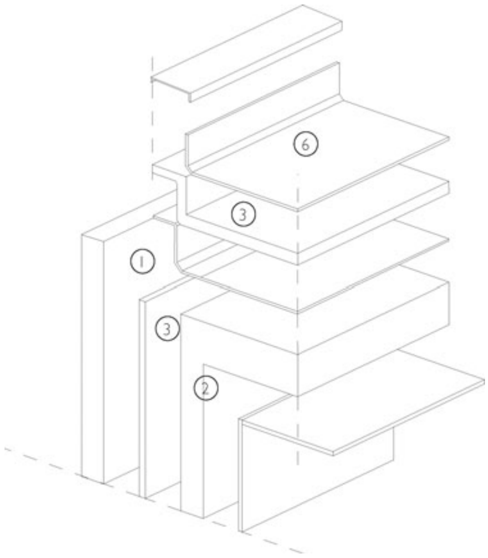


3-D line drawing of concrete wall frame detail

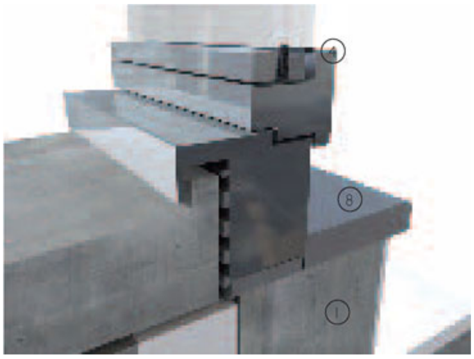
3-D exploded view of concrete wall frame detail

3-D view of loadbearing concrete wall gutter detail

3-D exploded loadbearing concrete wall gutter detail



Exploded axonometric view of loadbearing concrete wall gutter detail

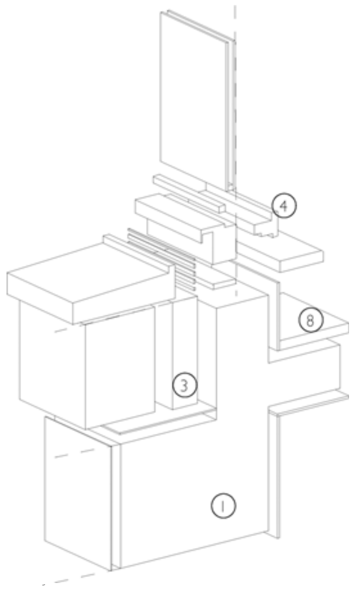


3-D view of loadbearing concrete wall cill detail

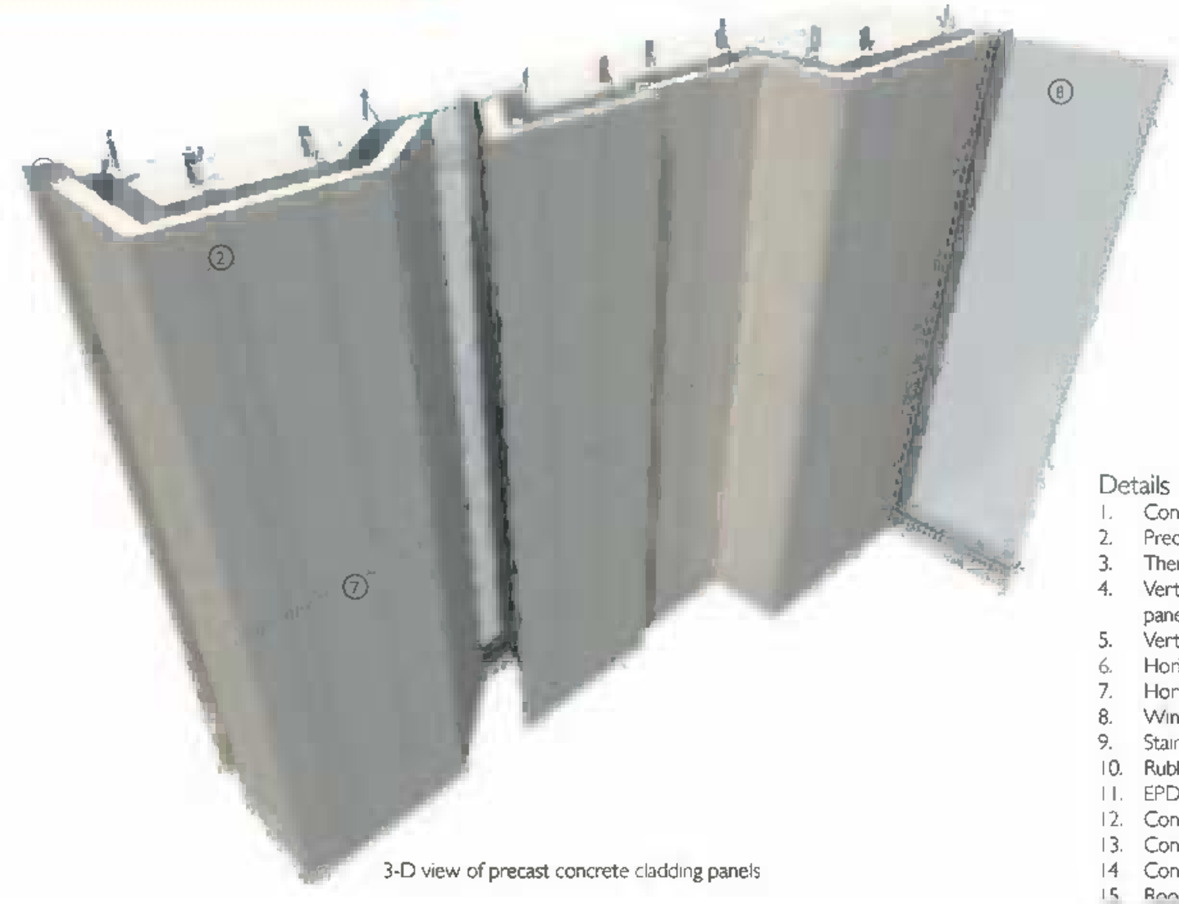
Details

1. Concrete external wall
2. Concrete internal wall
3. Thermal insulation
4. Window frame
5. Waterproof membrane
6. Metal parapet flashing
7. Internal finish
8. Metal cill
9. Drip
10. Metal lined gutter

3-D exploded view of loadbearing concrete wall cill detail



Exploded axonometric view of loadbearing concrete wall cill detail



3-D view of precast concrete cladding panels

Details
1. Concrete floor deck
2. Precast concrete panel
3. Thermal insulation
4. Vertical baffle joint between panels
5. Vertical butt joint between panel
6. Horizontal lap joint
7. Horizontal butt joint
8. Window opening
9. Stainless steel dowel or angle
10. Rubber-based baffle
11. EPDM or silicone-based seal
12. Concrete column
13. Concrete corner panel
14. Concrete coping
15. Roof assembly

While in-situ concrete is a loadbearing form of construction, precast concrete can be formed as either loadbearing walls or as non-loadbearing cladding panels. Loadbearing panels are increasingly popular, since they provide a weathertight structural wall with high fire resistance combined with high acoustic insulation and thermal mass. In loadbearing construction, panels are stitched together to form a monolithic structural wall. Non-loadbearing cladding panels have maintained their popularity by providing greater freedom in design, from the visual point of view, than the structural constraints imposed on loadbearing panels.

Loadbearing types consist of units stacked together to support floors by transferring their own weight and a floor loading to a foundation. The unit/floor connection is usually made with a pin joint rather than a moment (rigid) joint since these are difficult to create in precast concrete, as the amount and length of built-in reinforcement is high, as well as the fact that the tensile forces within the unit can be high. The horizontal stability, which is not provided by the pin joint, is usually provided by service cores elsewhere in a building. In addition to floor-height loadbearing panels, loadbearing precast spandrel panels are used. These are in effect structural beams spanning between columns. Principles of connections to floor slabs are the same as for full-height panels, but loads from the panels and floors are taken back to structural columns rather than down through the wall panels.

Non-loadbearing cladding panels are fixed back to the primary structure either by concrete brackets forming an integral part of the panel, by stainless steel brackets, or by a combination of both. Typically panels are supported on an edge beam at the base of each panel and are restrained at the top with stainless steel brackets. Some cladding panels are top hung in order to benefit from the tensile qualities of the steel reinforcement or framing. Cladding panels are usually made to span one storey high, with a width or height of panel up to a maximum of 3600mm in order that the panel can be transported on a standard flat trailer. In addition, weight usually has a maximum of around 10 tonnes to prevent cracking during lifting and to allow a regular site crane to be used.

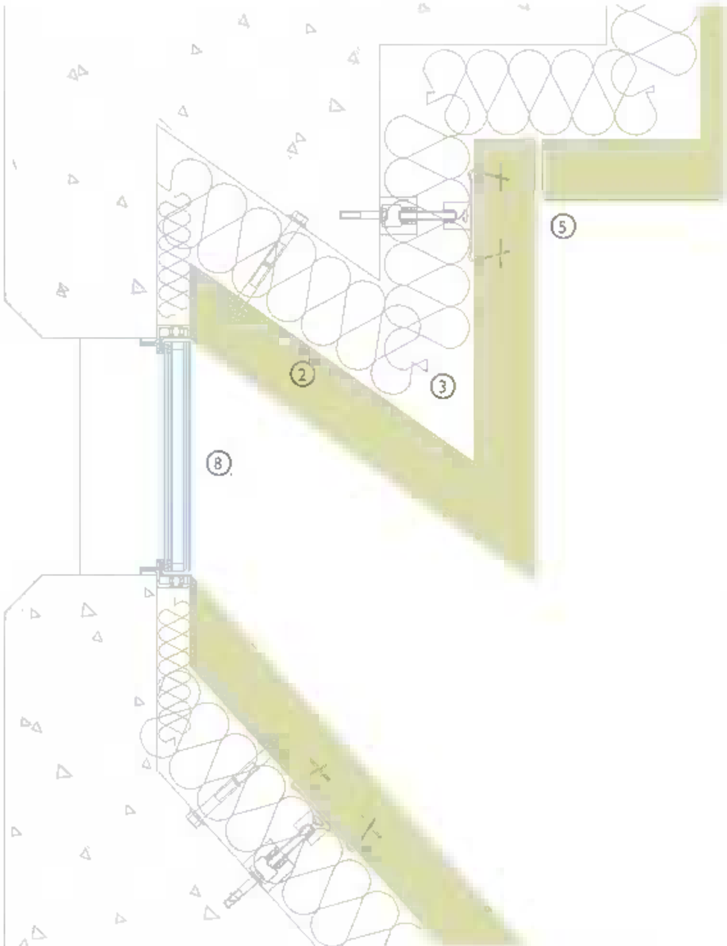
Panel types

Precast concrete panels are formed mainly by either forming the finish in the bottom of the mould, the top of the mould with another material to the face of the panel, or as an insulated sandwich panel.

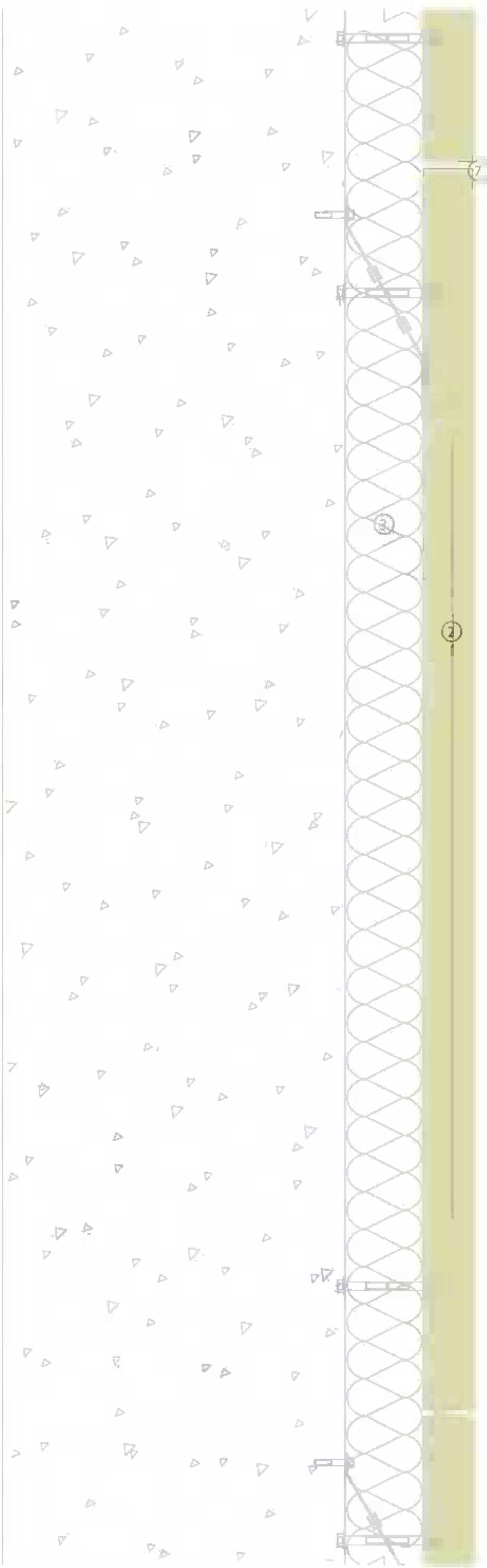
Bottom formed panels, where the finish is set on the bottom of the mould, are used where additional linings, typically polystyrene board, polyurethane sheet or silicone rubber sheet, as described in the text on in-situ cast concrete, are used to create a textured surface in the face of the panel. Sometimes, ceramic tiles or stones are laid in the bottom of the panel in order to bond to the concrete poured on top. The small size of terracotta or ceramic tiles allows them to be laid at the bottom of the mould and be individually bonded to the concrete.

In top formed panels, an additional decorative layer is applied to the top of the poured concrete. The thickness of the decorative layer is usually 25mm – 30mm. The

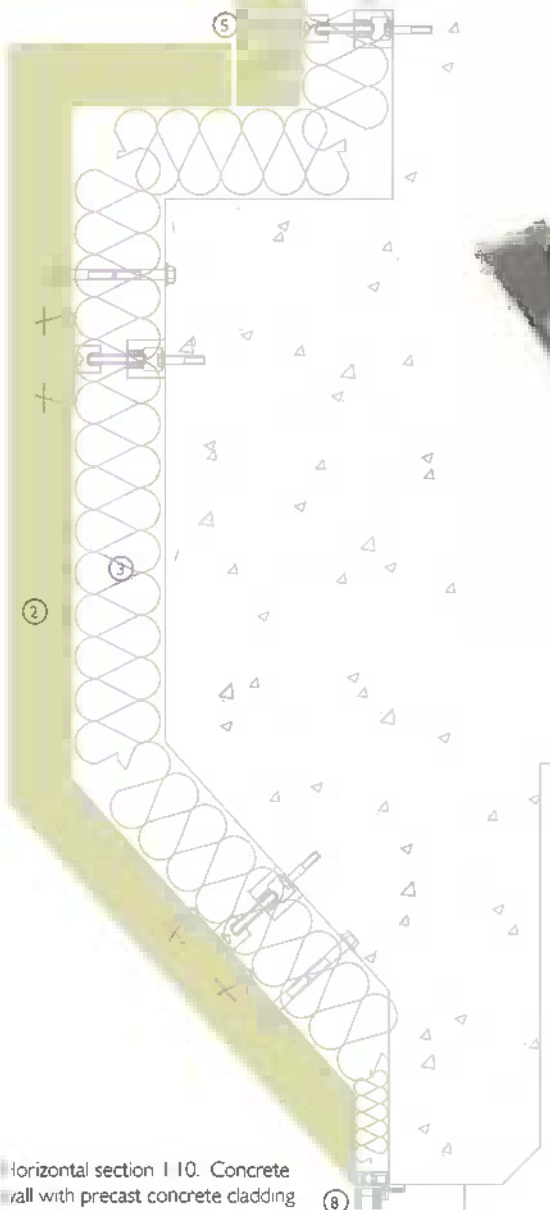
Cutaway 3-D view of wall clad in precast concrete cladding panels showing wall construction



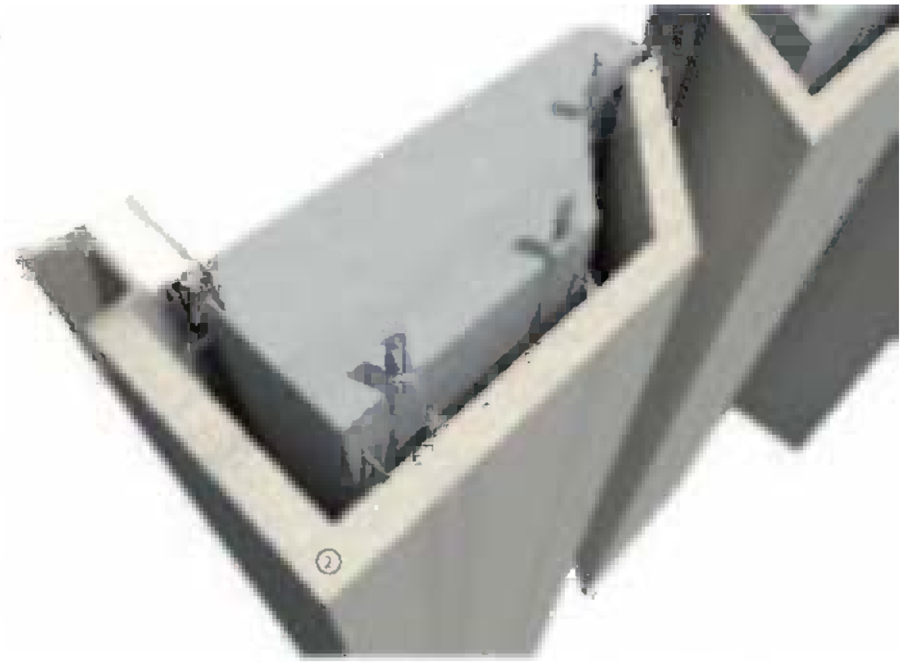
Horizontal section 1:10. Wall with precast concrete cladding panels, showing junction with window



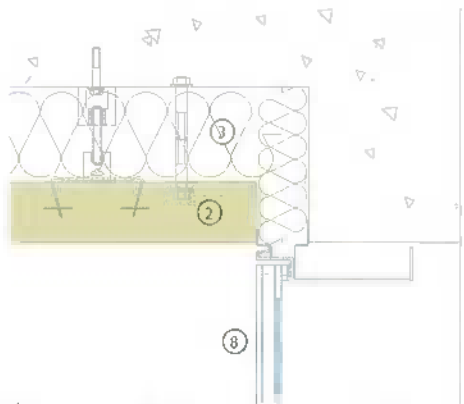
Vertical section 1:10. Wall clad with precast concrete panels



Horizontal section 1:10. Concrete wall with precast concrete cladding panels



3-D detail view of concrete wall with precast concrete cladding panels

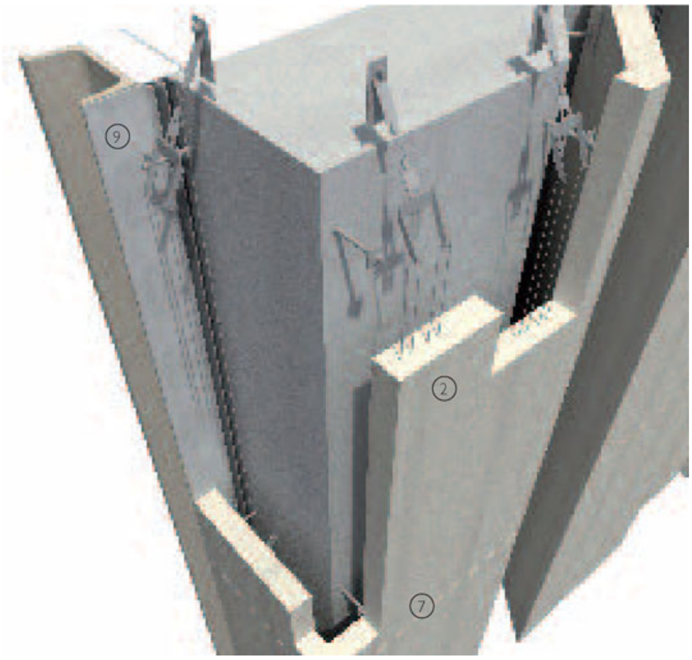


Horizontal section 1:10. Concrete wall with precast concrete cladding panels, showing junction with window

Details
1. Concrete floor deck
2. Precast concrete panel
3. Thermal insulation
4. Vertical baffle joint between panels
5. Vertical butt joint between panels
6. Horizontal lap joint
7. Horizontal butt joint
8. Window opening
9. Stainless steel dowel or angle
10. Rubber-based baffle
11. EPDM or silicone-based seal
12. Concrete column
13. Concrete corner panel
14. Concrete coping
15. Roof assembly

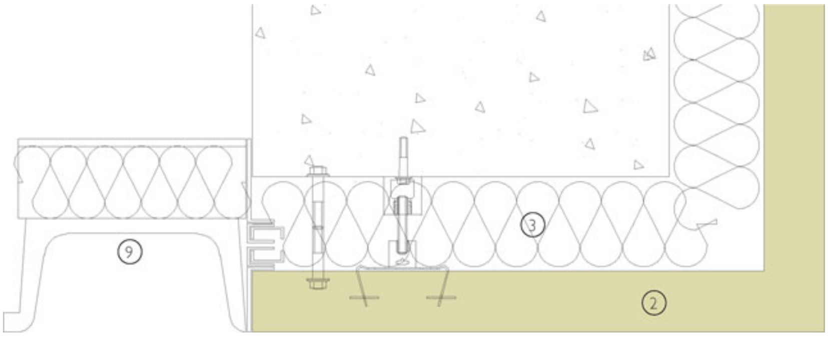
concrete in the decorative layer is minimised since it is usually much more expensive than grey structural concrete. Alternatively, larger scale facing pieces than those which can be bonded directly to the concrete in the bottom of the panel, such as terracotta, ceramic tiles or natural stone, are mechanically fixed to the top of the concrete in the mould as a decorative finish. Due to its larger size and weight, stone is usually fixed with pins or stainless steel brackets back to the precast panel. The greater size of stone panels over tiles makes them susceptible to relatively significant thermal movement for which the pins or brackets allow.

Another method of construction is to form an insulated sandwich panel where the inner part of the wall is loadbearing. Thermal insulation is set between the decorative and structural layers of concrete. This removes the thermal bridge across the panel and, if the interior concrete face is exposed, provides a thermal mass for night-time cooling in the building. The temperature of the outer lining can reach about 70°C in summer time, depending on geographical location. The sandwich panel ensures that the outer facing only is susceptible to thermal movement, the continuous insulation is kept dry and the inner massive loadbearing structure is protected from external temperature variations, reducing its own thermal movement. In addition the thermal capacity of the inner structure provides a regulation of temperature variations within the building from internal heating and heat sources by absorbing sur-

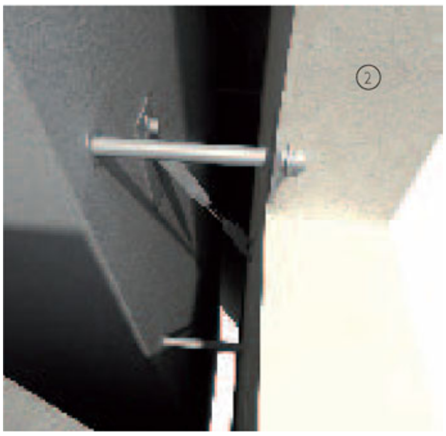


3-D detail cutaway view of concrete wall with precast concrete cladding panels

3-D view of fixing elements



Horizontal section 1:10. Concrete wall with precast concrete panel, junction with shadow gap



3-D view of fixing elements

pluses and supplementing deficiencies. External temperature changes in the daily cycle can be absorbed by the outer layer, with the thermal insulation keeping the internal heat in and external solar radiation out.

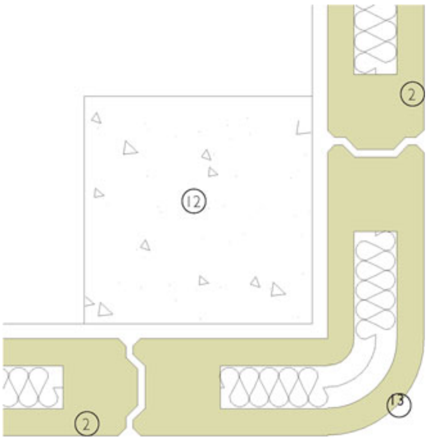
Thermal Insulation

Both loadbearing and non-loadbearing types without integral insulation have thermal insulation fixed to the internal face of the concrete wall. However, the thermal mass of the construction is lost. Where an additional external finish is used, typically a rainscreen panel in another material, the thermal insulation can be set on the outside of the precast panels, which maintains the ability to use the thermal mass of the interior face of the wall.

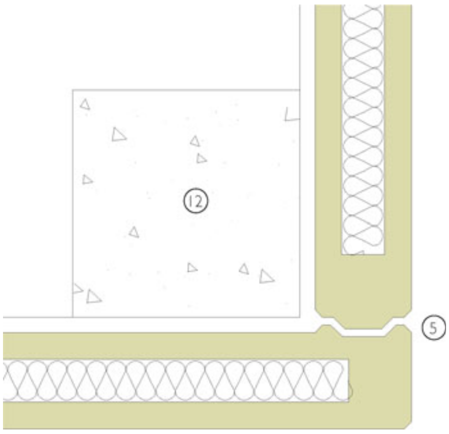
When thermal insulation is set on the inside face of precast panels, windows can be set directly above the insulation, avoiding the need to fit the window directly into the opening in the concrete. The window, typically aluminium or timber, has metal profiles that form a cill that is continuous with the window, avoiding any source of leaks across the gap between window and precast panel. Where windows are set directly into openings in precast panels, the opening often has a rebate (step) cast into the edge to provide more protection against rainwater penetrating the joint.

Joints

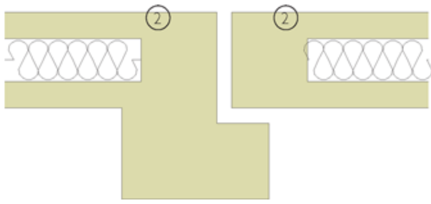
Joints between panels are of open or closed type. The open type has an inner membrane seal and an outer flexible mastic seal on the



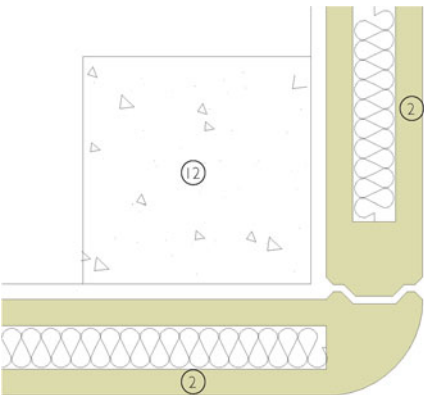
Horizontal section 1:10. Panel junction at corners. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



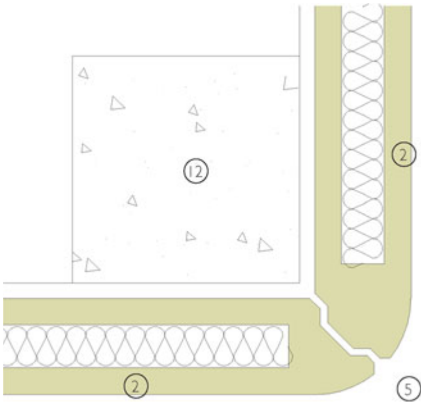
Horizontal section 1:10. Panel junction at corners. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



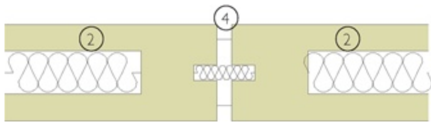
Horizontal section 1:10. Panel-to-panel junctions. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



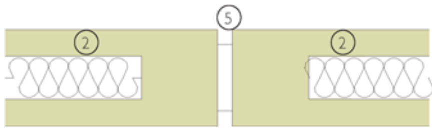
Horizontal section 1:10. Panel junction at corners. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



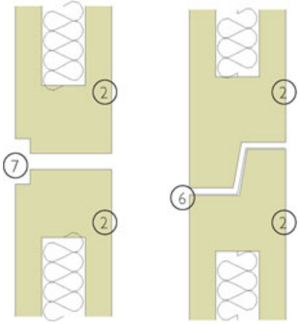
Horizontal section 1:10. Panel junction at corners. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



Horizontal section 1:10. Panel-to-panel junctions. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins



Horizontal section 1:10. Panel-to-panel junctions. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins

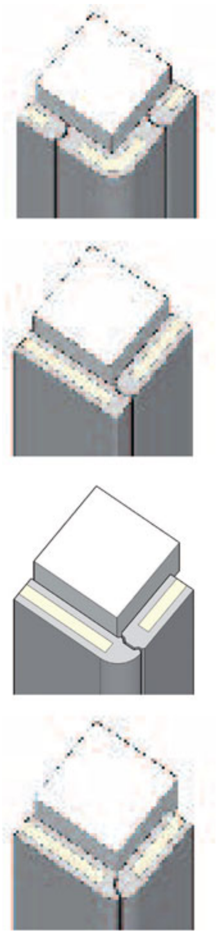


Vertical section 1:10. Panel-to-panel junctions. In-situ cast concrete wall cast in 2 skins with rigid closed cell insulation between skins

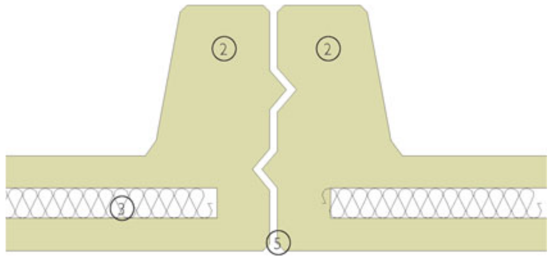
inner face. The closed type has a single outer seal of flexible mastic. These principles apply to both vertical and horizontal joints. In the horizontal joints, a step in the panel may be provided to assist in weather tightness of panels, which are upwards of 150mm thick. Minimum joint widths are typically 10-12mm thick for panels ranging from 1800mm wide to 2400mm wide, increasing to a joint width of 16-18mm for panels 6000mm wide. These widths help reduce visually any variations in the width of the joint as a result of joining panels. Visually, joints are recessed as shadow gaps in order to conceal small differences of alignment between panels.

Open joints are internally drained and ventilated in the manner of unitised curtain walling. In an open joint, windblown rain is allowed to pass through an outer gap between two panels that form a vertical joint. An EPDM baffle strip is set into a continuous slot formed in the edges of two adjacent panels and 3water entering this joint, which forms an inner chamber, is drained away from the slot and out through the horizontal joint below. The interior face of the joint is either closed with an air seal formed using wet or extruded silicone, in the case of a non-load-bearing cladding panel, or is mechanically fixed to the panel below and grouted with a cement-based material in the case of load-bearing panels.

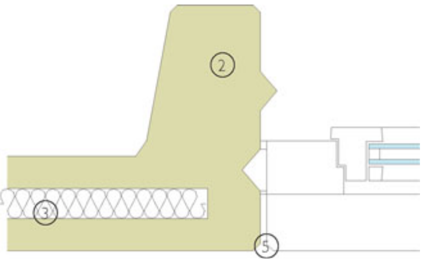
Horizontal open joints between panels are made by forming a step in the profiles of the top and bottom edges of adjacent panels in order to drain water out of both vertical



Details
1. Concrete floor deck
2. Precast concrete panel
3. Thermal insulation
4. Vertical baffle joint between panels
5. Vertical butt joint between panels
6. Horizontal lap joint
7. Horizontal butt joint
8. Window opening
9. Stainless steel dowel or angle
10. Rubber-based baffle
11. EPDM or silicone-based seal
12. Concrete column
13. Concrete corner panel
14. Concrete coping
15. Roof assembly

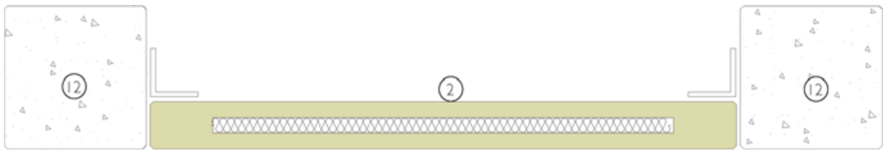


Horizontal section 1:10. Joint between precast panels

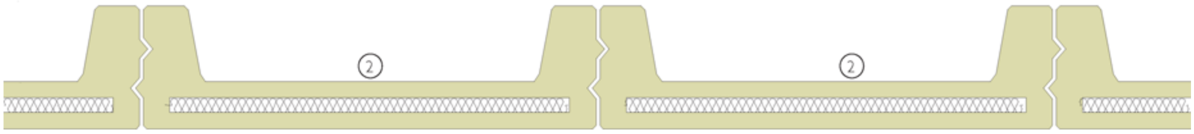


Horizontal section 1:10. Connection between precast concrete panel and window

3-D views of corner junction between precast panels



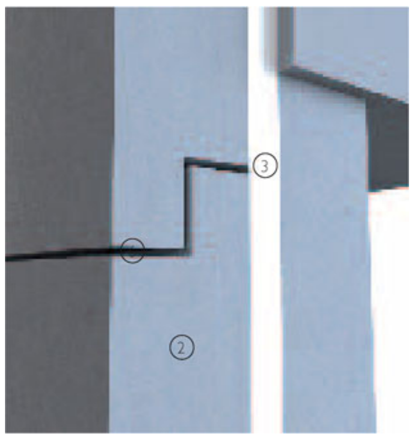
Horizontal section 1:25. Connection between precast concrete panel and building structure



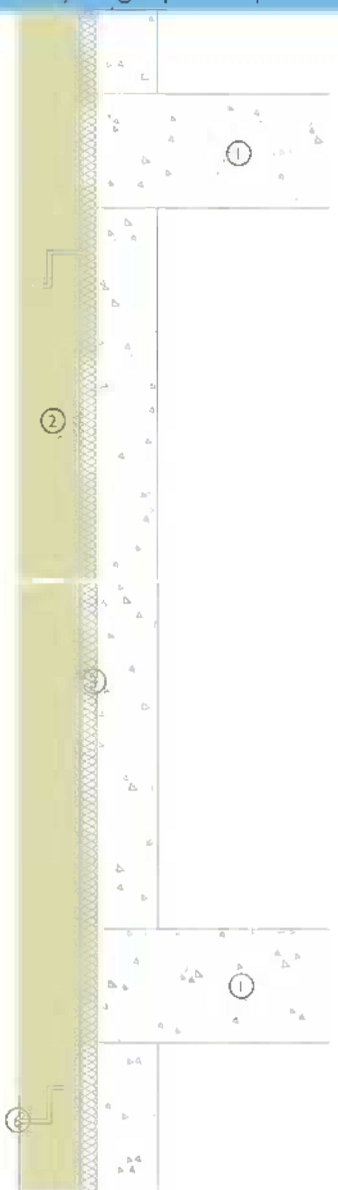
Horizontal section 1:25. Joint between precast concrete panels

and horizontal joints as well as to prevent rainwater from flowing directly through the joint. The horizontal stepped joint is used for both loadbearing and non-loadbearing type panels, but the detail varies with the way the upper panel is either supported on the lower panel in a loadbearing panel or is separated from the lower panel in a non-loadbearing panel. However, the general principle for all panel types remains the same. This ensures that water running down the EPDM baffles in the vertical joints is drained out where it meets the horizontal joints. A continuous horizontally-set EPDM strip is set on the inner face of the joint, in the top of the lower panel. The EPDM strip in the vertical joint is lapped over the face of the EPDM on the horizontal joint. The rear of the joint, adjacent to the interior face of the panel is either closed with an air seal as for vertical joints, or is mechanically fixed to the panel below and grouted in the same way as the vertical joints.

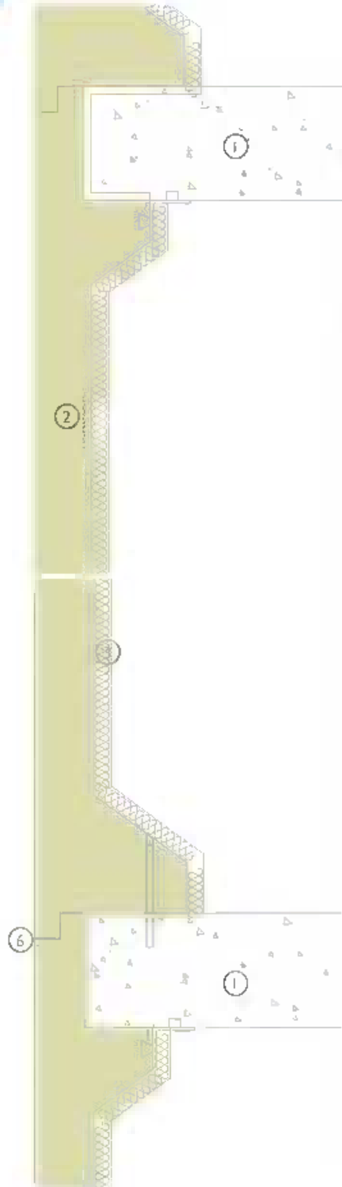
Closed joints are sealed on the outside face with a wet applied silicone or polysulphide sealant. Any water that penetrates this outer seal is drained away in the void behind. Water is released through weep holes (small holes) in the horizontal joints. Closed joints are more commonly used with loadbearing panel construction where panels are bonded together at joints and where most of the joint is required to be filled to provide structural continuity from panel to panel.



3-D view of junction between precast panels



Vertical section 1:25. Wall to floor connection with



Vertical section 1:25. Wall to floor connection with insulation on inner face

3-D view of precast concrete wall

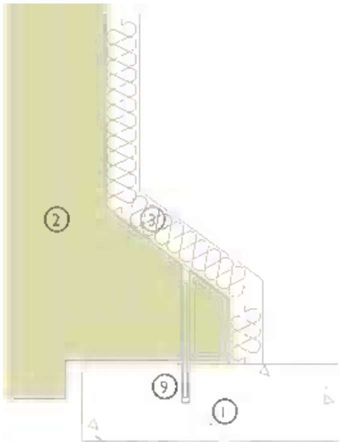
3-D view of precast concrete wall

Acid etched finish

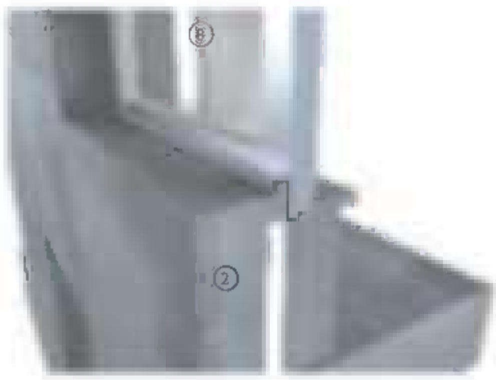
In addition to the finishes described in the previous section on in-situ cast finishes, which can also be used in precast panels, acid etching is possible. Acid etching is particularly well adapted to precast panels since they are cast flat, where acid treatments can be carefully controlled.

In cured panels, the surface of the precast concrete is treated with hydrochloric acid, which is then rinsed off. This method first removes the cement skin, then strips away the grains of sand within the concrete beneath, depending on the concentration of the acid solution and length of time for which it is applied. The acid etching method can be used to create either a weathered finish or an acid washed finish. A weathered concrete effect is produced by submerging a precast concrete panel in an acid bath. This process is most commonly used when all faces of the unit need to be treated. With acid washed concretes, a gel containing acid is applied to the surface to be treated. This method is well adapted to treatment on specific areas of concrete, to form a surface texture or pattern on the concrete wall.

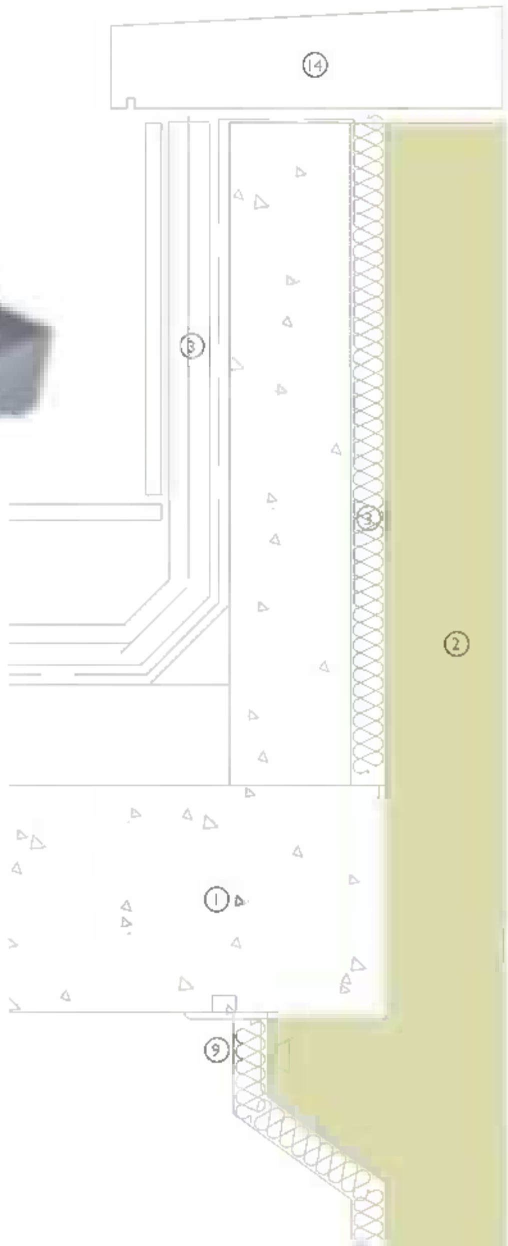
Acid etching is well suited to exposing small aggregate in the panel surface by exposing only a small amount of the concrete texture beneath its skin after casting has taken place. The precipitation of salts from the acid-cement and aggregates quickly neutralises this, which can only be continued



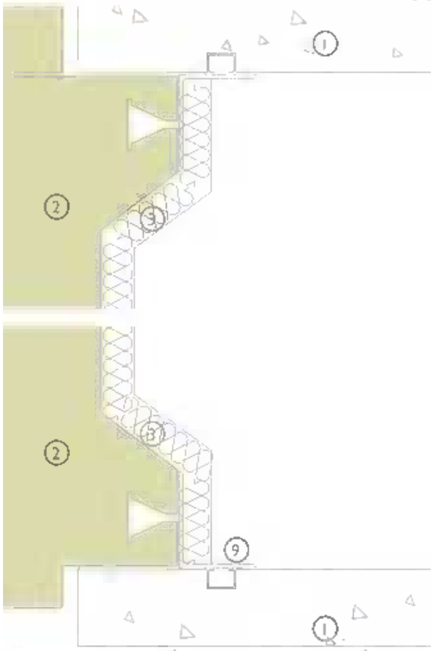
ertical section 1:10. Junction between
anels. Panels insulation on inside face



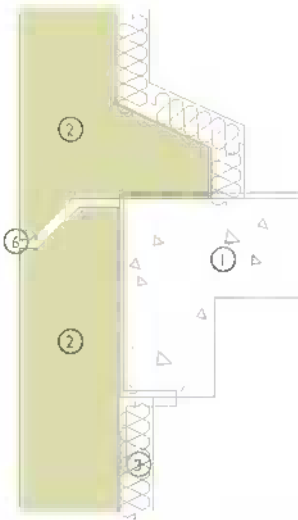
3-D view of junction at window jamb. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



Vertical section 1:10. Junction at parapet level for typical wall condition and for window jamb. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins



ertical section 1:10. Junction between
anels. Panels Insulation on inside face

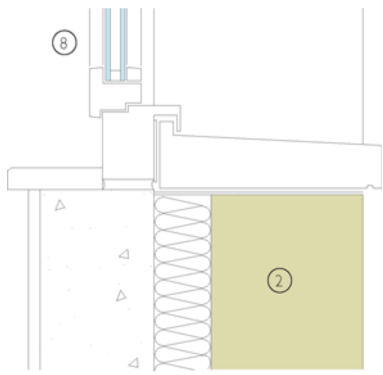


Vertical section 1:10. Junction between panels. Panels insulation on inside face

by rinsing and applying more acid. Acid etching always requires rinsing to remove the precipitated salts and neutralise the surface. Acid etching attacks limestone aggregates, and sometimes more quickly than the cement, while the silica-based aggregate remains. The surface texture can be quite different, depending on the fine aggregate material, being more granulated in the case of silica and less coloured in the case of limestone.

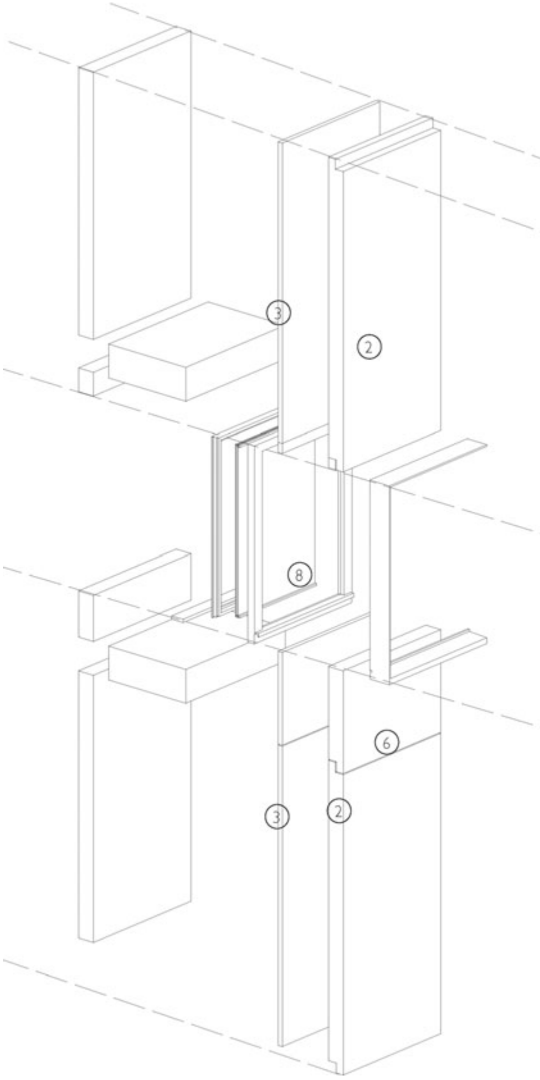
Details

1. Concrete floor deck
2. Precast concrete panel
3. Thermal insulation
4. Vertical baffle joint between panels
5. Vertical butt joint between panels
6. Horizontal lap joint
7. Horizontal butt joint
8. Window opening
9. Stainless steel dowel or angle
10. Rubber-based baffle
11. EPDM or silicone-based seal
12. Concrete column
13. Concrete corner panel
14. Concrete coping
15. Roof assembly

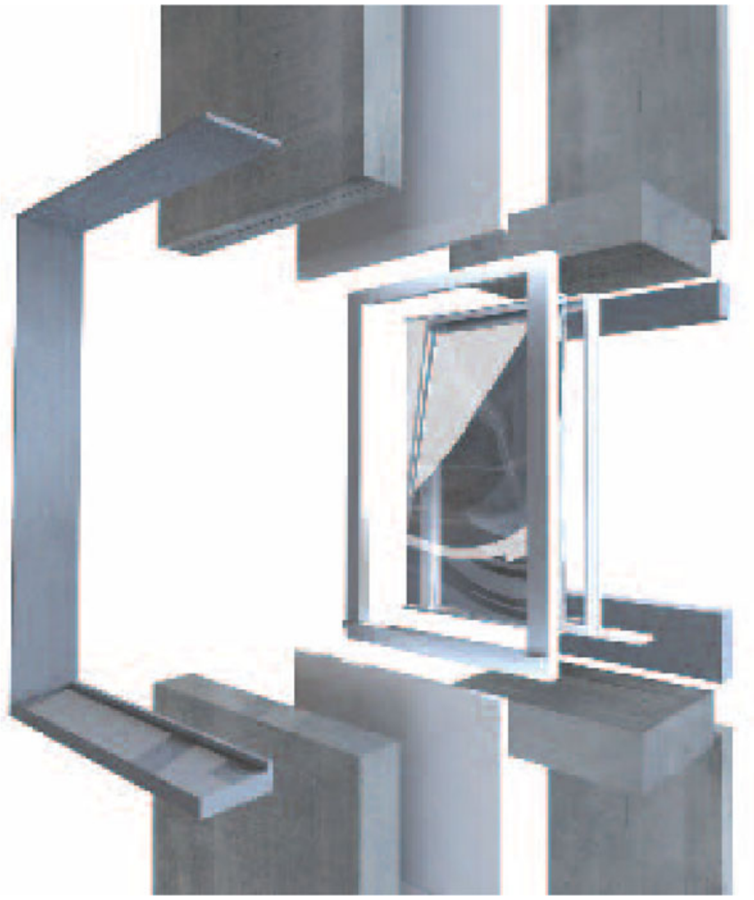


Vertical section 1:10. Junction at window jamb. In-situ cast concrete wall cast in two skins with rigid closed cell insulation between skins

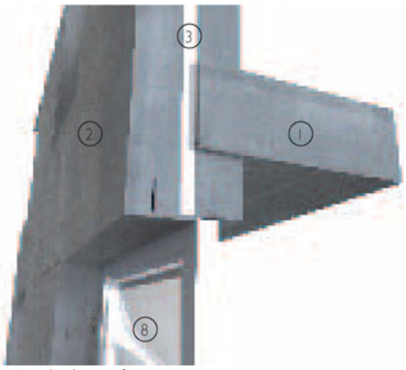
3D view of precast concrete wall



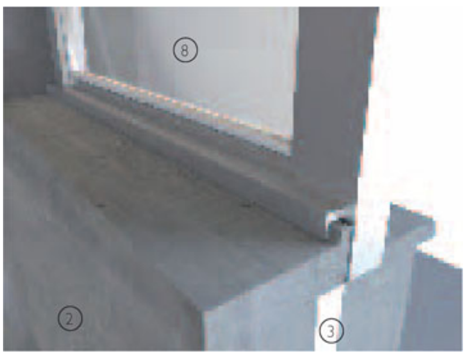
Exploded axonometric of wall assembly



3-D exploded view of wall assembly



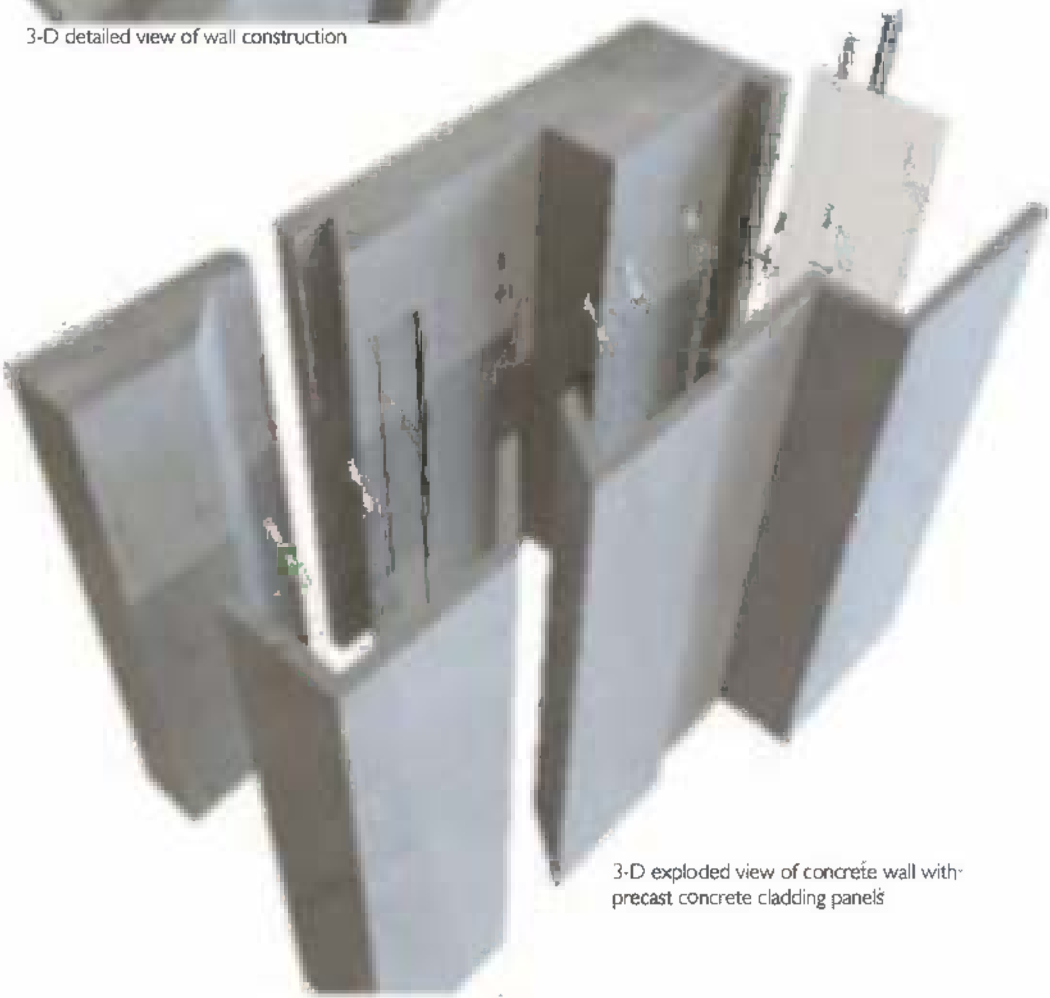
3D detail view of precast concrete wall



3D detail view of precast concrete wall

3-D detailed view of wall construction

3-D detailed view of wall construction



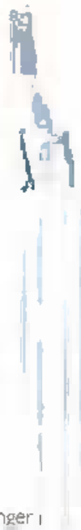
3-D exploded view of concrete wall with precast concrete cladding panels

Details

1. Concrete floor deck
2. Precast concrete panel
3. Thermal insulation
4. Vertical baffle joint between panels
5. Vertical butt joint between panels
6. Horizontal lap joint
7. Horizontal butt joint
8. Window opening
9. Stainless steel dowel or angle
10. Rubber-based baffle
11. EPDM or silicone-based seal
12. Concrete column
13. Concrete corner panel
14. Concrete coping
15. Roof assembly

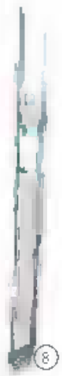
Series of components of wall assembly

Internal concrete wall



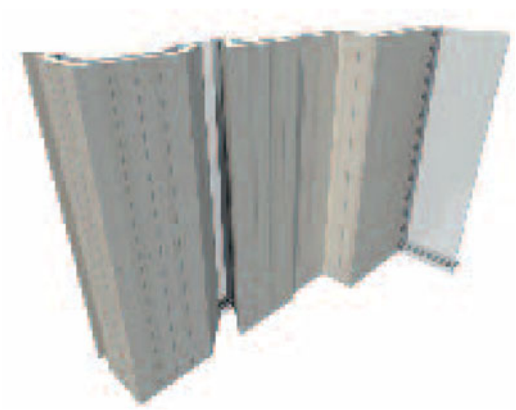
Hanger

Bolts

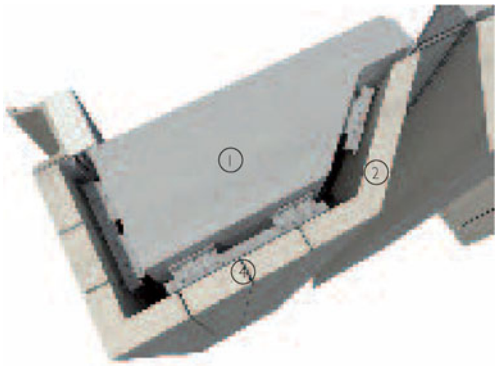


Window

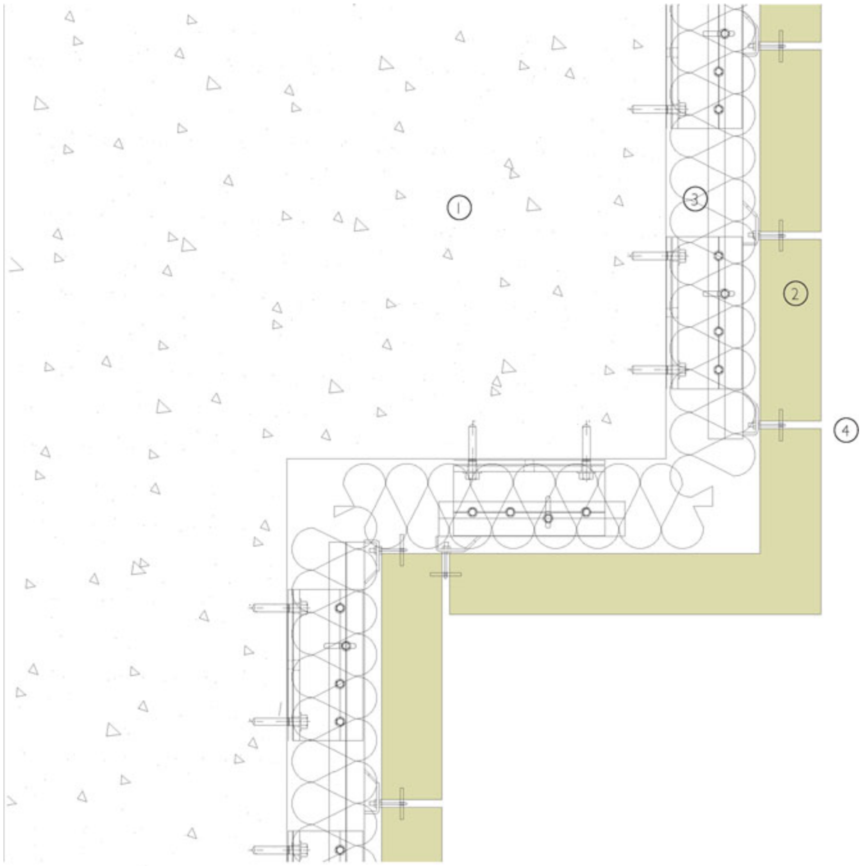
Precast concrete panels



3-D view of wall with small precast cladding panels



3-D view of wall with small precast cladding panels



Horizontal section 1:10. Wall construction with small precast cladding panels

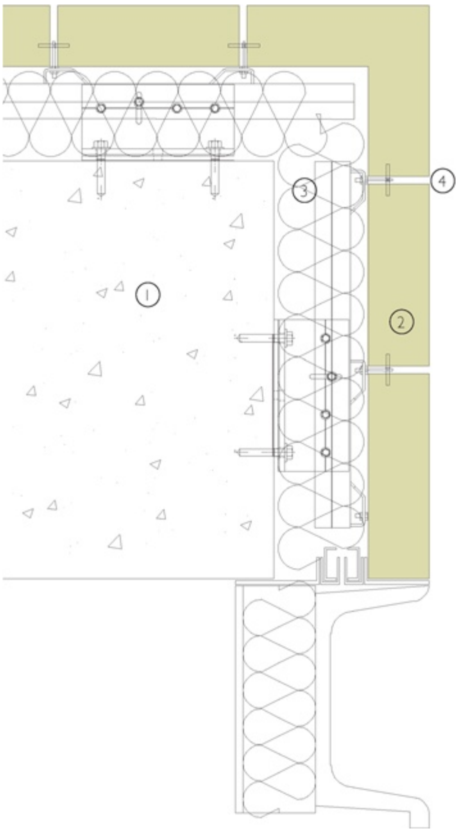
Smaller precast panels than those used in storey height sizes have been undergoing considerable development over the past 20 years. They are made as either individually supported panels or as self-supporting stacked panels.

Individually supported panels are fixed directly to a background supporting wall, usually formed either in reinforced concrete or in concrete block. Panels are usually open jointed to allow them to dry easily after wetting in rain and to allow rainwater to drain easily down the backs of the panels or down the face of the backing wall. Spandrel panels are usually part of a proprietary precast concrete system of frame, floor slab and spandrel panel, with ribbon windows added as separate elements, or full-height glazing in areas where sprinklers are not required. Self supporting panels are a more recent development and comprise precast panels which are stacked together in the manner of metal composite panels, with a tongue-and-groove connection between panels in the horizontal joints. These panels have the advantage of having internal insulation together with external and internal faces that require no further treatment.

Individually supported panels

This system allows narrower joints to be formed between panels than those possible in full-height panels, and allow a varied, non-rectangular layout to be used with a joint pattern independent of the backing wall. Individually supported panels use a fixing method which is similar to stone cladding panels, but with the possibility of much bigger panel sizes. Natural stone cladding is limited to sizes that can be cut from a stone block, which is usually around 2000mm x 2000mm x 2000mm, depending on stone type. This yields stones which are a maximum of around 1500mm x 750mm, or 1500mm x 1000mm depending on the strength of the stone. Precast concrete panels can be much larger, typically 1500mm x 3000mm which can be supported on stainless steel fixings back to floor slabs and the primary structure. An advantage of precast concrete over natural stone in smaller panels is that corner units and non-rectangular shaped units can be formed more easily and economically than in stone, though the number of panel types is restricted for any project in order to keep the system economic. Small precast concrete rainscreen panels are used increasingly in apartment buildings where large areas of opaque wall can be given a high degree of finish in the material while benefiting from the casting ability of the material.

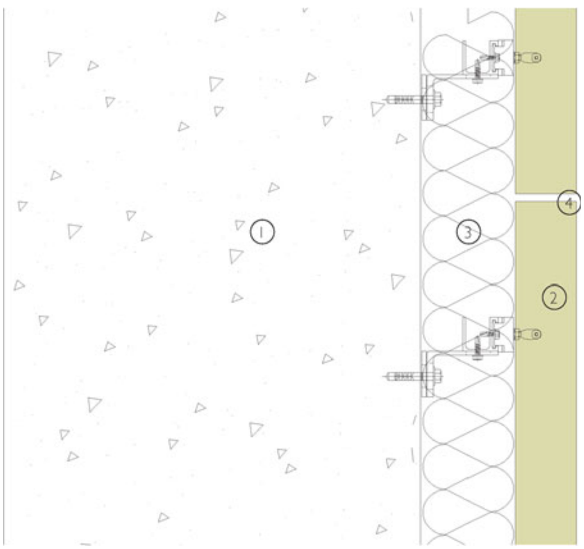
Panels are most commonly fixed with stainless steel angles which are either cast-in or are bolted to the concrete. The angles are secured to brackets fixed to a backing wall. Slotted holes provide adjustment vertically, horizontally and laterally. These panels have the advantage of being able to have a rich surface texture as a result of the casting process in an individual mould. Slots, grooves and complex profiling can be incorporated in the manner of profiled metal cladding. Backing walls are usually waterproofed in the outer face. Closed cell thermal insulation is set on the outside of this to insulate the building structure. An alternative method is to use metal foil faced insulation which is semi-rigid. The insulation is fixed directly to



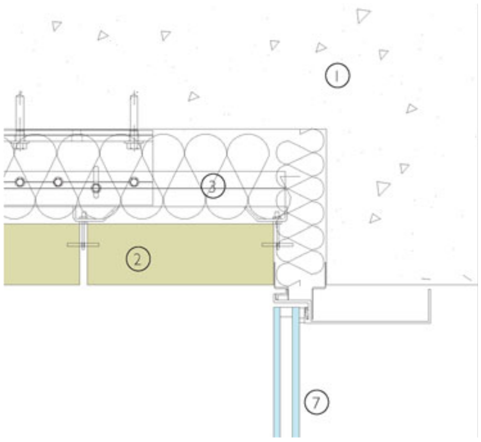
Horizontal section 1:10. Wall construction with small precast cladding panels and shadow gap

Details

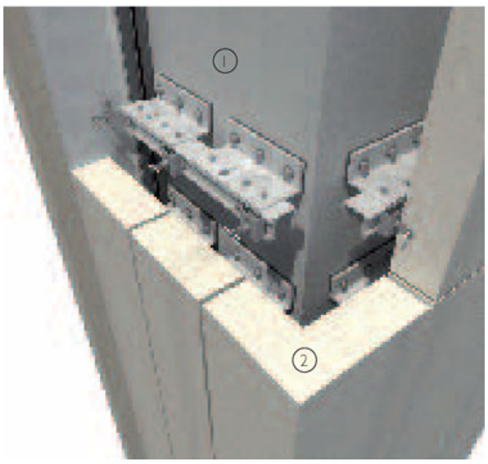
1. Backing wall
2. Precast concrete panel
3. Closed cell thermal insula tion
4. Vertical joint open or closed type
5. Horizontal joint (typically a lap) open or closed type
6. Internal finish
7. Window frame
8. Reinforced concrete column
9. Metal corner trim
10. Metal parapet coping
11. Concrete floor deck
12. Adjacent panel in different material
13. Waterproof membrane
14. Precast concrete coping



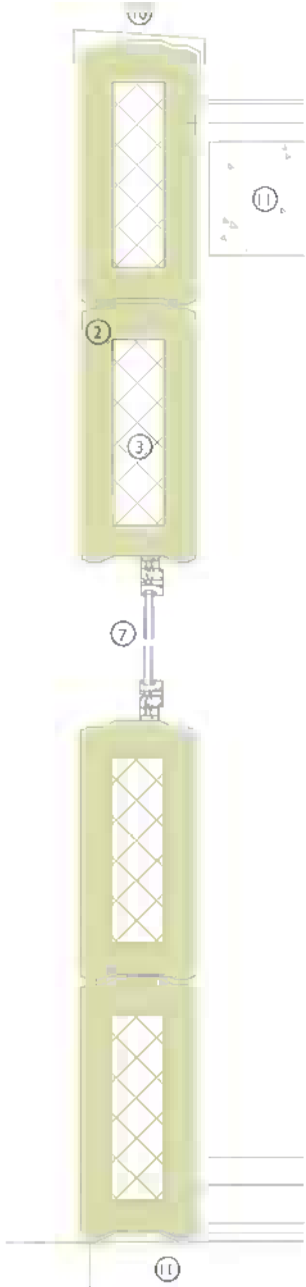
Vertical section 1:10. Wall construction with small precast cladding panels



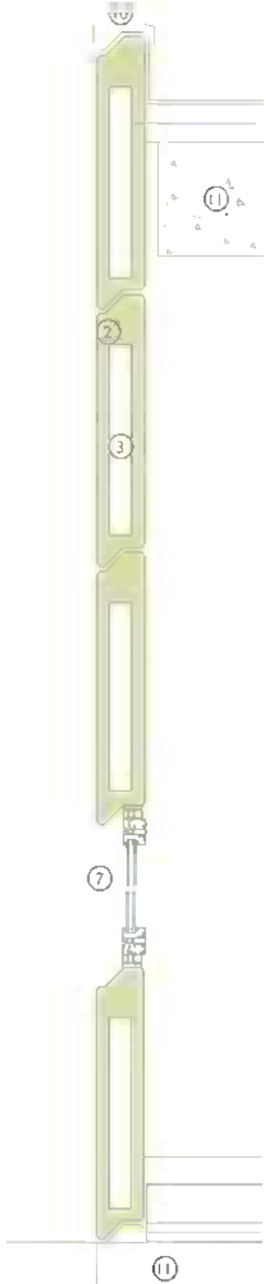
Horizontal section 1:10. Wall construction with small precast cladding panels, window junction



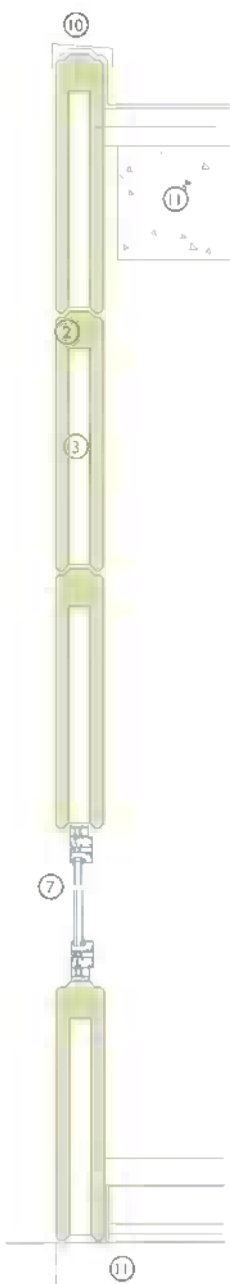
3-D cutaway view of small precast panel construction



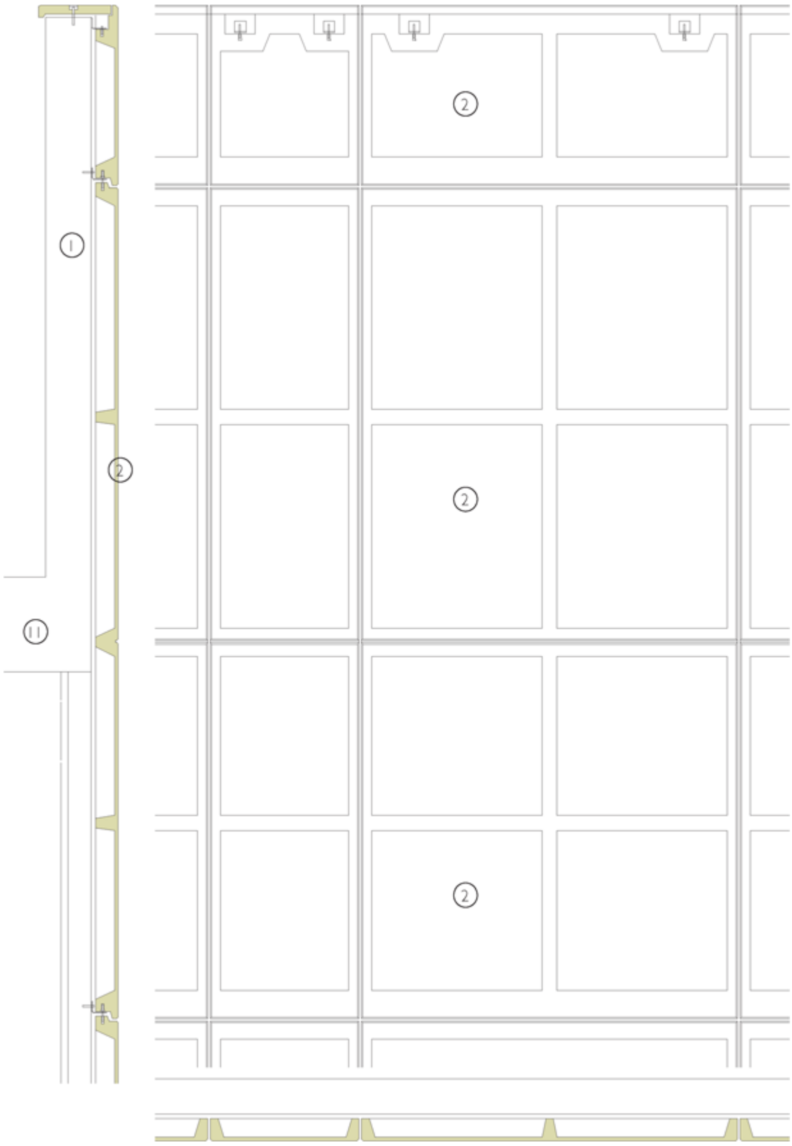
ertical section 1:25. Typical pre-ast concrete wall construction. arge scale pan ls



Vertical section 1:25. Typical precast concrete wall construction. Small-scale panels with drained joint



Vertical section 1:25. Typical precas concrete wall construction. Small-scale panels with sealed joint



Horizontal, vertical sections & elevation 1:50. Glass reinforced concrete (GRC) panels with open joints

3-D view of blockwork wall clad in small precast panels

Details

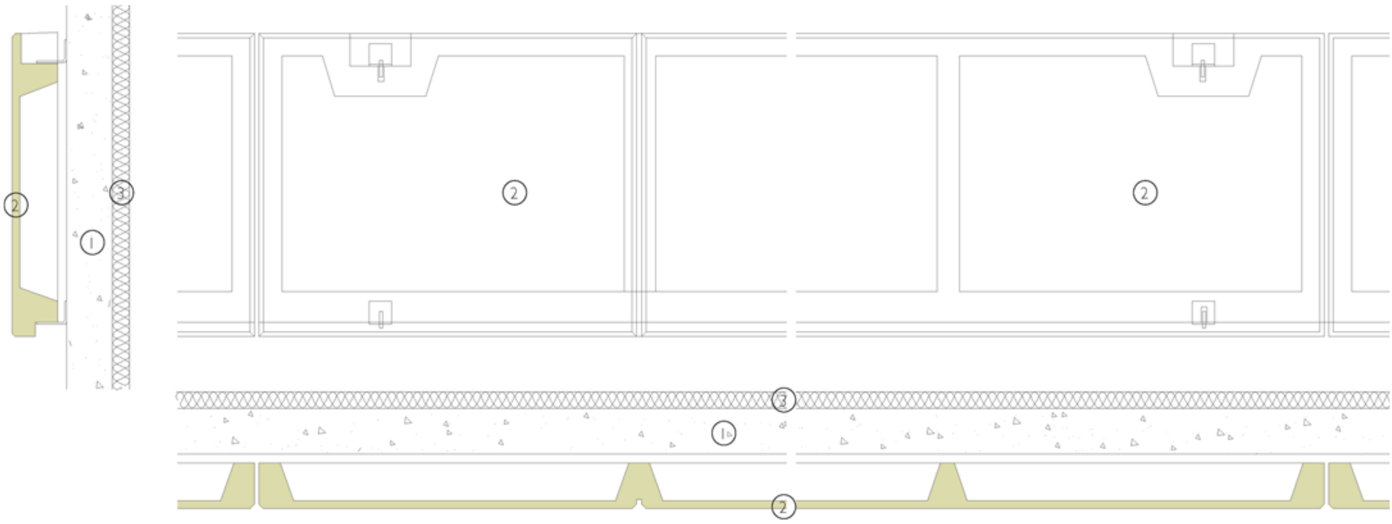
1. Backing wall
2. Precast concrete panel
3. Closed cell thermal insula tion
4. Vertical joint open or closed type
5. Horizontal joint (typically a lap) open or closed type
6. Internal finish
7. Window frame
8. Reinforced concrete column
9. Metal corner trim
10. Metal parapet coping
11. Concrete floor deck
12. Adjacent panel in different material
13. Waterproof membrane
14. Precast concrete coping

the blockwork backing wall, with an outer metal foil face that provides the full weather protection. Joints between strips of insulation are sealed with adhesive foil tape.

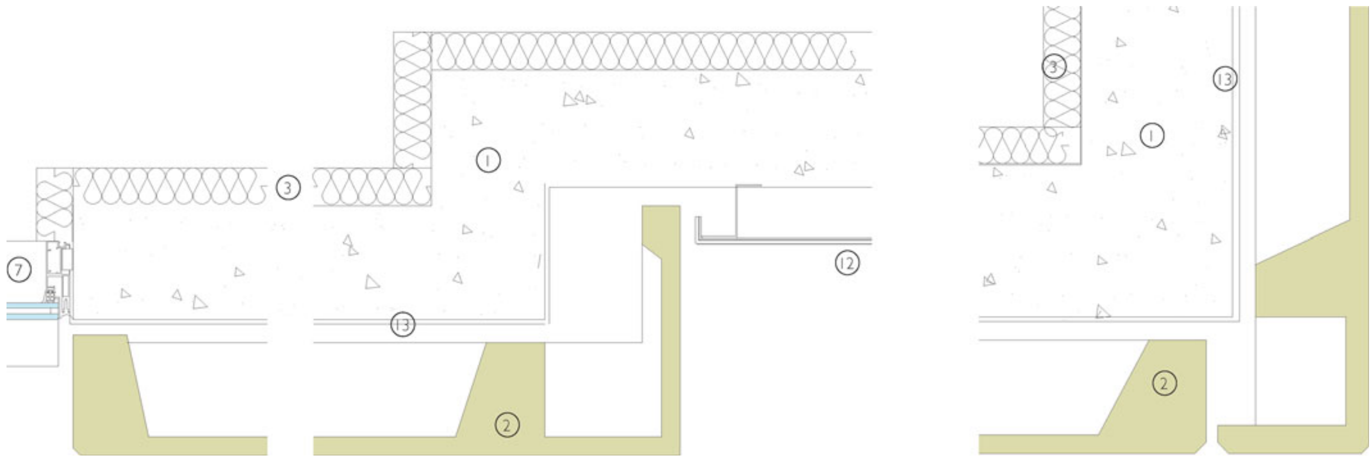
Like stone cladding, panels are usually supported on short lengths of stainless steel angle at each floor level, back to the floor slab. This overcomes the risk of progressive collapse of a cladding panel, where a failure in one panel would cause it to drop onto the panel below, causing further collapse down the facade. Panels at floor level are fixed directly to the slab, with fixings designed so that they can take the full load of the panels immediately above, in the event of fixings to panels above failing either partially or completely.

Self supporting stacked panels

Stacked panels have the advantage of being supported at the base of the wall in single floor buildings up to around 10 metres, and at every floor level in buildings of more than one storey. When supported at their base, stacked panels are set on a concrete beam or strip foundation forming part of the primary structure. Panels are stacked with continuous vertical joints where they are restrained by columns, in either reinforced concrete or steel, but concrete is more common due to the greater ease of connecting the panels to the primary structure. The need to support panels at joints results in their being wide in order to maximise the distance between columns, or support posts. As a result they are not very tall in order to



Horizontal, vertical sections & elevation 1:25. Glass reinforced concrete (GRC) panels with open joints

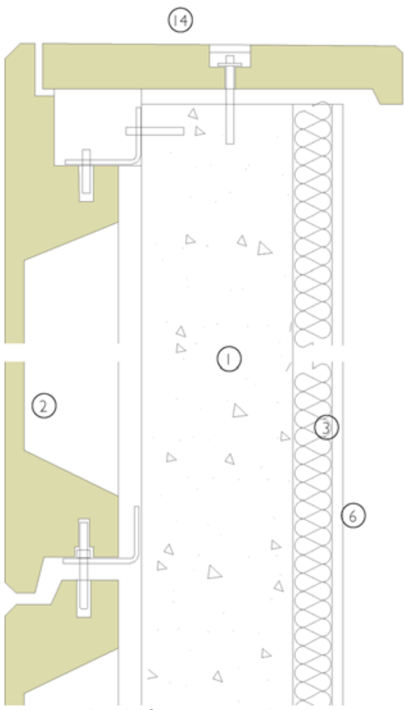


Horizontal sections 1:10. Window junctions and corners. Glass reinforced concrete (GRC) panels with open joint

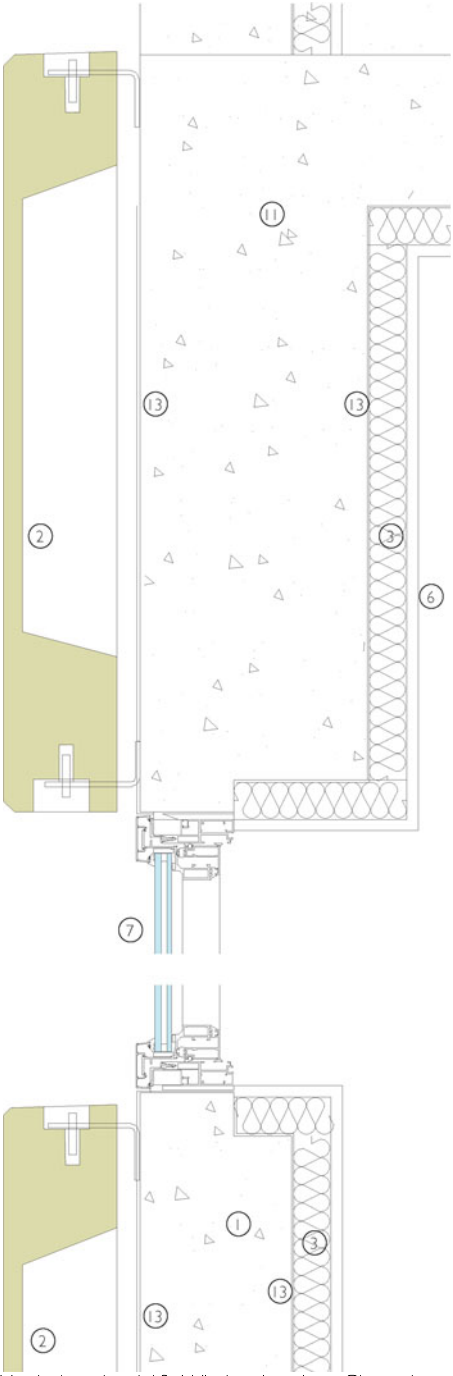
reduce their weight to that which can be lifted by a modest sized crane, typically with a lifting capacity of 4 to 6 tonnes.

The thermal insulation in panels does not create a complete thermal break from outside to inside, since the concrete block has concrete faces on its top and bottom edges in order to serve as a method of creating a tongue and groove joint in the horizontal joints. If the concrete panel were formed as a sandwich panel then mechanical fixings, such as stainless steel cramps, would be needed both to hold the two sides of the concrete panel together and to connect them together as they are stacked vertically. This would create a diaphragm wall rather than a monolithic loadbearing wall, making it much more expensive as a result of all the mechanical fixings needed. However, the thermal bridge across the vertical and horizontal joints in the panel can result in pattern staining as the result of heat transmission across the panel. This is particularly noticeable on the internal face of the panel.

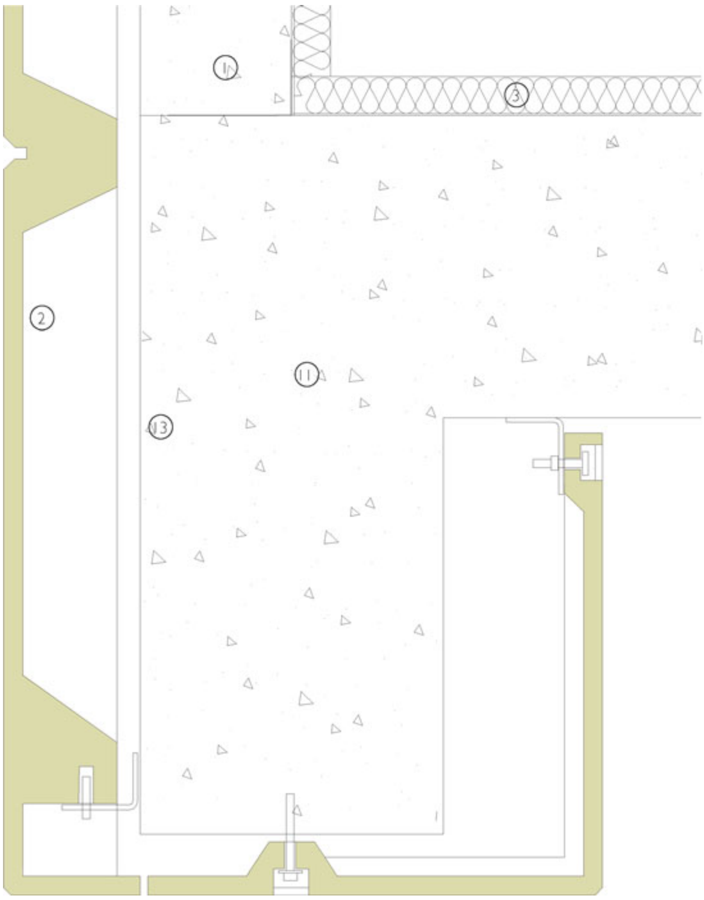
Stacked panels fabricated in thicknesses of 75mm to 100mm can form part of a complete cavity wall construction of 200mm – 300mm thickness when used as a self-supporting outer skin. The inner wall can vary widely in its construction from concrete block to light gauge metal stud wall with a waterproofed outer facing. The cavity between the outer concrete panel wall and the inner backing wall has a ventilated cavity of 50mm – 75mm width. The cavity is ventilated at the top and bottom of the wall.



Vertical section 1:10. Parapet and panel-to-panel joint. Glass reinforced concrete (GRC) panels with open joints



Vertical section 1:10. Window junctions. Glass reinforced concrete (GRC) panels with open joints



Verticalsection 1:10. Panel soffit. Glass reinforced concrete (GRC) panels with open joints

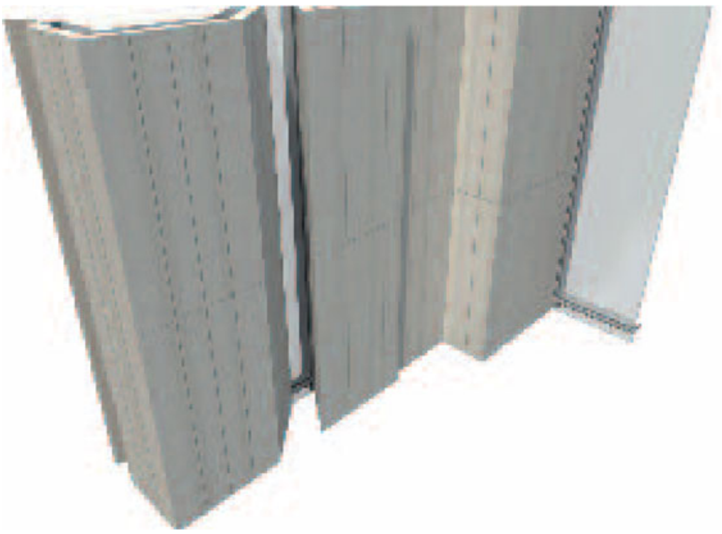
Details

1. Backing wall
2. Precast concrete panel
3. Closed cell thermal insulation
4. Vertical joint open or closed type
5. Horizontal joint (typically a lap) open or closed type
6. Internal finish
7. Window frame
8. Reinforced concrete column
9. Metal corner trim
10. Metal parapet coping
11. Concrete floor deck
12. Adjacent panel in different material
13. Waterproof membrane
14. Precast concrete coping

Parapets and cills

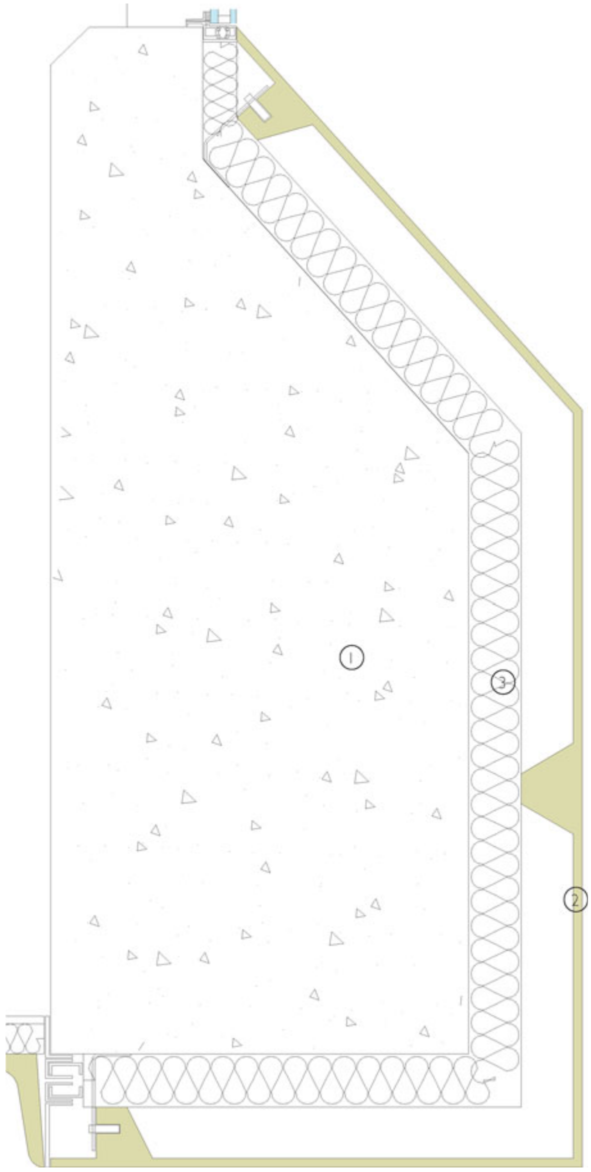
The detailing of parapets and cills for both individually supported panels and for stacked panels follows the same principles. At parapet level, self-supporting concrete panels have the advantage of not needing an additional inner parapet wall but require a pressed aluminium coping over the top of the wall to both keep rain from penetrating the top panel, where it is most vulnerable, as well as to throw rainwater off the coping inwards to an inner gutter at the edge of the roof. The visible vertical face of the coping is usually kept to a minimum in order to reduce its visual impact on the facade. A precast coping is also used instead of aluminium, but this is essentially for visual reasons. The advantage of an aluminium coping is that it can be pressed to fold over the inside face of the parapet wall, which protects the roof membrane from the effects of sunlight. It also provides an overcloak to the roofing membrane which wraps up the inside face of the parapet wall and across the top of the precast panel, where it forms a complete weathertight seal to the top of the wall. A coping made from precast concrete is less easy to handle, but provides effective protection to the waterproof membrane beneath.

The base of walls in precast panels are detailed in a similar way to other forms of loadbearing masonry. A continuous damp proof membrane (DPM) extends up from the outside of the structure beneath and forms a damp proof course (DPC) which is positioned so that it extends at least 150mm



3-D view of wall clad in small GRC panels

3-D detail view of wall clad in GRC precast panels

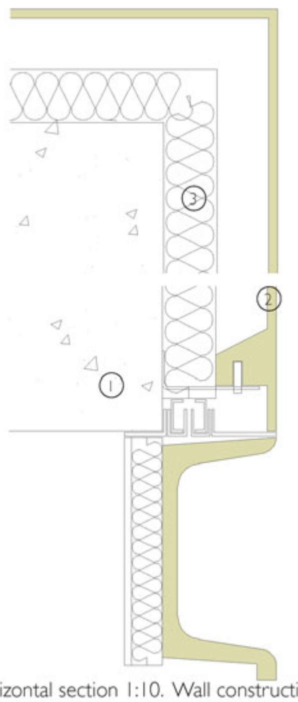


Horizontal section 1:10. Wall construction with small GRC cladding panels

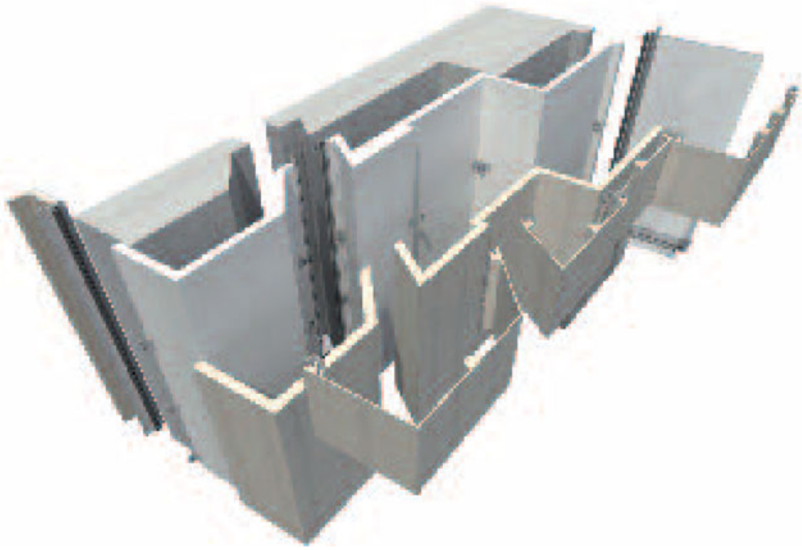
above external ground level. The DPC is positioned so that the lowest row of panels at ground level appears to sit on the ground with its bottom course level with the adjacent ground or pavement. This avoids the need for a 150mm - 200mm plinth around the base of the wall that is popular in load-bearing brick construction in order to avoid rainwater that is splashed off the ground soaking into the base of the wall and causing damp penetration on the inside of the wall at floor level.

Openings

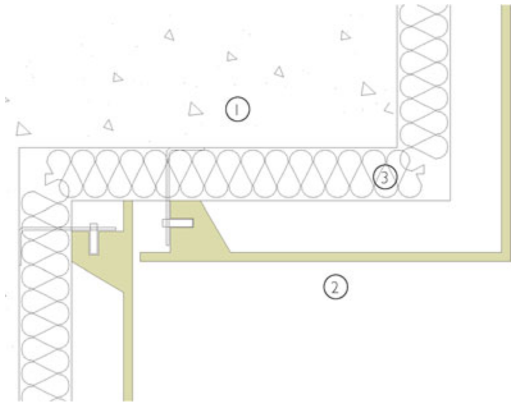
The characteristic tongue-and-groove profile of horizontal joints makes it necessary to provide a complete edging to the openings formed in precast panels. Special precast panels for openings are not usually made since this adds considerable cost to the system. The most common method of forming an edge to a window or door opening is to use metal sheet on all sides of the reveal to the opening. This provides usually a thin edge as well as being able to be continuous with a window or door frame and providing an integral cill to the opening.



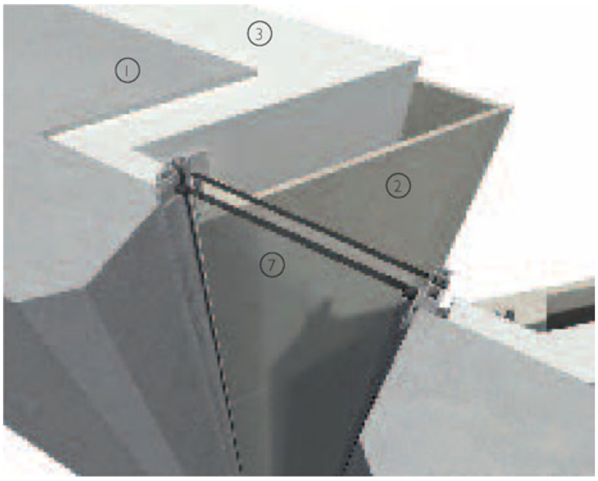
Horizontal section 1:10. Wall construction with small GRC cladding panels



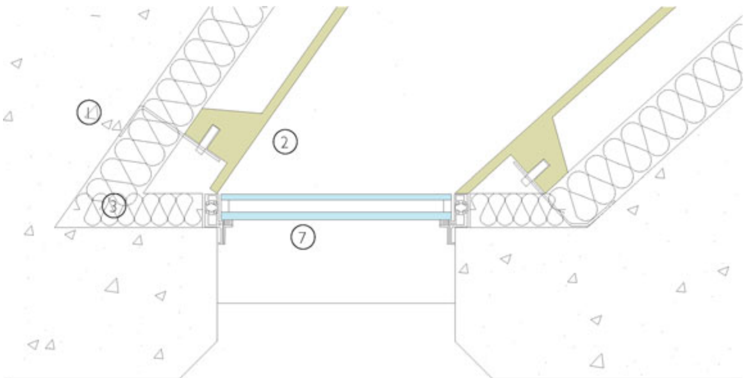
3-D exploded view of wall construction



Horizontal section 1:10. Wall construction with small GRC cladding panels



3-D detail view of junction between wall and window



Horizontal section 1:10. GRC cladding panels construction with window connection

Details

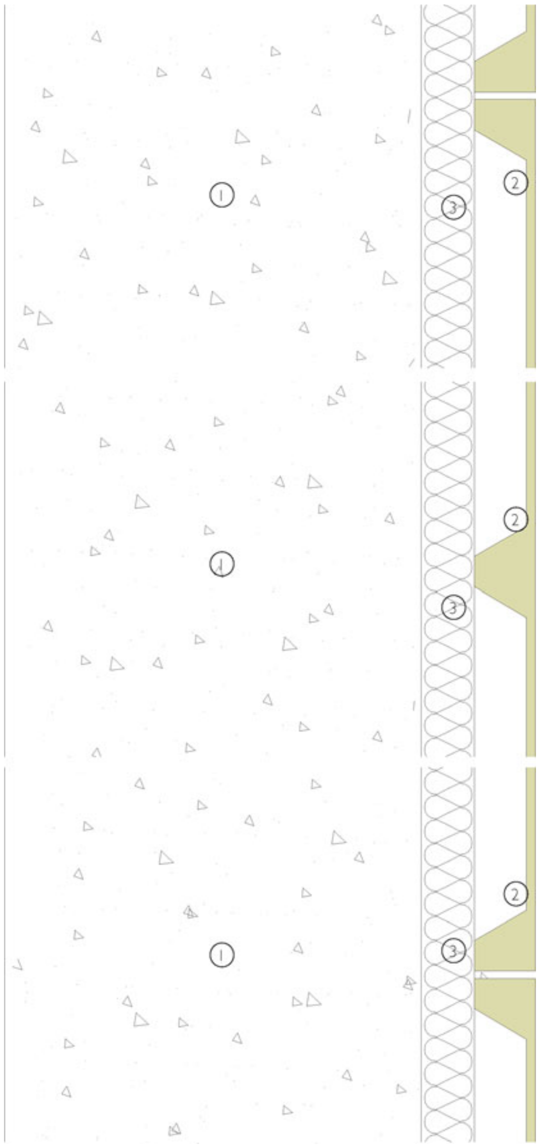
1. Backing wall
2. Precast concrete panel
3. Closed cell thermal insula tion
4. Vertical joint open or closed type
5. Horizontal joint (typically a lap) open or closed type
6. Internal finish
7. Window frame
8. Reinforced concrete column
9. Metal corner trim
10. Metal parapet coping
11. Concrete floor deck
12. Adjacent panel in different material
13. Waterproof membrane
14. Precast concrete coping

Sand blasted finish and tooled finish

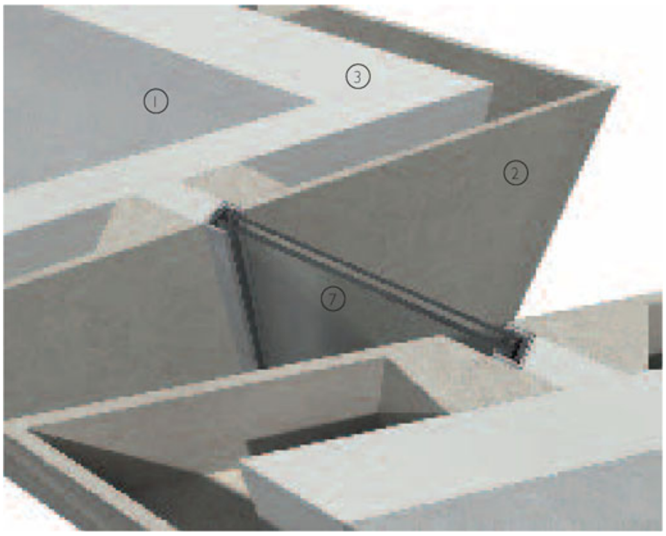
In addition to the finishes described in the texts on both in-situ concrete and precast concrete panels, the techniques of sand blasting and tooling are commonly used on small cladding panels.

The sand blasting of concrete panels is usually done with iron filings rather than sand particles. Concrete is blasted with differing amounts of abrasive iron filings at high pressure, depending on the hardness of the concrete wall panel. This slightly erodes the face of the concrete, either back to the surface sand grains or more deeply to the coarse aggregate beneath. The essential visual characteristic of this method is that it abrades all aggregates and dulls them as a result, producing a characteristic matt surface. Sand blasting abrades both in proportion to the hardness of the concrete surface and to the proportion of coarse aggregate in the cement mix. This leads to different surface textures, depending on the type of small aggregate, and the quality and degree of hydration of the cement mix. Sand blasting allows the finish to be obtained gradually and controlled visually as work progresses, without the need for rinsing which slows down the process. Acid etching also allows very localised working with the use of stencils.

Tooled concrete is a method of texturing concrete by either striking the material with chisel or pick, or by rotation, using diamond



Vertical section 1:10. Wall construction with small GRC cladding panels



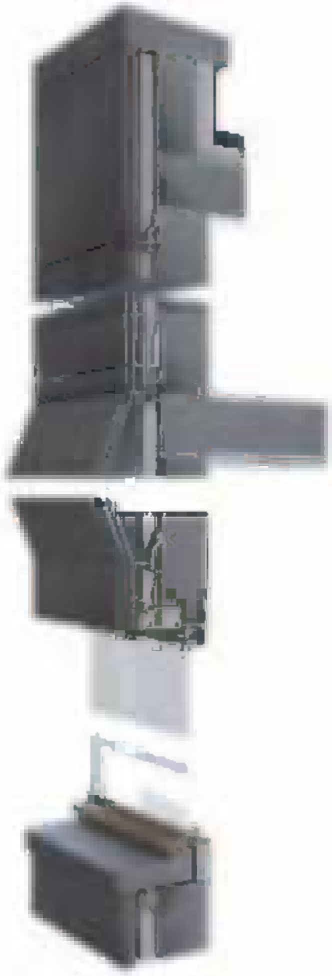
3-D detail view of junction between wall and window

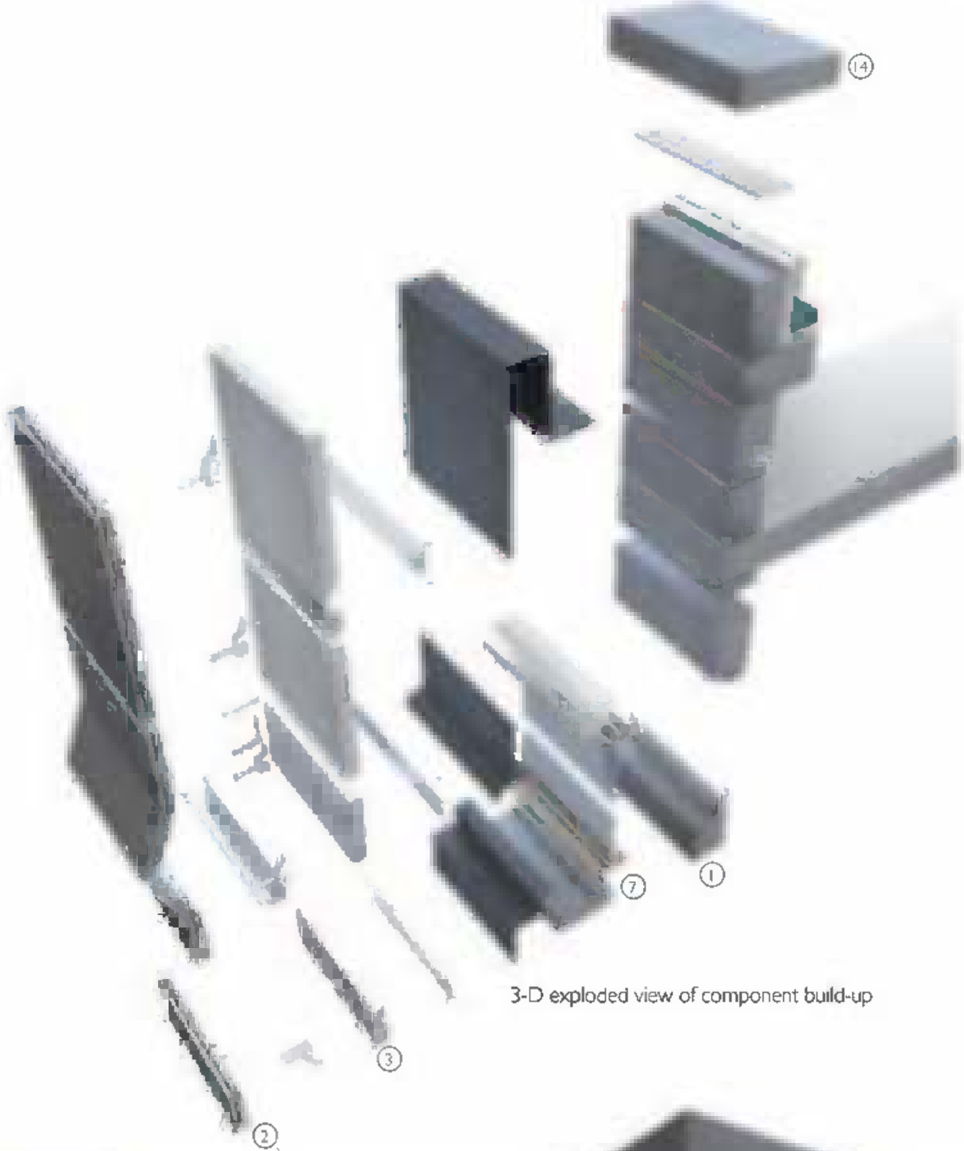
3-D detail view of wall construction

tipped burring tools to make grooves for any shape, depth and distance apart. A claw chisel has a toothed flat head that breaks the surface, while a pick is a chisel with a sharp point that can be used to create a roughened surface. A boasting chisel is a grooving chisel used to make a set of parallel grooves in the face of the concrete. These textures usually stop short of corners of walls to give a crisp edge.

3-D view of wall clad with small GRC panels

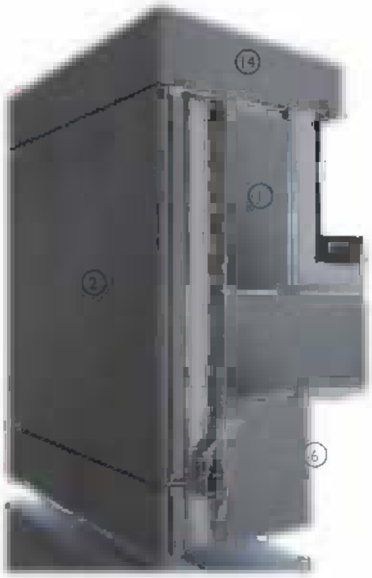
Concrete Walls 03
Small precast / GRC cladding panels


3-D view of wall with small precast cladding panels



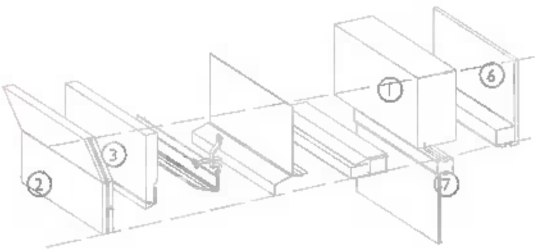
3-D exploded view of component build-up

3-D view of frame detail

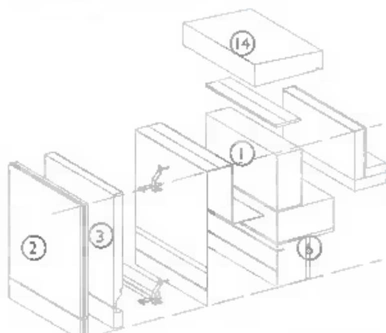


3-D view of wall detail

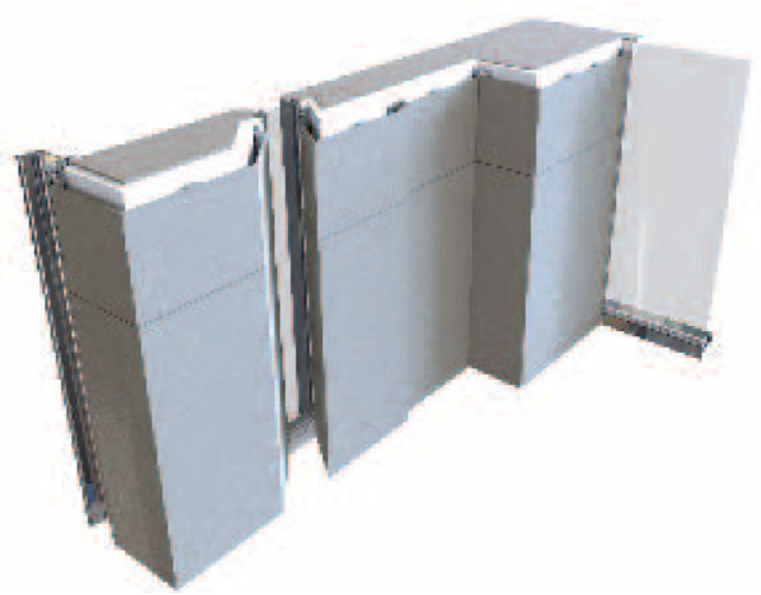
Details
1. Backing wall
2. Precast concrete panel
3. Closed cell thermal insula tion
4. Vertical joint open or closed type
5. Horizontal joint (typically a lap) open or closed type
6. Internal finish
7. Window frame
8. Reinforced concrete column
9. Metal corner trim
10. Metal parapet coping
11. Concrete floor deck
12. Adjacent panel in material
13. Waterproof membrane
14. Precast concrete coping



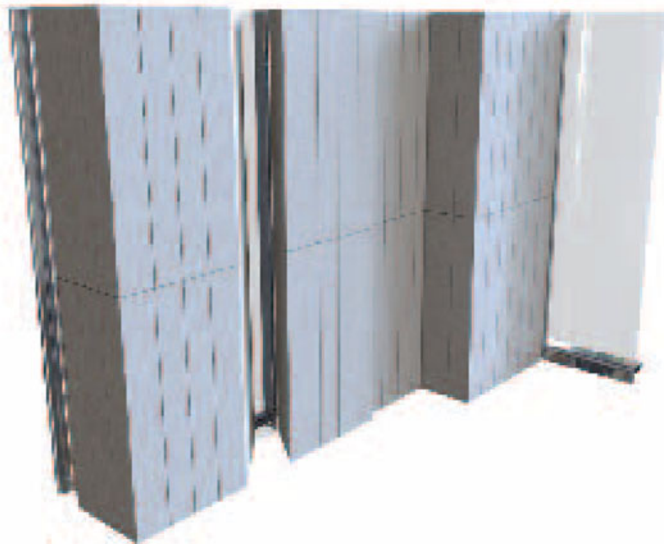
Exploded axonometric drawing of frame detail



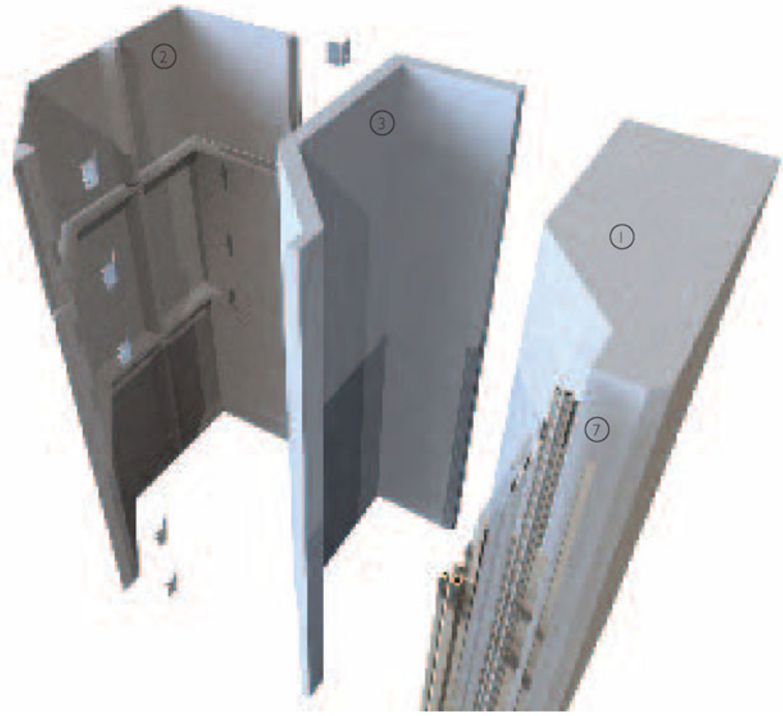
Exploded axonometric drawing of wall detail



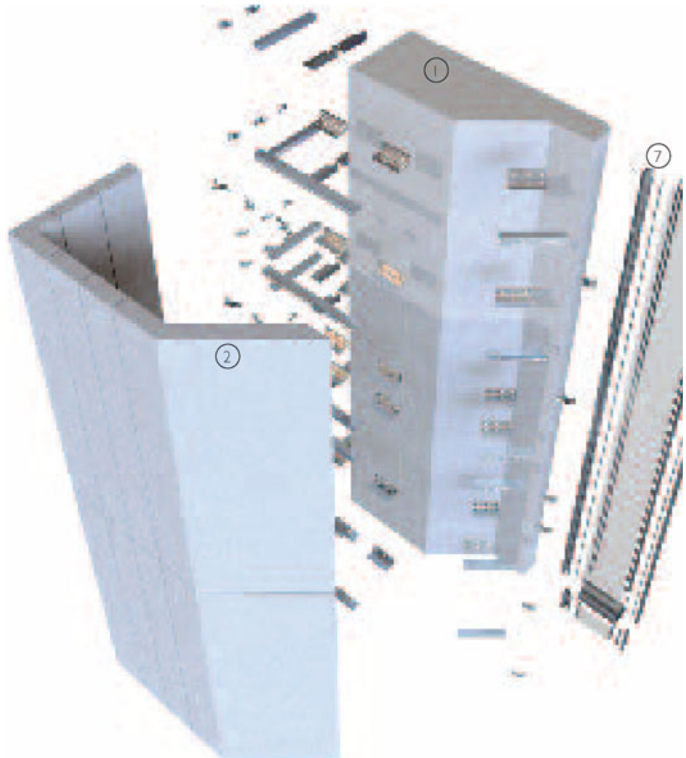
3-D view of wall with precast cladding panels



3-D view of wall with precast cladding panels

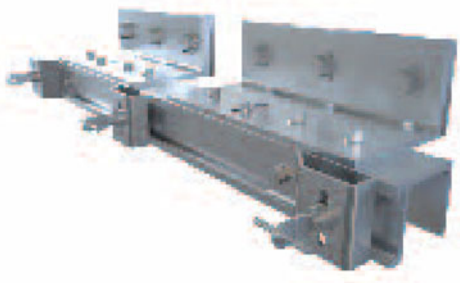


3-D exploded view of component build-up



3-D exploded view of component build-up

3-D view of fixing element



3-D view of fixing element

4

MASONRY WALLS

(1) **Masonry loadbearing walls:**

Brick, stone and concrete block

Mortars

Parapets

Cills and openings

(2) **Masonry cavity walls:**

Brick

Ground level

Window and door openings

Eaves and parapets

(3) **Masonry cavity walls:**

Stone and concrete block

Wall structures

Ground level

Openings in walls

Eaves and parapets

(4) **Stone cladding:**

Fixings

Cladding to precast concrete panels

Closed joints

Movement joints

Stone finishes

(5) **Terracotta rainscreens:**

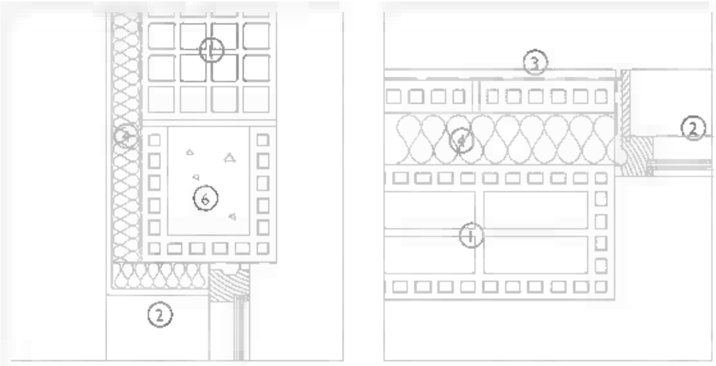
Manufacture of panels

Corner pieces

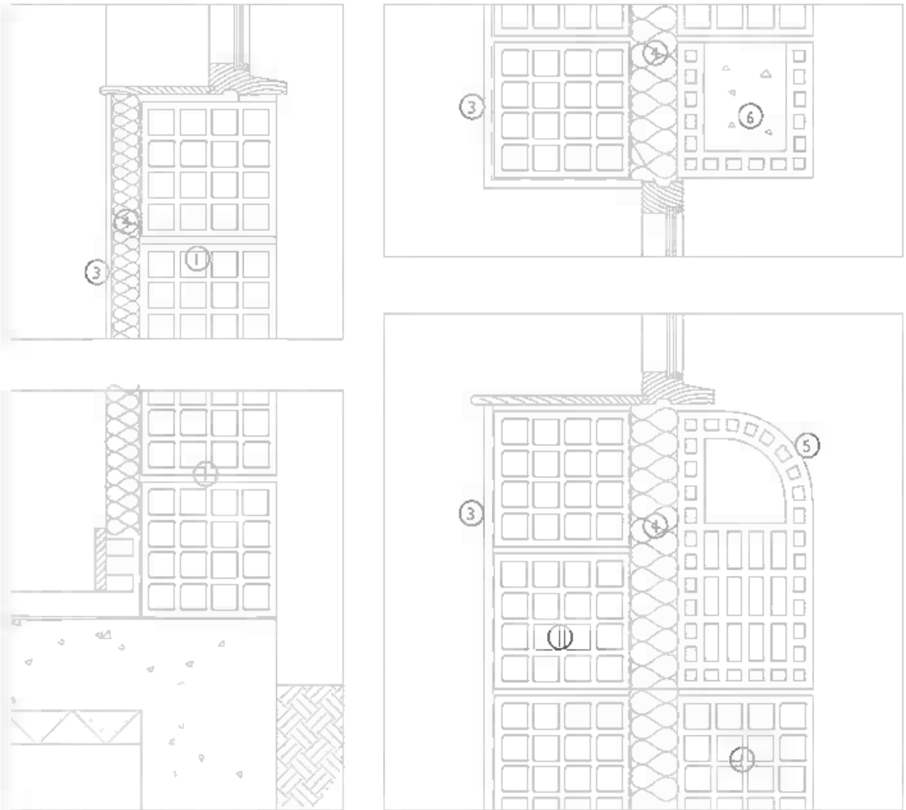
Fixing systems

Panel sizes

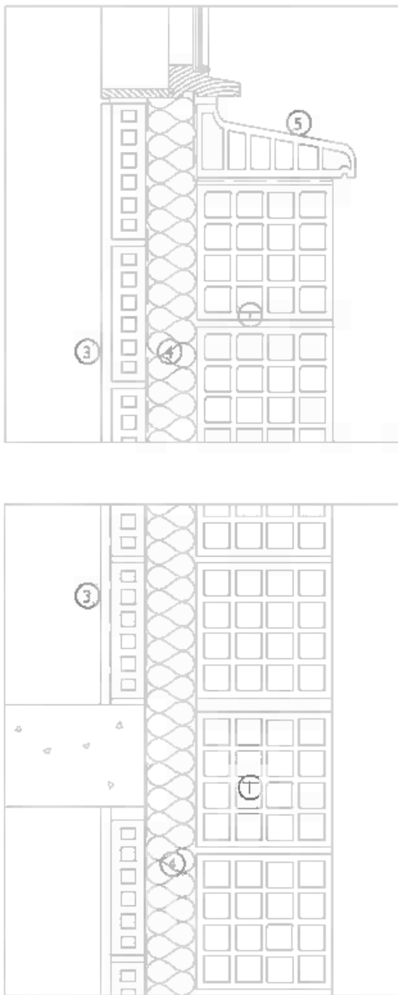
Openings



Horizontal section 1:10. Window opening



Vertical sections 1:10. Window openings and restraint/support at floor level



Vertical sections 1:10. Window opening and restraint/support at floor level

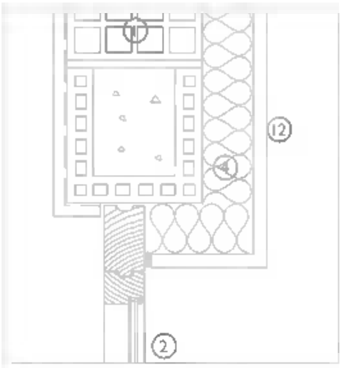
Details for hollow brick

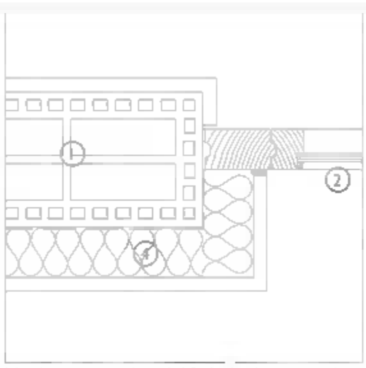
1. Loadbearing hollow brick wall
2. Timber framed window
3. Internal finish
4. Thermal insulation
5. Hollow brick cill

In masonry loadbearing construction, a complete wall is bonded together to form a single structure. Loadbearing brick walls formed with traditional sized bricks follow traditional bonding patterns which set the bricks together in a way that avoids continuity in vertical joints. In other words, each course is laid in a way that is different from the course below, in order to ensure that joints between bricks are staggered vertically. This ensures that the wall behaves structurally as a homogenous construction with discontinuous joints. Traditional brick bonds have a recognisable appearance in elevation. For example, Flemish bond has courses of alternate headers (short edge) and stretchers (long edge) set side by side. Each course is offset from the one below to avoid a continuity of vertical joints that would weaken it structurally. English bond has alternate courses of all headers set on courses of all stretchers.

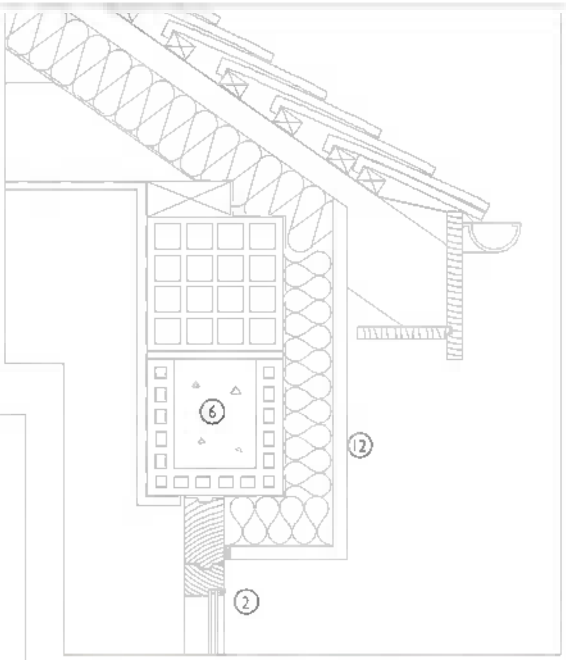
In the horizontal joints, bonds in all loadbearing materials have a continuous path from outside to inside, which reduces its resistance to water penetration. Traditionally, this is overcome by making the wall sufficiently deep to avoid the passage of water through the thickness of the wall. In contemporary construction, a vapour barrier is usually added to the inside face if the wall is dry lined, or the wall is faced internally with a waterproof render to ensure moisture does not penetrate the joint.

In brick construction it is usually assumed that a wall around 315mm (12in), which corresponds to one brick length plus

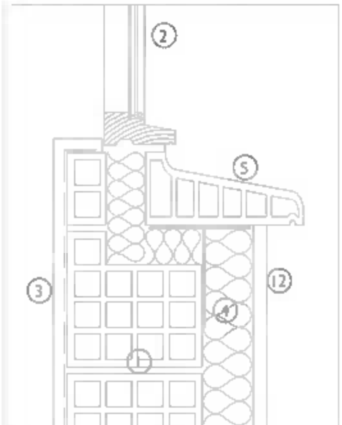


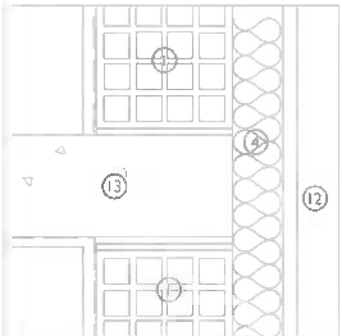


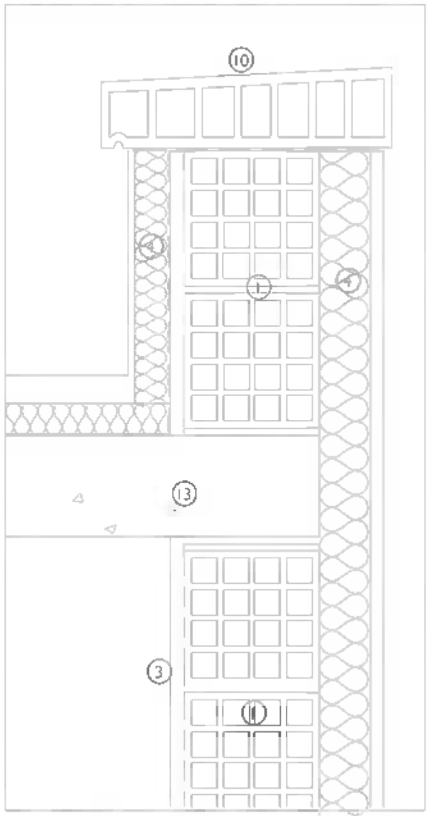
Horizontal section 1:10. Window opening



Vertical section 1:10. Window opening and restraint at roof leve







Vertical sections 1:10. Window openings and restraint/support at floor and roof levels

3-D view of wind

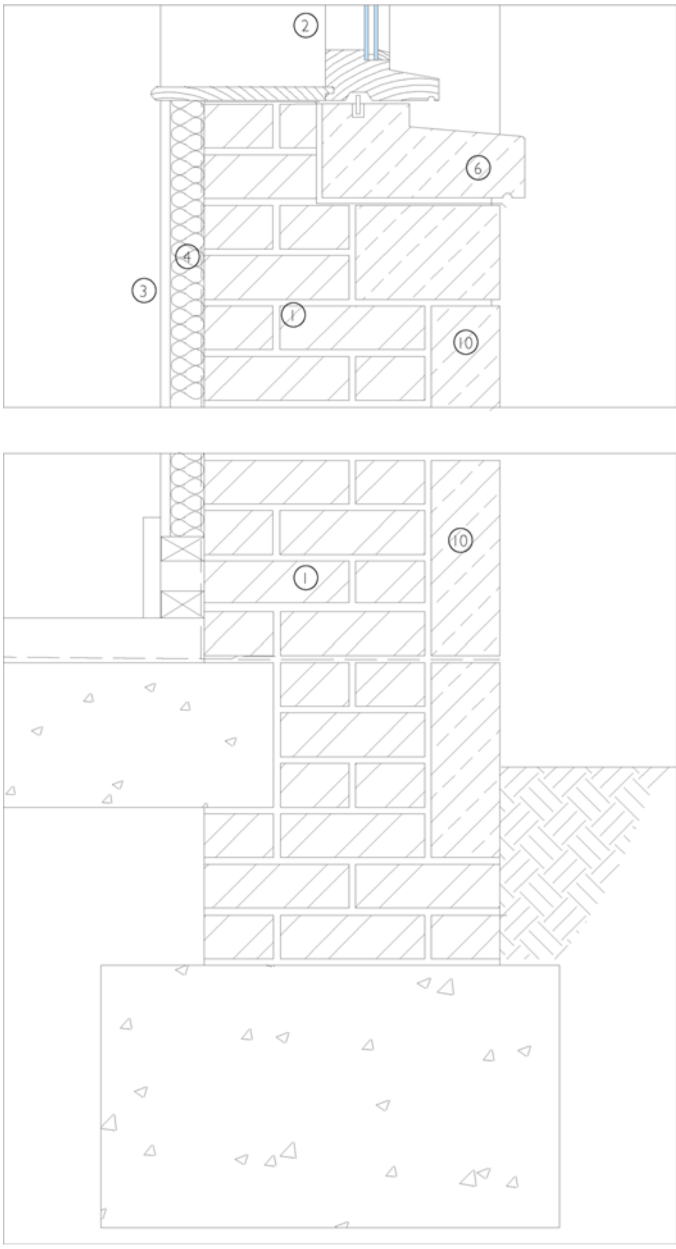
one brick width in a bond, is sufficient to resist rainwater penetration in temperate climates. This is dependent upon brick density and manufacturing dimensions, but walls of a thickness corresponding to one brick length only are usually not deemed to be thick enough, and often suffer from dampness on their internal faces if there is no damp proof membrane and/or waterproofed render on the inside face.

While loadbearing concrete block is common in housing, stone is used mainly as part of a loadbearing stone wall where block or brick is the primary material. It is often the case that stone is used as a facing material to a more economic material behind. If stone is used as a loadbearing material rather than as additional cladding then its properties must be compatible with those physical properties of the backing wall.

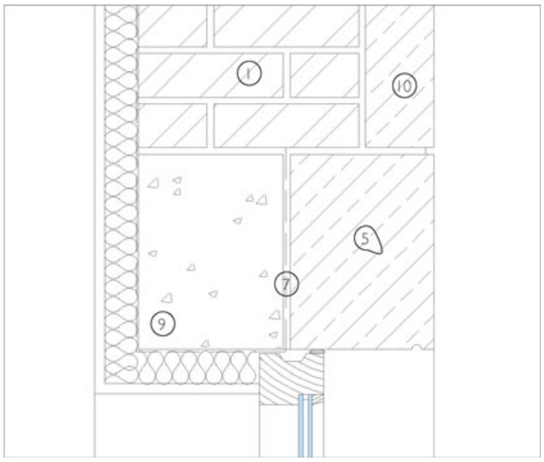
With the increased use of thermal insulation to reduce energy consumption within buildings, thermal insulation is set on the inside face to allow the material to be visible on the outside face. However, this results in the thermal mass of the wall not being used for night time cooling. Where the internal face of the wall is required for night time cooling, the thermal insulation can be set in the middle of the wall construction, with the leaves of brick, stone or block on either side linked by stainless steel ties to form a diaphragm wall. However, this is an unusual solution as structural discontinuity in the wall construction is less efficient from the structural point of view. As the height of the

Details

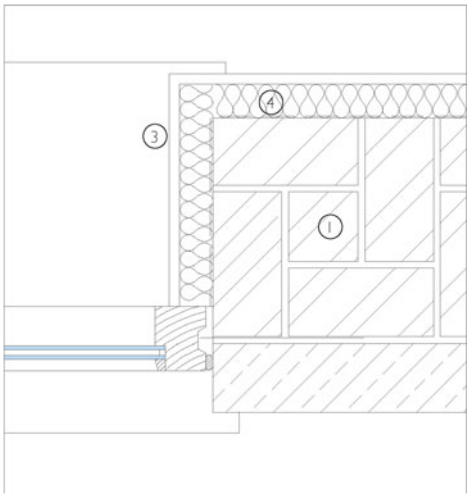
6. U-shaped brick, filled with reinforced concrete
7. Waterproof membrane
8. Damp proof course (DPC)
9. Weather bar
10. Hollow brick coping
11. Roof construction
12. Rendered finish
13. Floor slab



Vertical sections 1:10. Window opening and ground level junction



Vertical section 1:10. Window opening



Horizontal section 1:10. Window jamb

Solid brick details

1. Loadbearing brick wall
2. Timber framed window
3. Internal plaster finish or dry lining/drywall
4. Thermal insulation
5. Stone lintel
6. Stone cill
7. Waterproof membrane
8. Damp proof course (DPC)
9. Reinforced concrete lintel
10. Stone facing blocks

wall increases between floor slabs or between points of restraint, the thickness of the wall also increases to provide stability. An alternative to the traditional method of simply making the wall thicker is to form a diaphragm wall. Two skins of brick, typically 215mm to 315mm thick (9in-12in), are set apart with fin walls set perpendicular to the direction of these brick walls. Concrete block walls will be typically 200mm or 300mm thick (8in or 12in).

When used internally, thermal insulation provides a full continuity between the insulated wall and insulated glazed units set into openings. The thermal insulation passes under the internal cill and is set in a way that avoids visual clumsiness that can spoil the appearance of loadbearing brick, stone and block. Internally, the insulation is finished with plaster and a projecting cill that gives a traditional visual appearance around a window.

The colour range of cut stone is very important in loadbearing stonework in order to ensure that a wall has a 'massive' appearance, as if almost cut from a single block of stone. This is quite different from masonry cladding, where the stone can be much more varied across the facade if preferred, since cladding rarely tries to achieve a truly monolithic appearance.

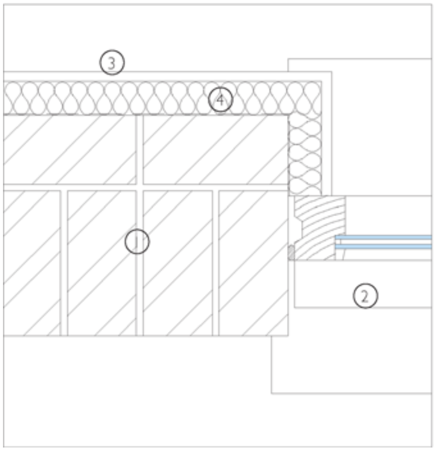
Mortars

An essential benefit of using loadbearing masonry walls is their ability to avoid movement joints with the use of lime mortar. This binding material is a traditional mortar mix

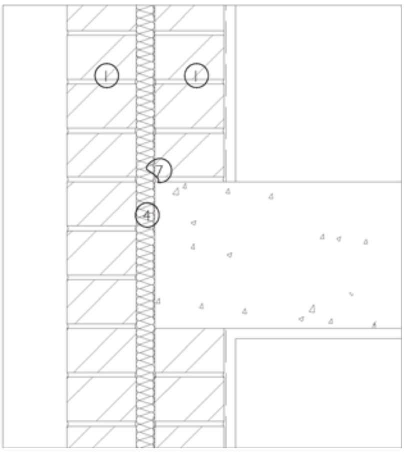
3-D view of window detail
3-D view of window detail

Window details

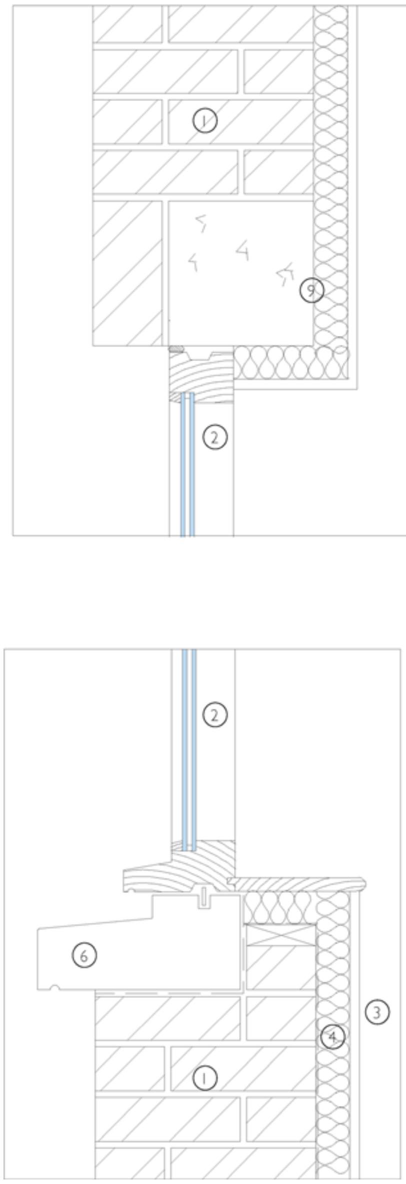
1. Ground floor or floor slab
2. External ground level
3. Screed
4. Waterproofing layer to roof
5. Brick parapet
6. Angle fillet
7. External wall
8. Roof substrate
9. Damp proof course (DPC)
10. Damp proof membrane (DPM)



Horizontal section 1:10. Window jamb



Vertical section 1:10. Floor junction

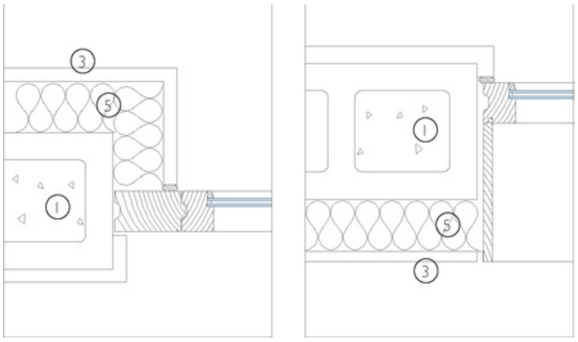


Vertical sections 1:10. Window openings

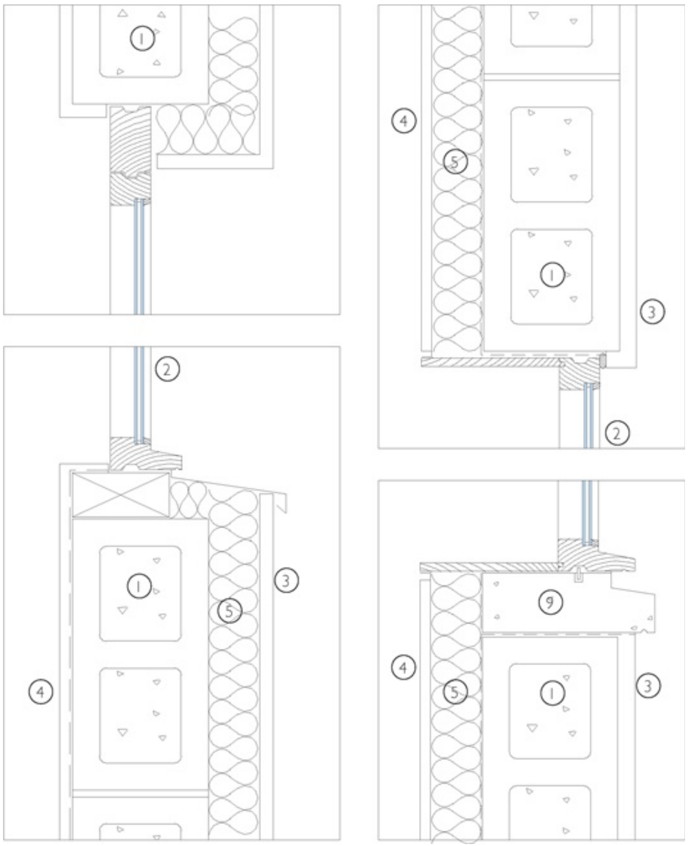
with lower strength than mortars used in cavity wall construction but has greater flexibility as a material, allowing it to move more freely without cracking. This reduces, or can avoid the need for, movement joints which are introduced to avoid cracking in masonry walls. Movement joints are typically set at 6.5 metres to 8.0 metres (21ft-26ft), depending on the strength and size of the wall.

The same principles are used for mortar mixes in loadbearing walls as for cavity walls and masonry cladding, and follow the same principles in brick, stone and concrete block. It is common to use the mortar of minimum strength required, since an increase in strength results in a corresponding increase in rigidity which increases the risk of cracking occurring at joints. The strength of mortars is varied by varying the proportion of cement and lime which are used to bind the mortar together. A higher proportion of cement increases strength, while a higher proportion of lime increases flexibility. Mixing the correct mortar for a particular wall construction is achieved through a balance of strength and flexibility. In addition, the comparatively low water permeability of lime gives it greater resistance to rain penetration than more cement-based mortars. Lime makes a mortar lighter in colour than cement-based types. Colour can be modified by pigment additives. In stone walls, crushed stone is added to the mix instead of sand in order to give mortar the texture and some of the appearance of the stone itself.

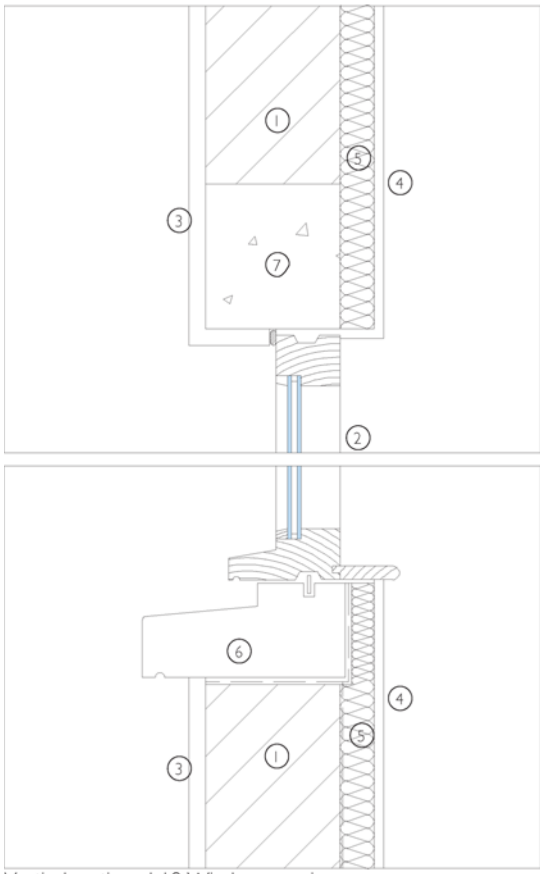
3-D view of cill detail



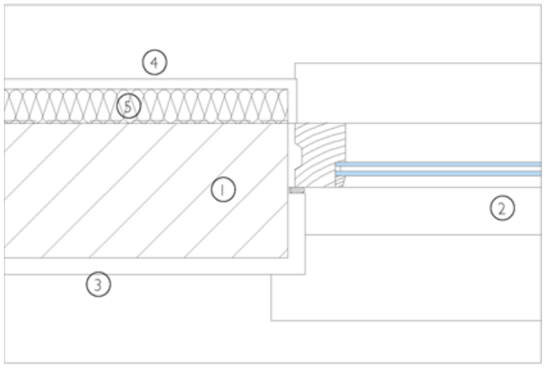
Horizontal sections 1:10. Window jambs



Vertical sections 1:10. Window openings



Vertical sections 1:10. Window openings



Horizontal section 1:10. Window jamb

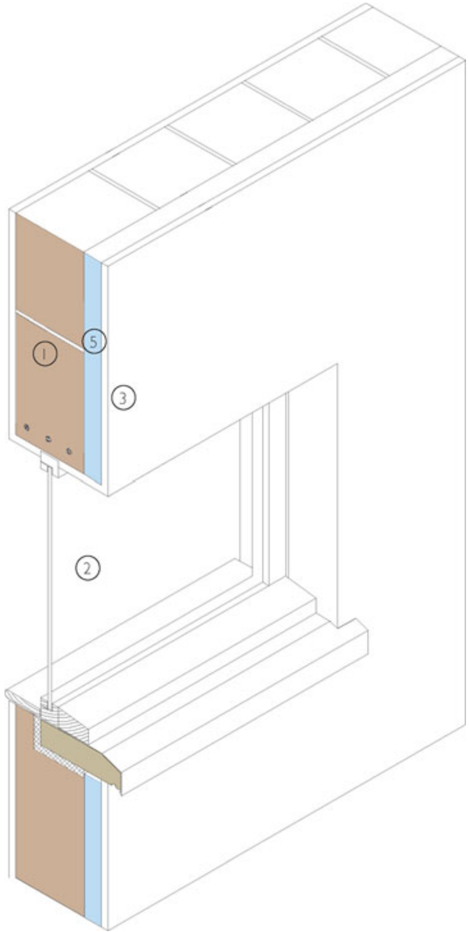
Concrete block details

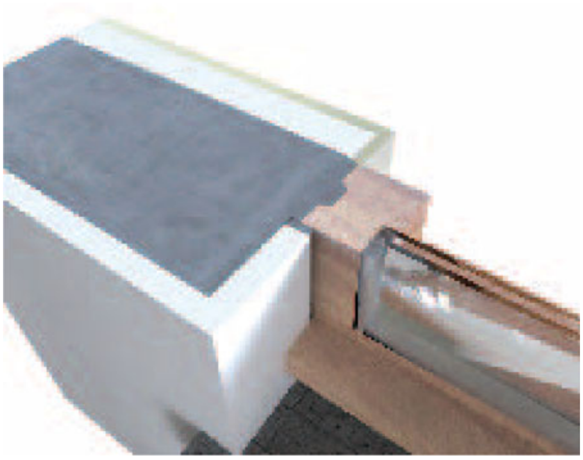
1. Loadbearing block wall
2. Timber framed window
3. External render finish
4. Internal finish
5. Thermal insulation
6. Precast concrete cill
7. Precast concrete lintel
8. Damp proof course (DPC)
9. Weather bar
10. Seal

Parapets

Unlike parapets in masonry cavity walls or cladding, there is little opportunity to incorporate thermal insulation without concealing the internal face of the parapet. In practice, the parapet is often insulated only up to the height of the waterproofing layer in order to reduce the thermal bridge between the insulated roof and the top of the thermal insulation in the external wall. Loadbearing stone allows for considerable modelling of the parapet wall without the need for complex pieces of stone that would be needed in cavity walls or cladding. The thickness of the stone can be expressed to its full extent in a parapet and this is a common feature of their design, particularly where the parapet also serves as a balustrade. The coping stone is usually much thicker than that used in cladding to ensure that it will not easily crack due to freeze / thaw action and is strong enough to absorb normal impact loads, typically from maintenance equipment. A damp proof course (DPC) is set underneath the coping stone to avoid water being absorbed too far down into the construction from its top surface, and this DPC may be continuous with a waterproofing layer extending up from the internal face of the parapet. In common with other copings, the top is sloped inwards to drain water towards the roof rather than down the front of the facade where it would cause staining. The coping usually projects beyond the face of the wall on the roof side in order to throw the water clear of the wall and avoid staining. A continuous groove, or

3-D view of cill detail on concrete block wall.





3-D view of window detail on concrete block wall.

Isometric view of concrete block wall assembly

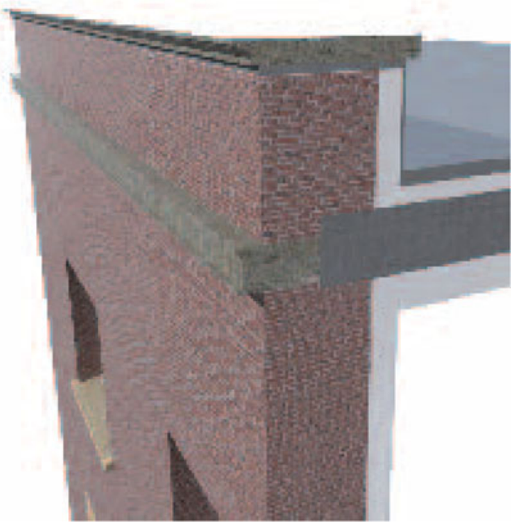
throating, is introduced to avoid rainwater being drawn back along the underside of the projecting coping. Copings are sometimes set forward on the external face of the stone but this is primarily done for visual reasons, since rainwater that falls onto the top of the coping is directed away towards the inside face with little risk of staining occurring on the external face of the wall.

Where brick is used, the coping is typically in stone or precast concrete. In order to secure the coping to the wall beneath, which is weakened by the need for a damp proof course, dowels are often set into the top of the wall. The coping is then set onto the dowels by means of holes drilled into the underside of the coping.

Cills and openings

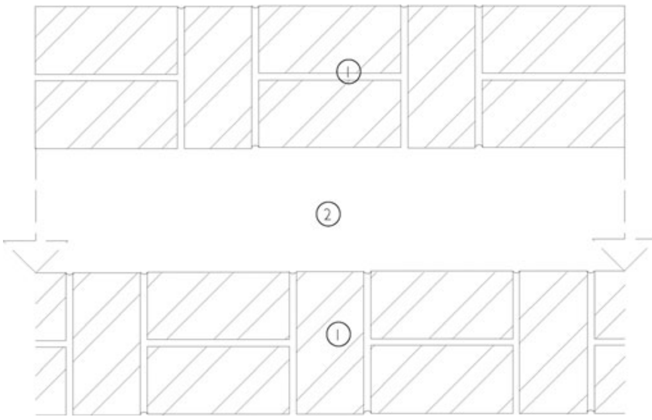
Openings in loadbearing stone, brick and block have the advantage of revealing the thickness of the material, giving a massive appearance to the wall. Openings in cavity walls and cladding require corner pieces that have a joint adjacent to the corner, giving the appearance of a wall covered in a different material rather than being a surface appearing to have been carved out of solid material. However, repetition in the size and shape of corner pieces is needed in order to keep the construction as economic as possible.

Cills are formed from either the same material if stone is used for the wall, or precast concrete if the wall is made from brick or block. In common with copings, cills are sloped with a projecting edge that throws



3-D view of parapet detail on loadbearing masonry wall

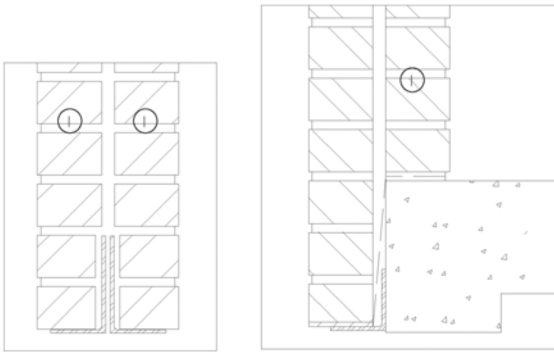
Masonry loadbearing walls: Brick, stone and concrete block

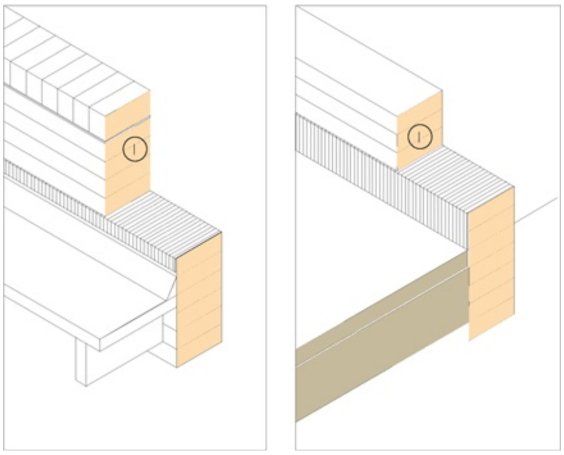


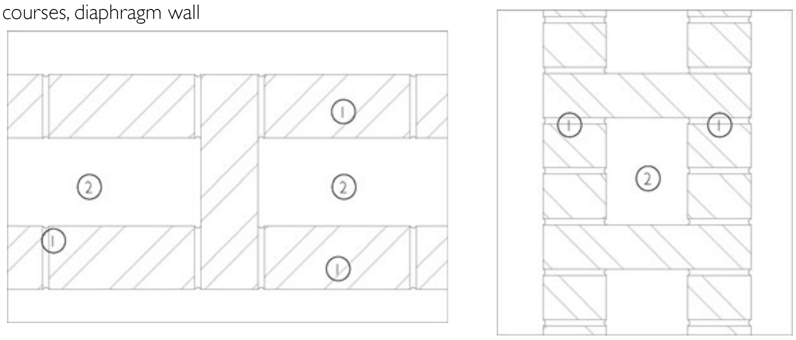
Horizontal & vertical sections 1:10. Bedding reinforcement between courses, diaphragm wall

Diaphragm brick wall details

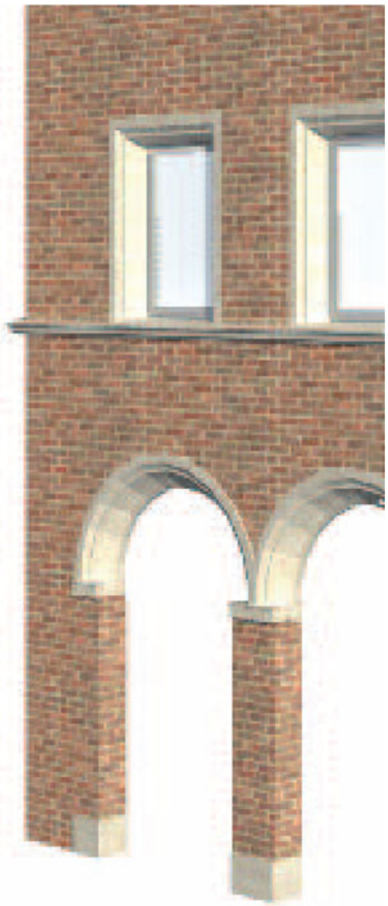
1. Loadbearing diaphragm brick wall
2. Air void or thermal insulation







Isometric views of wall assembly,
1. parapet level, 2. ground level

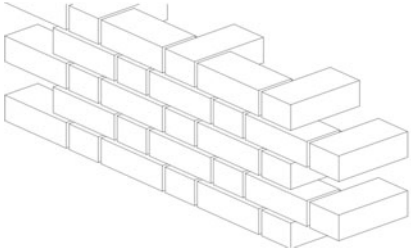


3-D view of loadbearing brick wall

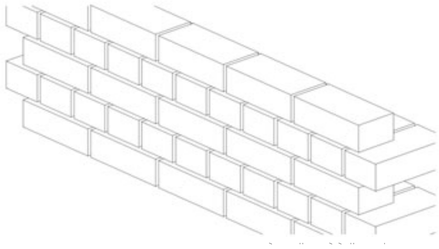
the rainwater clear of the wall beneath. A throating is also used to avoid water running back to the facade from the underside of the projecting cill. Where stone is used, the type of stone must be suitable for use as a cill. Where softer stones such as limestones and sandstones are used for the wall, stone for the coping must be sufficiently dense and durable to avoid rainwater being absorbed into the cill itself, causing staining on the top of the cill. More dense stones will absorb little water, which will instead be thrown clear of the cill during rain. Some harder limestones and sandstones may still be suitable for use as cill pieces. Cills are usually made in single pieces, but where openings are wide, sections are set side by side with mortar joints between them. The DPC, incorporated beneath cills in all materials, drains away any water that soaks through the cill, particularly at the joints.

The heads of openings in loadbearing masonry walls are supported by lintels or arches. In traditional brick construction, a flat or curved arch is used to support the brickwork above. In concrete block construction, a reinforced concrete lintel is used, which spans the complete width of the wall, while in stone a thin arch is used on the outer face of the wall, often with a more rudimentary brick arch behind it, concealed by the window frame. Since the thermal insulation is set usually on the inside face, the thermal bridge is avoided. Throatings are incorporated into concrete and stone faced lintels in order to avoid staining, but this is not usually done in brick, which is more absorbent and in which it is difficult to form a groove.

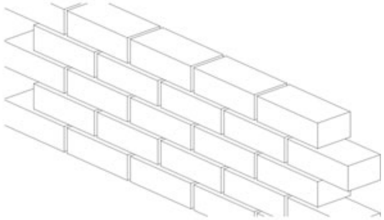
Types of brick bonds



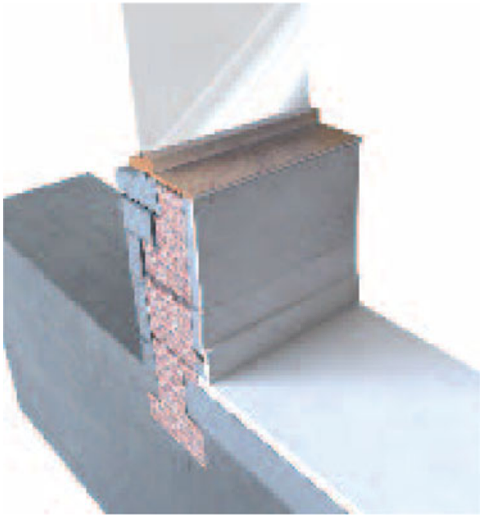
Flemish bond



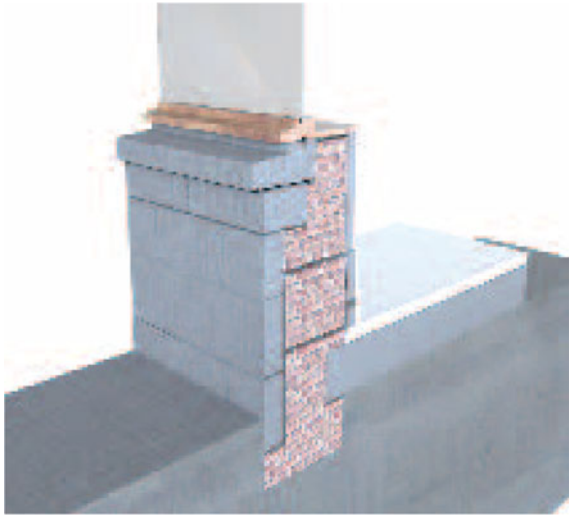
Old English bond



Stretcher bond



3-D view of loadbearing masonry wall with stone cladding

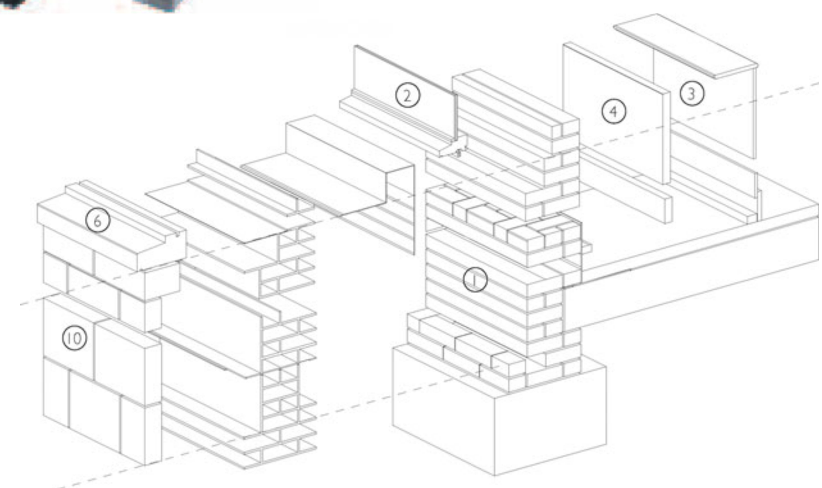


3-D view of loadbearing masonry wall with stone cladding

3-D exploded view of loadbearing masonry wall with stone cladding

Solid brick details

1. Loadbearing brick wall
2. Timber framed window
3. Internal plaster finish or dry lining/drywall
4. Thermal insulation
5. Stone lintel
6. Stone cill
7. Waterproof membrane
8. Damp proof course (DPC)
9. Reinforced concrete lintel
10. Stone facing blocks



Exploded axonometric view of loadbearing masonry wall with stone cladding

Masonry Walls 01
Masonry loadbearing walls: Brick, stone and concrete block

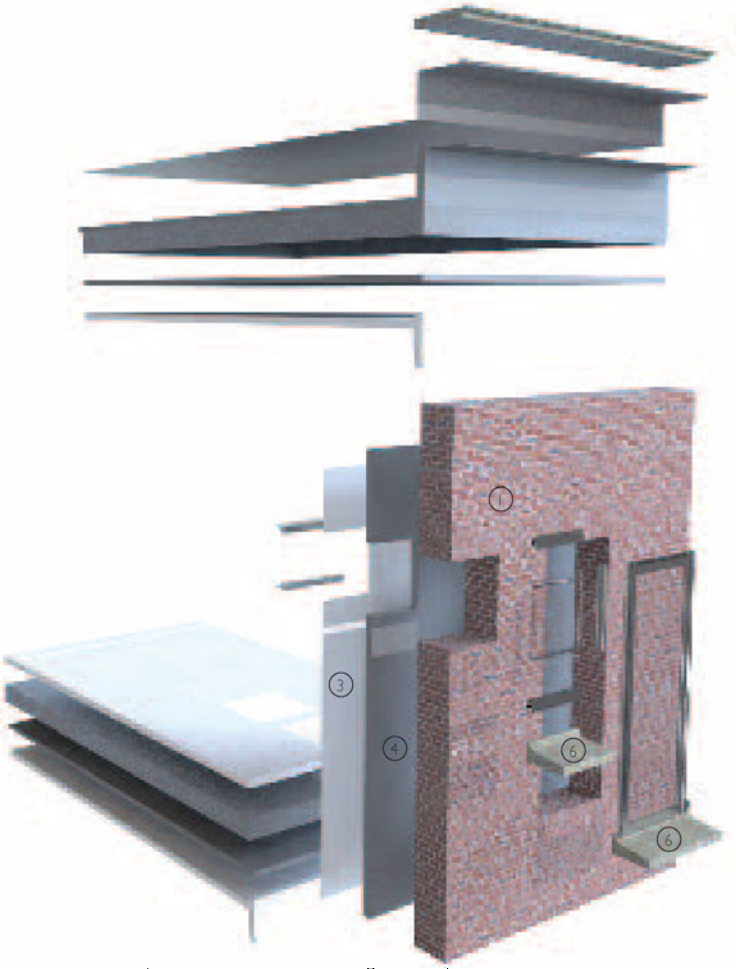
3-D view of loadbearing brick wall

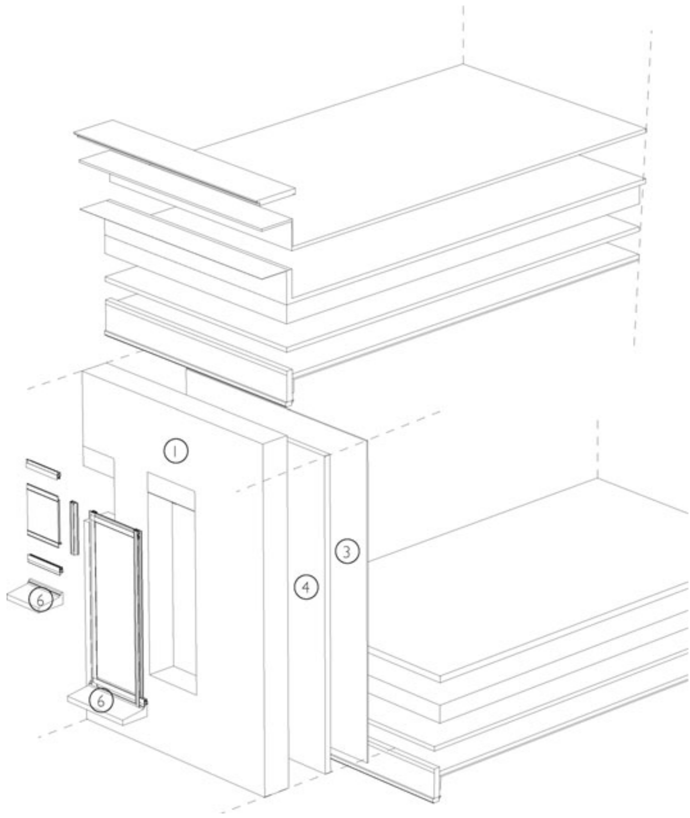
Solid brick details

1. Loadbearing brick wall
2. Timber framed window
3. Internal plaster finish or dry lining/drywall
4. Thermal insulation
5. Stone lintel
6. Stone cill
7. Waterproof membrane
8. Damp proof course (DPC)
9. Reinforced concrete lintel
10. Stone facing blocks

3-D view of loadbearing brick wall cill detail

3-D view of loadbearing brick wall parapet detail

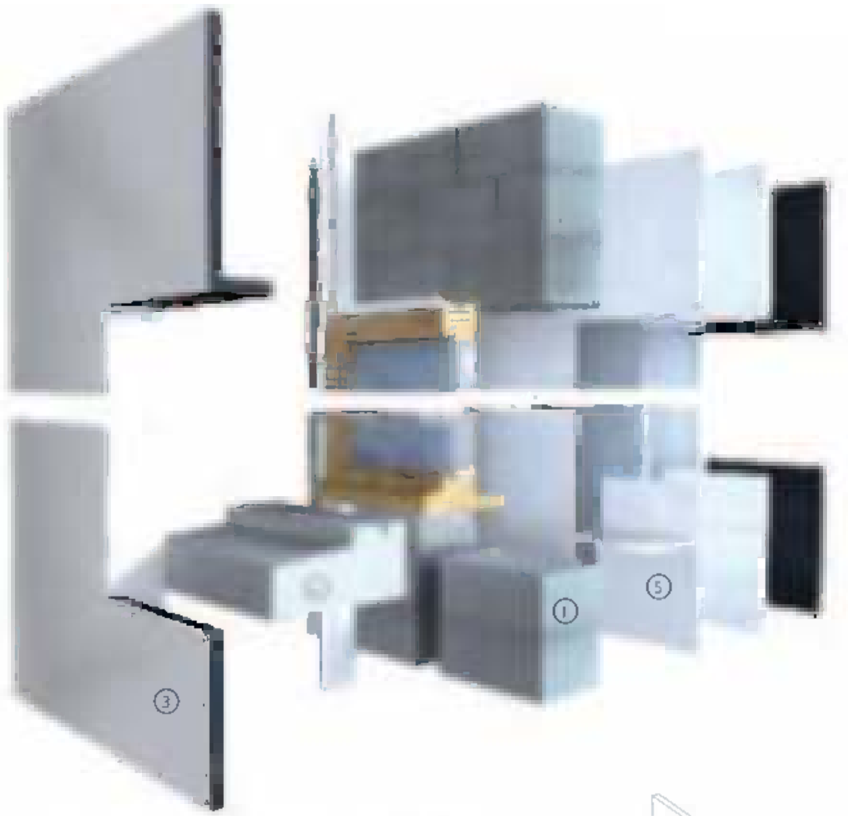




Exploded axonometric view of loadbearing masonry construction

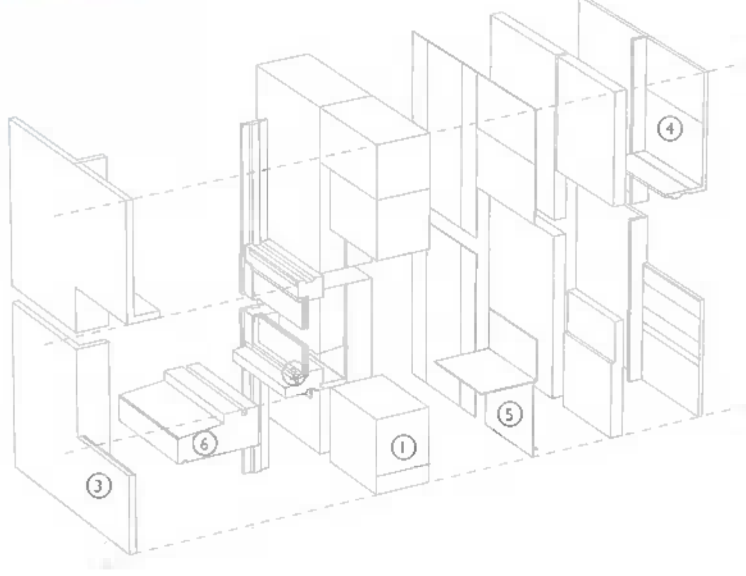
3-D view of loadbearing block wall

3-D exploded view of loadbearing block wall construction



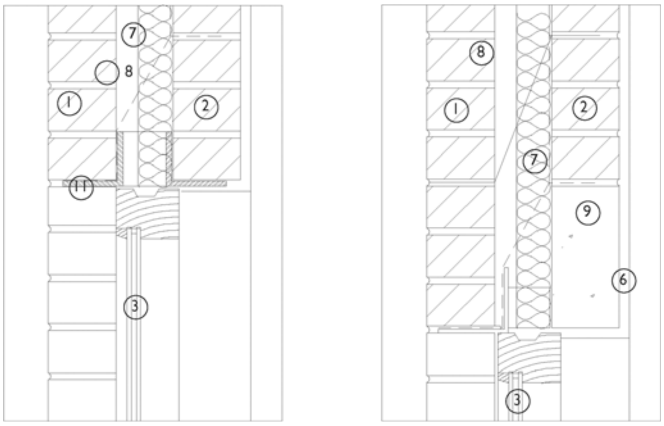
3-D exploded view of loadbearing block wall with window

3-D view of window detail

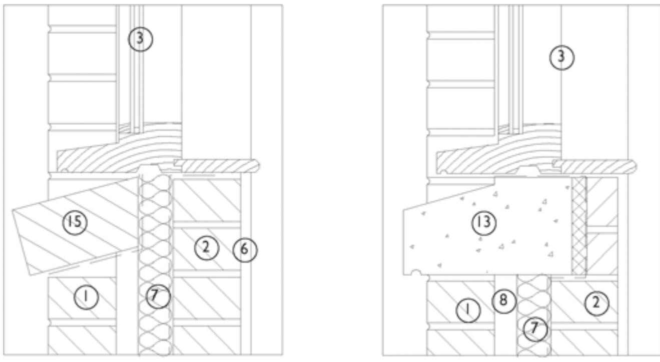


Concrete block details

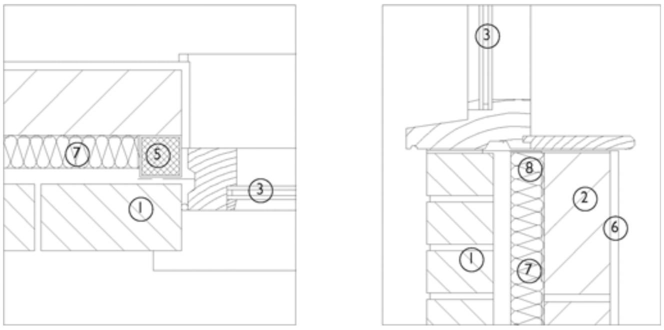
1 Loadbearing block wall
2 Timber framed window
3. External render finish
4 Internal finish
5 Thermal insulation
6. Precast concrete cill
7 Precast concrete lintel
8. Damp proof course (DPC)
9. Weather bar
10. Seal



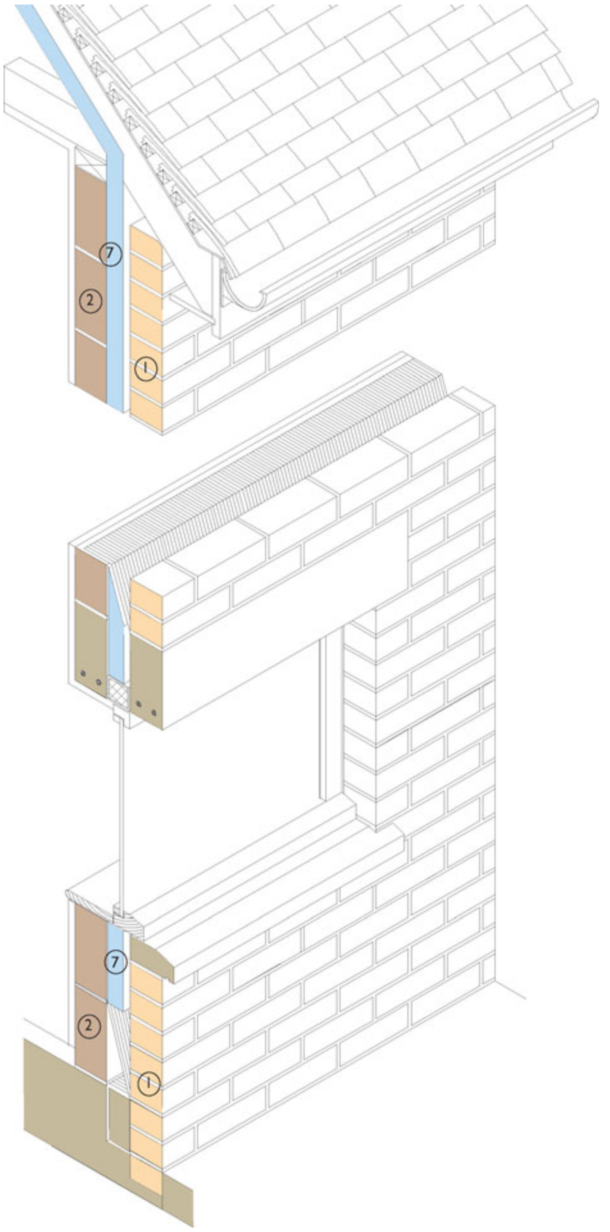
Vertical section 1:10. Typical connection or restraint to primary structure



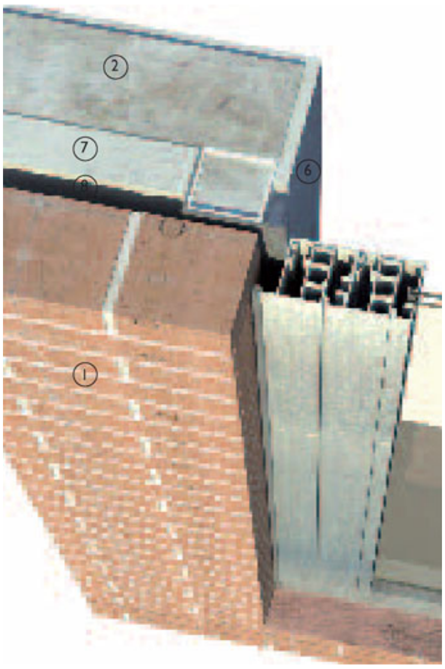
Vertical section 1:10. Typical connection or restraint to primary structure



Horizontal & vertical section 1:10. Typical window at cill and head



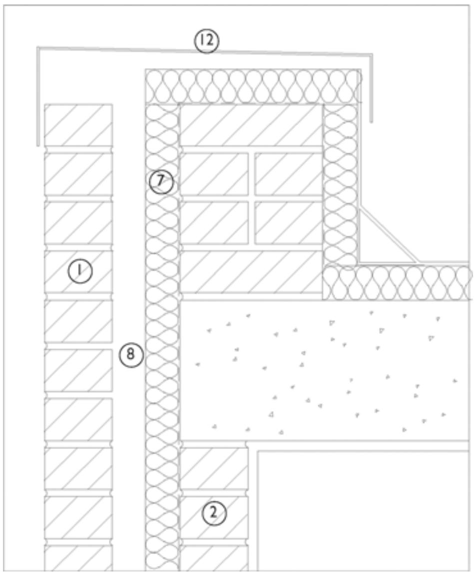
Isometric view of wall assembly

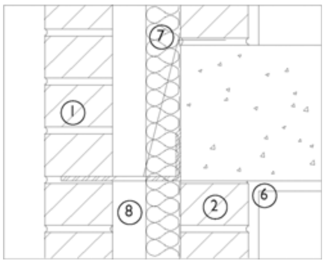


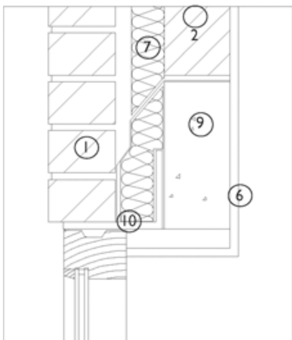
3-D view of typical window assembly

Brick cavity walls have the advantage of providing a cavity within the depth of a wall for drainage of rainwater before it is allowed to be absorbed too far into the wall construction. Whereas loadbearing brick walls use the overall wall thickness to stop the passage of rainwater from outside to inside, cavity walls use two skins of brickwork separated by a ventilated air gap. The inner skin is increasingly formed in concrete block, hollow terracotta block or timber studwork. Thermal insulation is usually set on the external face of the inner skin in order to keep the building structure insulated.

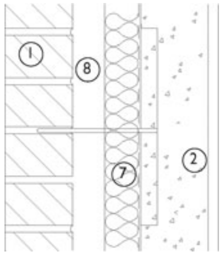
The outer brick skin is usually only 100mm/4in thick (one brick width) with both skins being supported either at ground level or at intermediary floor levels. In the case of buildings up to two storeys, the outer skin is built up from the foundation and is restrained back to the floor slab at first floor level and at roof level. The inner skin is built off each floor slab and is restrained at the head by the floor slab or roof structure above. Taller buildings also have the inner skin built off floor slabs in the same way, but the outer skin is supported at each floor level on a continuous stainless steel angle, bolted back to the floor slab. A damp proof course (DPC) is set on top of the steel angle to drain the cavity. Slots called weep holes are formed in the vertical joints immediately above the steel angle in order to allow water in the cavity to drain out. In addition to being restrained at floor slabs, the outer skin is also tied at intermediary points back to the inner skin with

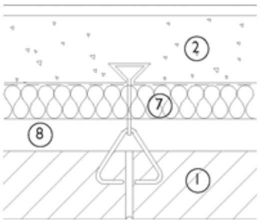


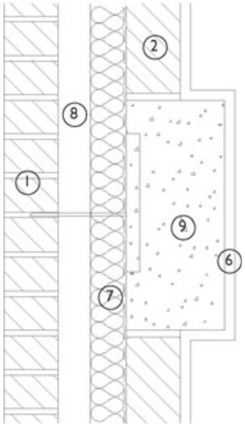




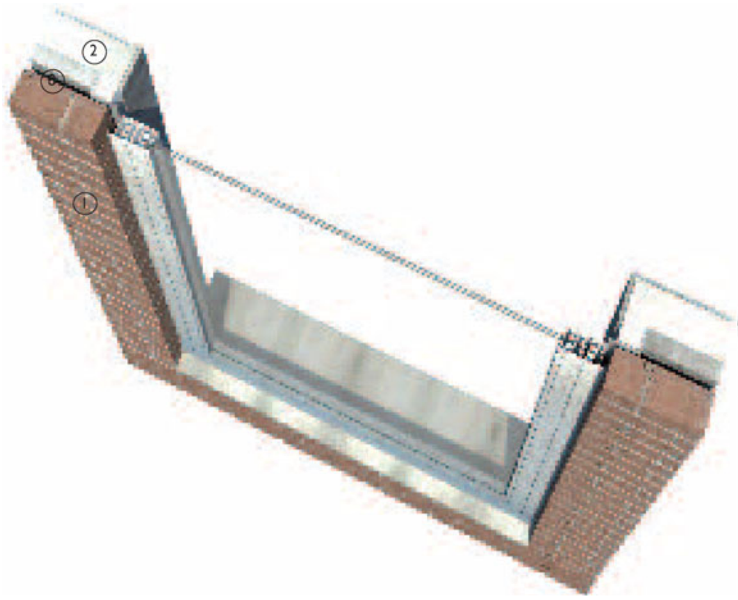
Vertical sections 1:10. Junction at parapet, support of outer leaf at floor slab, window opening



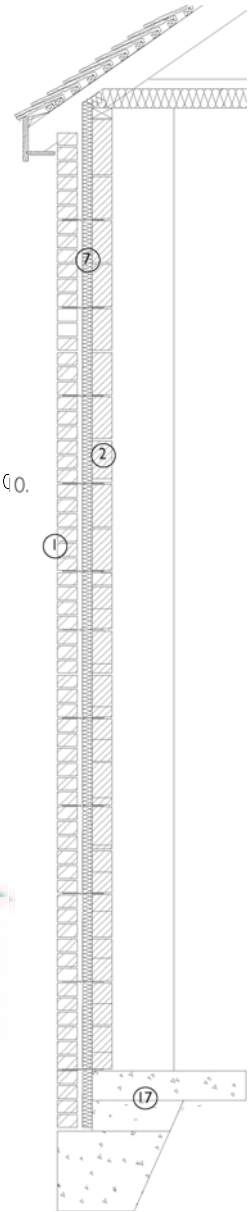




Vertical and horizontal sections 1:10. Typical connection or restraint to primary structure, window jamb



3-D top view of typical window opening in cavity brick wall



Vertical section 1:25. Wall assembly

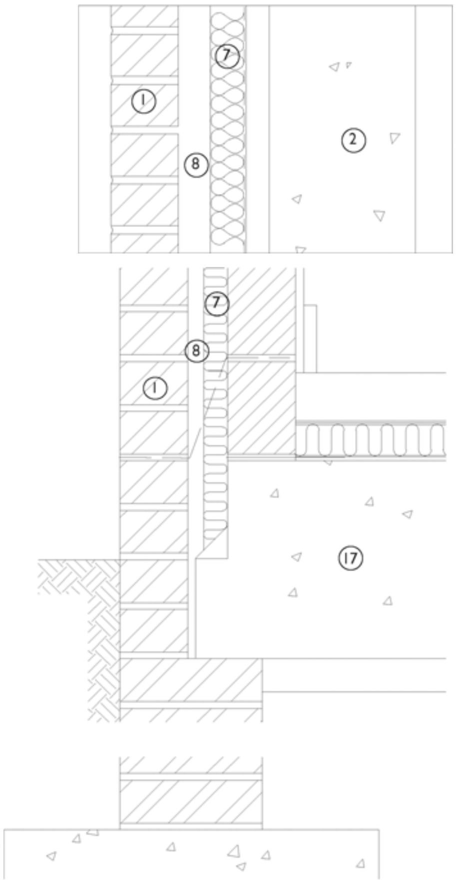
stainless steel ties. These are set typically at 450mm/18in horizontal centres and 900mm/3ft vertical centres.

Historically, inner and outer skins were tied together with floor slabs to form diaphragm walls, but their use is reduced with the concern over the thermal bridge created by linking the two skins of brick. Current practice uses the outer skin as cladding to a drained and ventilated void behind, with an inner skin that is waterproofed with a high level of thermal insulation. Brick types used in cavity construction vary widely, from traditional clay bricks which are either hand formed or wire cut to extruded hollow terracotta bricks. The cavity is vented top and bottom to ensure the free passage of air through the cavity. This allows the cavity to dry as well as drying out the outer skin of brick, which can become fully saturated in a rainstorm. The cavity is bridged only by openings for windows and doors.

When an opening is formed, the cavity is closed by a lintel (beam) to support the inner and outer skins at the top of the opening, and a cill piece at the bottom of the opening. The sides are closed by either returning one of the two skins to meet the outer skin, or by setting an insulated cavity closer, usually made as an aluminium extrusion filled with thermal insulation. Because the downward passage of water inside the cavity is blocked by the lintel at the head of the opening, a 'cavity tray' is set above the lintel to drain water out of the cavity. A cavity tray is formed from a bituminous felt strip

Details

1. Outer brick skin
2. Inner blockwork or brick skin
3. Timber framed window
4. Timber cill
5. Cavity closer
6. Internal plaster finish or dry lining/drywall
7. Thermal insulation in cavity
8. Air cavity (sometimes omitted where insulation fills cavity)
9. Inner concrete lintel or beam
10. Pressed steel lintel
11. Steel angle
12. Metal coping
13. Precast concrete cill
14. Damp proof course (DPC)
15. Brick cill
16. Movement joint
17. Ground floor slab
18. Steel cavity wall tie
19. Foundation



Vertical section 1:10. Junction at ground floor level

3-D view of brick cavity wall junction at ground floor level

which is set into a horizontal joint in the inner skin and set sloping downwards across the face of the cavity. The bottom of the tray is set on a horizontal course on the outer skin. Weep holes are left in the vertical joints immediately above the DPC to allow water to drain out. The ends of the DPC are tucked down into a vertical DPC set into the jambs (sides) of the opening. The vertical DPC is in turn linked to a DPC set under the cill to form a complete watertight seal to the opening which is drained and ventilated to the outside wall. A similar principle of cavity tray is used to drain water at roof level and at ground level. In addition, a DPC is used at ground level to avoid water being drawn up into the wall construction to the inside face of the wall within the building. DPCs are also used beneath parapets and copings as well as at the junction of wall and pitched roof. The use of the cavity tray together with a damp proof course are the two most important principles of cavity wall detailing.

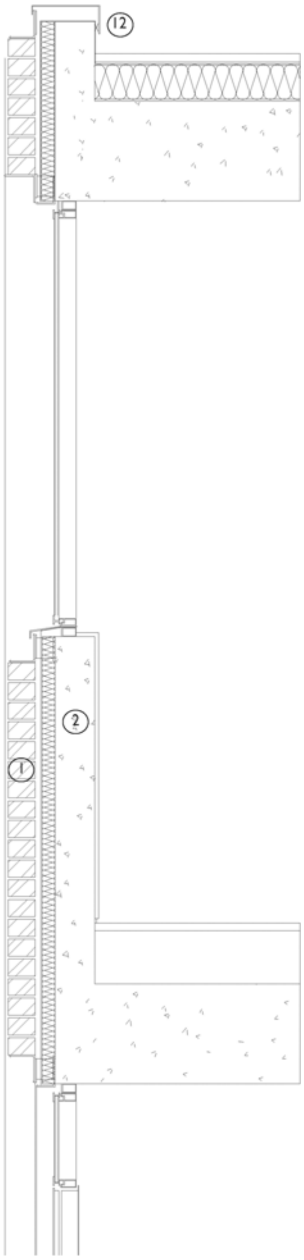
Ground level

The detailing of the DPC at ground floor level is dependent upon the difference in height between ground floor level in the building and the adjacent external level. The DPC in the outer skin is set at around 150mm above external ground level. The DPC for the internal skin is set at the same level if the step up from outside to inside is around 150mm. If the difference between outside and inside levels is around 300mm/12in then the DPC is stepped up from outer skin to inner skin in the same place but a separate DPC is added to the inner skin at the same level as the bottom of the cavity tray. The aim of the damp proofing is to provide a continuity of protection from underneath the ground floor or lowest basement slab up into the wall construction.

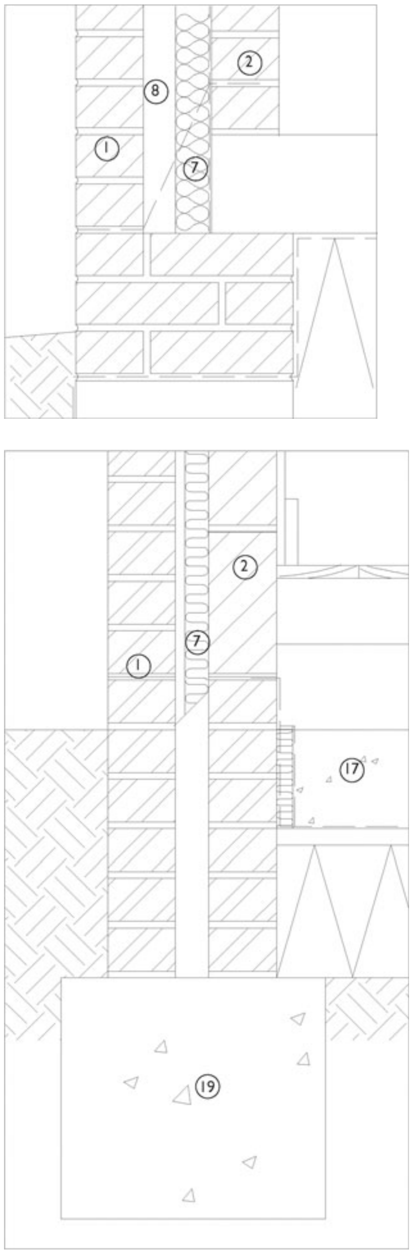
The cavity is filled below ground floor level to avoid it filling with water which would eventually damage the construction, particularly from freezing in winter in temperate climates. Until recently, thermal insulation was usually terminated at ground floor level. More recently, the thermal insulation continues down below ground where it is continuous with thermal insulation set on top of or beneath the floor slab to provide a completely insulated building enclosure.

Window and door openings

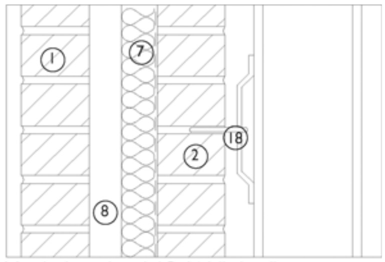
Since a window or door frame has a profile which is the same on all four sides, with an external modification for the cill, the profile of the opening into which it fits must be consistent on all sides. Visual considerations are equally important in the detailing of cavity wall openings. The depths of the reveal can make the outer skin appear more 'massive' if the reveal is made at least one brick deep or more like a thin skin if the window is set forward of the reveal. Where a loadbearing wall can incorporate a structural brick arch, this is much more difficult in a cavity wall. This is because the outer and inner skins of a cavity wall are kept separate, except where they are bridged by lintels. Because they are linked only at these points, the lintel needs to be a separate structural element which supports both skins without exerting lateral forces in the adjacent brickwork, where cracking could occur in both skins. For this reason, simply supported lintels are used, which exert balanced loads on both skins. Both reinforced concrete and steel types are used, which have the advantage of supporting a course of bricks to give



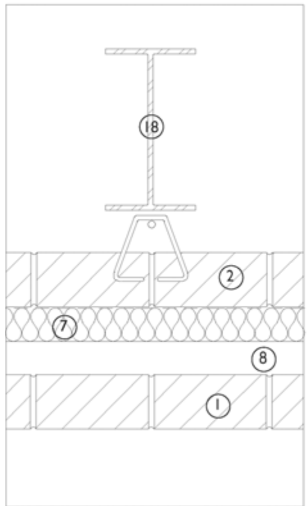
Vertical section 1:25. Wall assembly



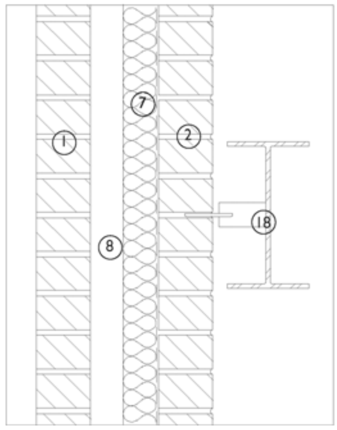
Vertical section 1:10. Junctions at ground floor level



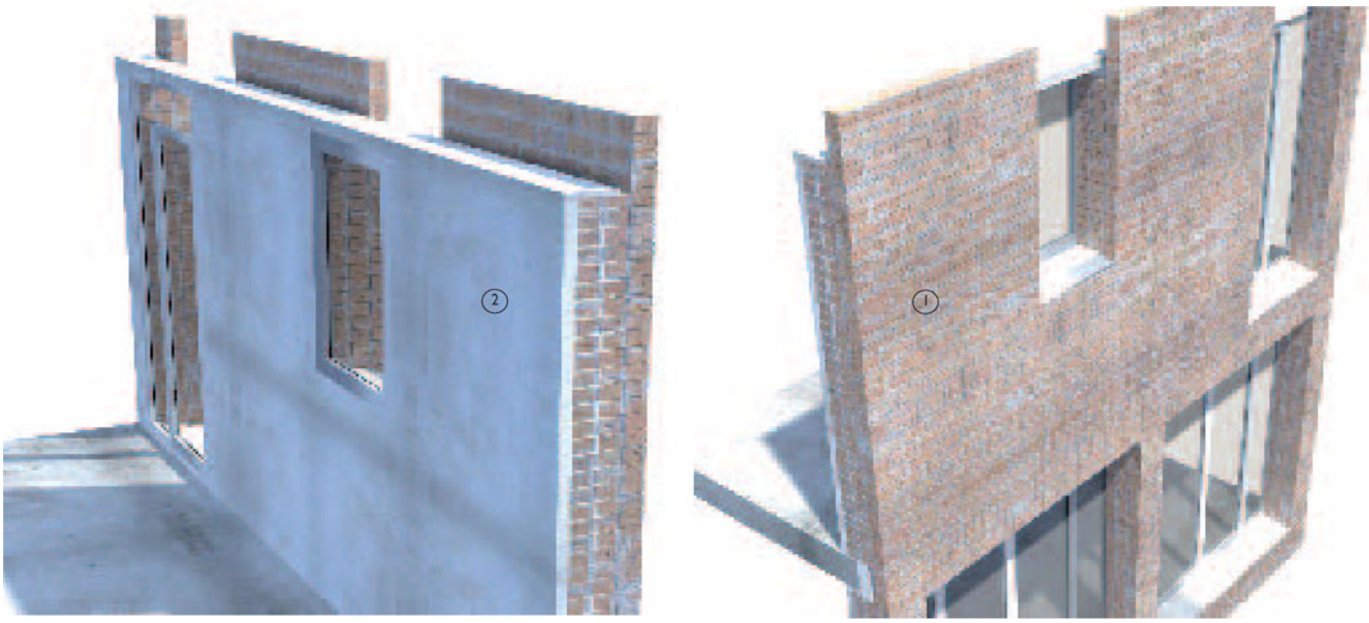
Vertical section 1:10. Wall detail



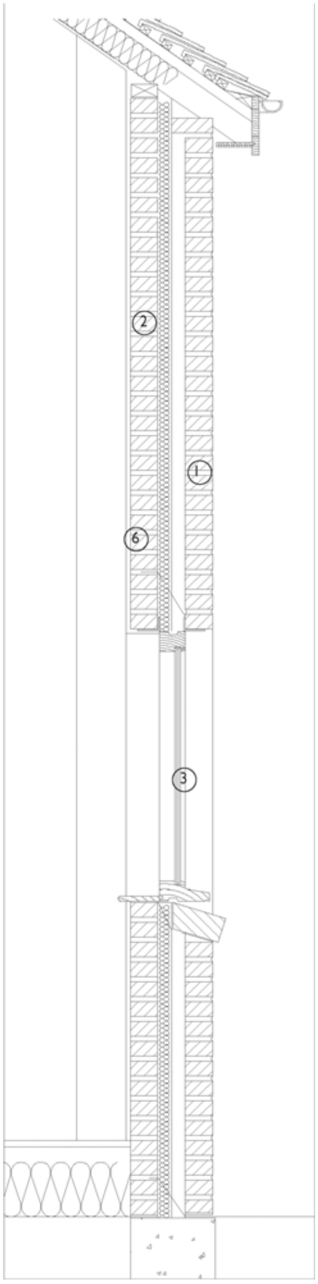
Horizontal section 1:10. Wall detail



Vertical section 1:10. Support of outer leaf at floor slab and at ground level



3-D cut-aways showing relationship between inner and outer cavity leaf



Vertical section 1:25. Wall assembly

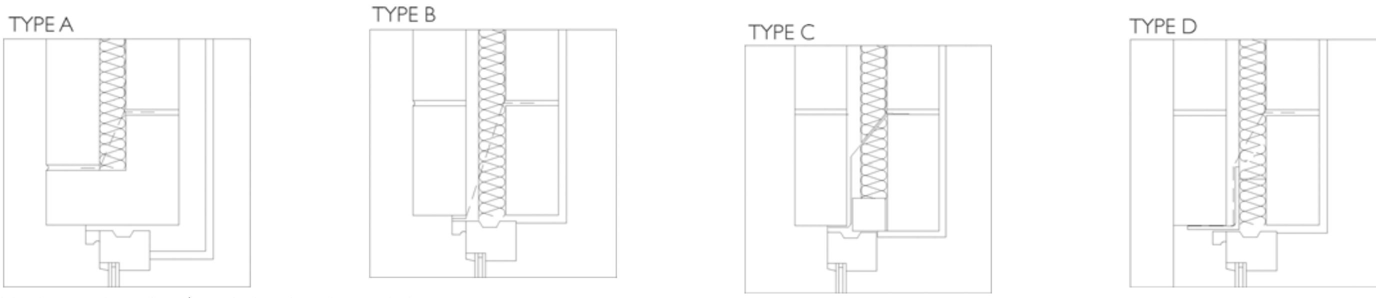
3-D view of cavity brick wall assembly

Details

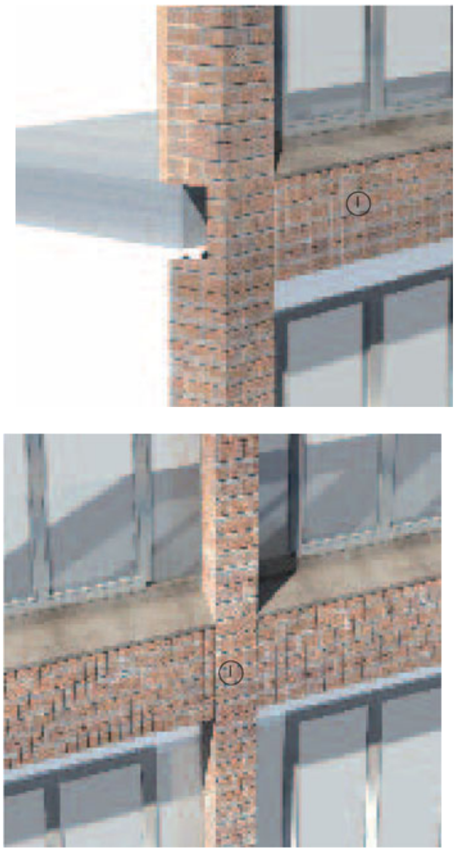
1. Outer brick skin
2. Inner blockwork or brick skin
3. Timber framed window
4. Timber cill
5. Cavity closer
6. Internal plaster finish or dry lining/drywall
7. Thermal insulation in cavity
8. Air cavity (sometimes omitted where insulation fills cavity)
9. Inner concrete lintel or beam
10. Pressed steel lintel
11. Steel angle
12. Metal coping
13. Precast concrete cill
14. Damp proof course (DPC)
15. Brick cill
16. Movement joint
17. Ground floor slab
18. Steel cavity wall tie
19. Foundation

the appearance of a flat arch. Reinforced concrete lintels appear as beams visible in both elevation and on the soffit (underside), while steel lintels are visible only on the soffit of the opening, making it clearly visible that the bricks across the top of the opening on the outer face are not self supporting unlike loadbearing wall construction. For this reason brickwork supported by a steel lintel is often not set on edge to form an arch, but is coursed the same as the brickwork above, since any arch supported by a steel lintel is decorative. However, an advantage of the steel lintel is that it can incorporate a cavity tray, with rainwater being drained through weep holes in vertical joints in the bottom course.

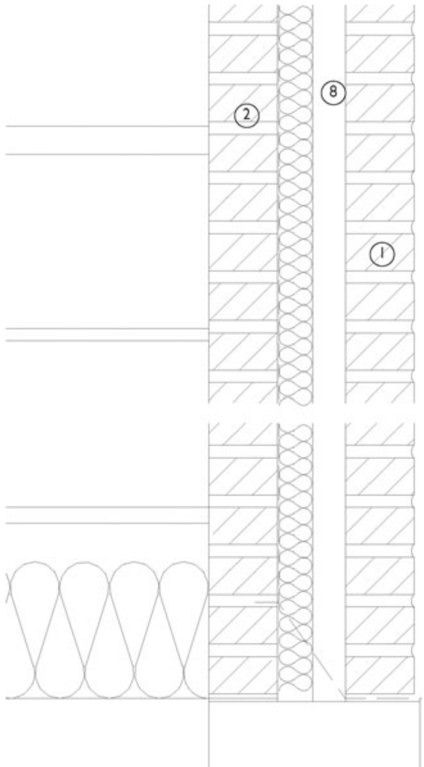
Lintels are supported on both skins at their bearing points. A reinforced concrete lintel spans across both skins either in a profile that also forms a cavity tray for wide spans or as a flat lintel for short spans. In some examples, the lintel has a beam section supporting the inner skin which provides the spanning element and a toe supporting the outer skin. A DPC is set onto the lintel to drain water. In other cases, the DPC can be set above the lintel depending on the configuration of the wall construction. In both cases thermal insulation is set on the inside face of the wall to avoid a thermal bridge. Steel lintels can be used either as a pressed mild steel lintel which has a profile for supporting both skins, or as reinforced concrete lintel

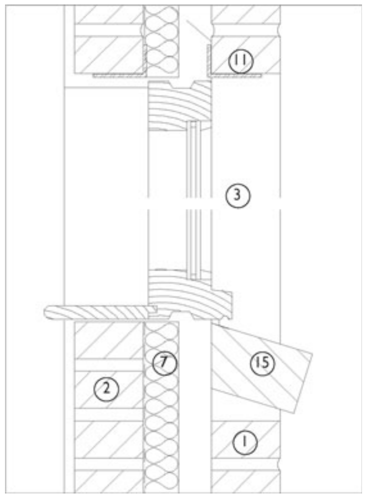


Vertical sections showing window junction variations

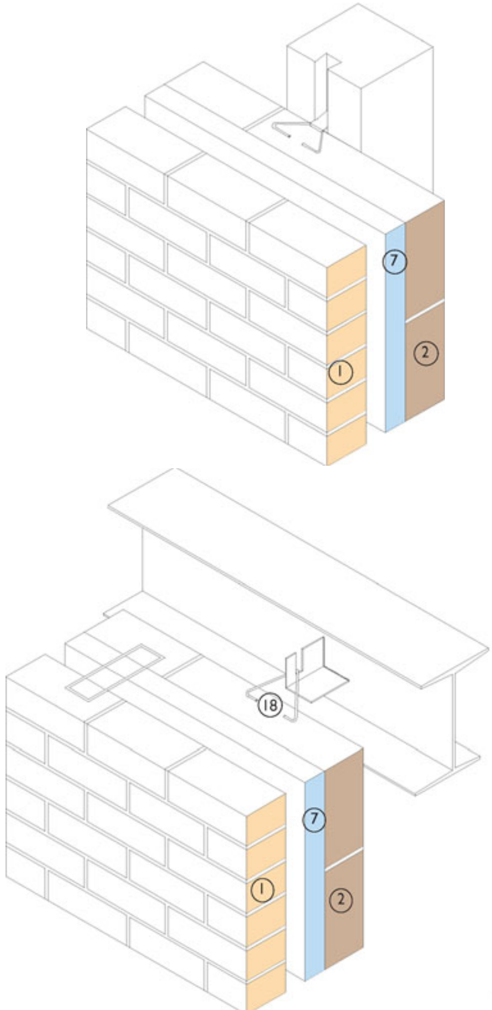


3-D views of window and floor junctions





Vertical sections 1:10. Junction at ground floor level and at window

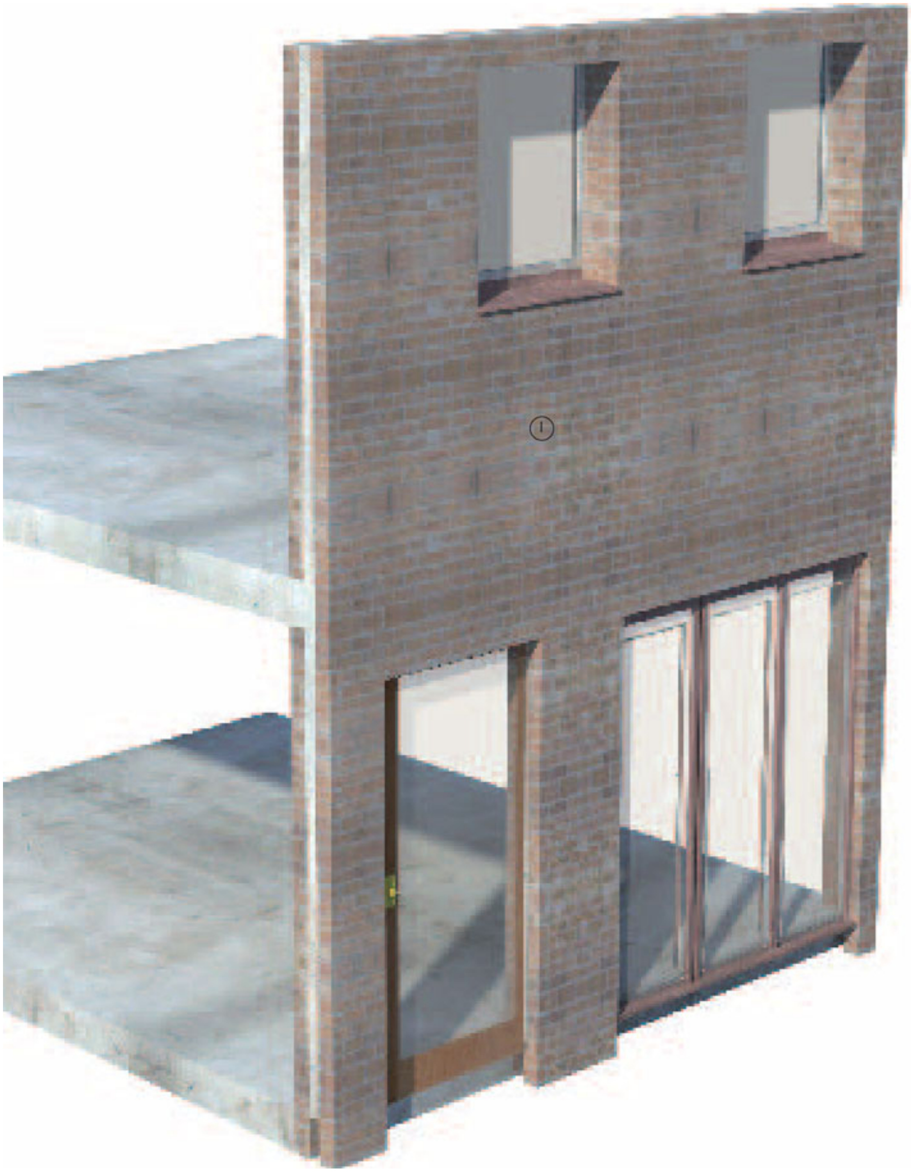


Isometric view of wall assembly; one with steel support (top) and one with concrete support (bottom)

with a stainless steel shelf angle bolted to it. In other examples, the lintel has a DPC set on top of the profile formed by the lintel where the inner block has no structural function but is instead used to infill the gap and provide a background for plaster. Optionally, the DPC can be set onto a stainless steel angle. The angle supports the outer skin, while the reinforced concrete inner beam supports both inner and outer skins.

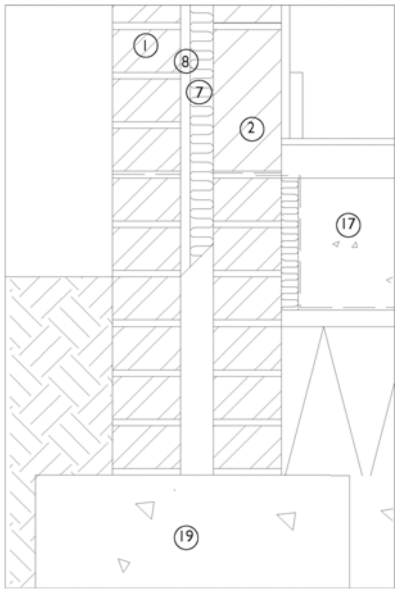
Eaves and parapets

At the eaves, the bottom of a pitched roof terminates against the top of a brick cavity wall. While there are many variations for the roof itself, the top of the wall maintains a consistent principle of closing the cavity at the top with a brick or block that allows the load from the roof structure to be supported on the inner skin. Alternatively, the roof structure may be supported on a column set into the inner skin of the wall or on blockwork piers, also forming part of the inner skin. The closing of the cavity wall at the top allows for continuity of thermal insulation from cavity wall to roof structure while allowing the roof construction to be ventilated where required, and the top of the cavity in the wall to be ventilated. The top of the wall usually has plastic spacers set into the horizontal or vertical joints to ensure that air movement can occur within the cavity. A DPC is set on the underside of the brick or block that closes the cavity to ensure conti-



3-D view of double brick skinned cavity wall system

3-D view showing opening in brick cavity facade

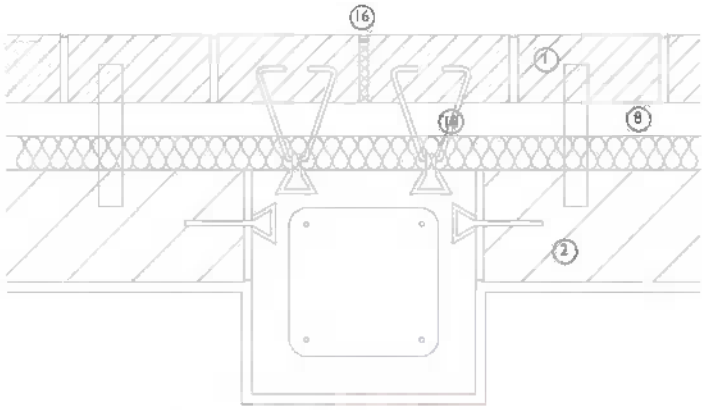


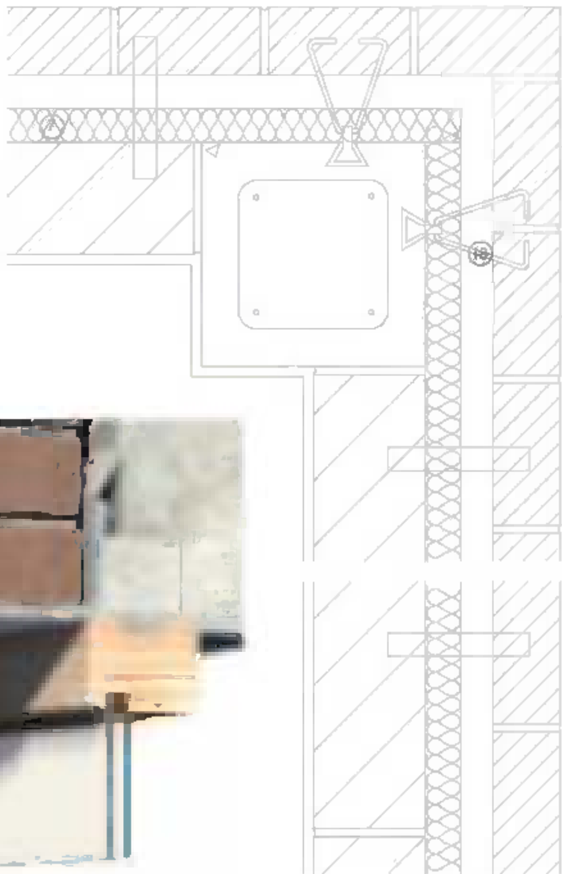
Vertical section 1:10. Junction at ground floor level

nuity between the damp proof membrane on the external face of the inner skin and the waterproofing layer of the roof.

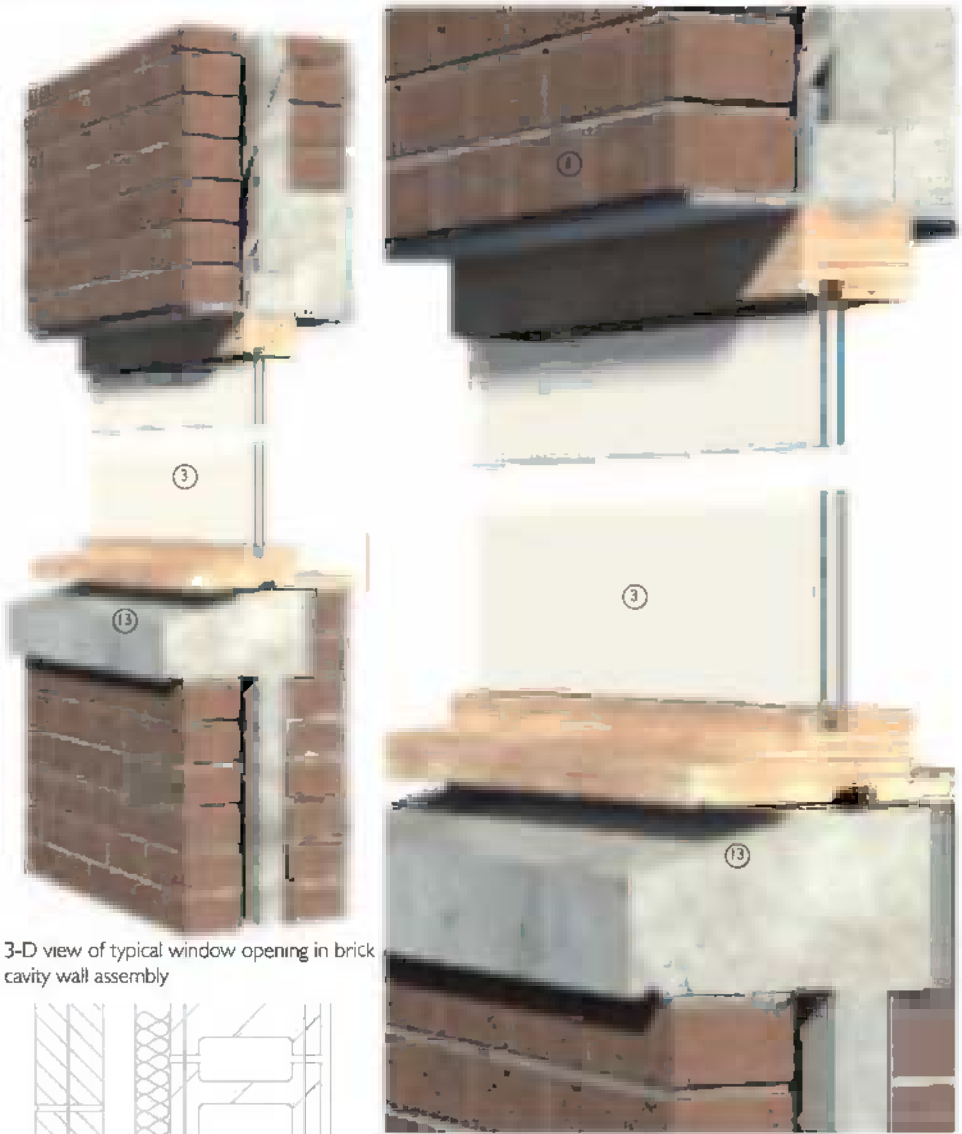
Parapets are closed at the top by a coping, usually in reinforced concrete or stone. A DPC is set beneath the coping to stop the passage of water downwards. Below this, rainwater can enter the cavity from both inner and outer skins and this is prevented by extending the waterproof layer from the roof up the side of the inner skin up to coping level. Thermal insulation is usually continued up the inside of the cavity wall as well as up the external face of the inner skin to avoid a thermal bridge through the inner skin.

3-D oblique view of cavity brick wall assembly facade

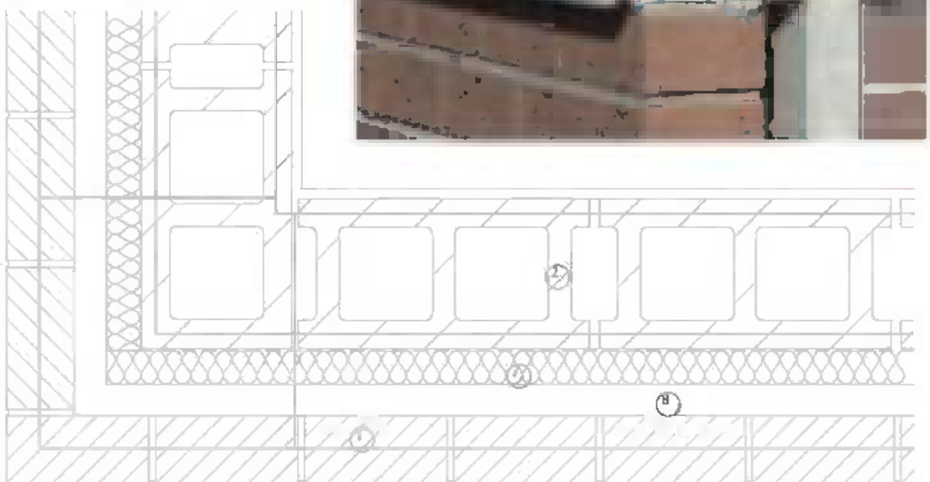




Horizontal sections 1:10. Corner conditions



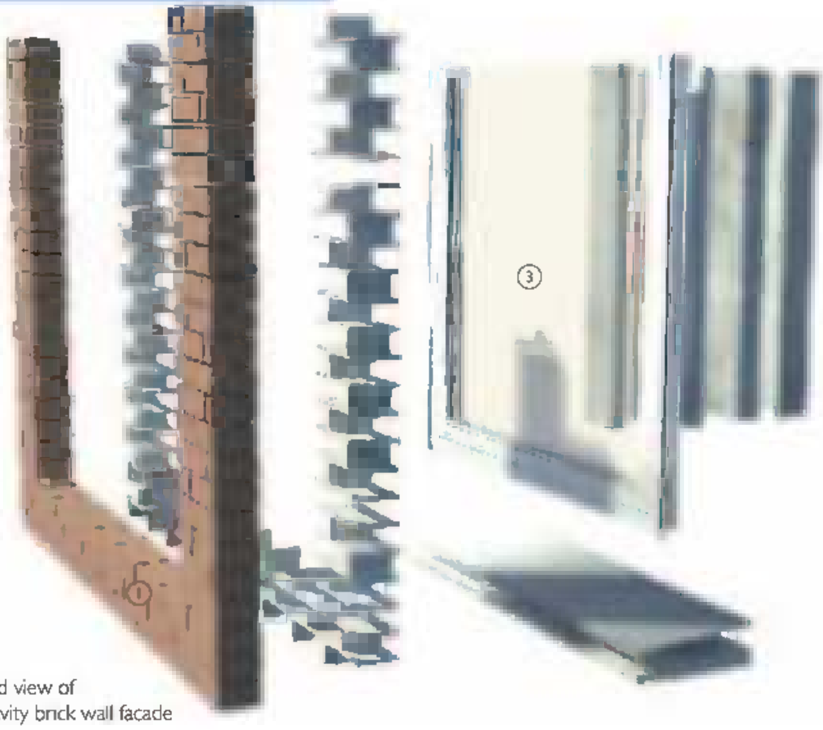
3-D view of typical window opening in brick cavity wall assembly



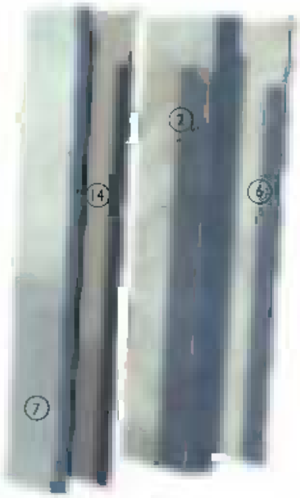
Details

1. Outer brick skin
2. Inner blockwork or brick skin
3. Timber framed window
4. Timber cill
5. Cavity closer
6. Internal plaster finish or dry lining/drywall
7. Thermal insulation in cavity
8. Air cavity (sometimes omitted where insulation fills cavity)
9. Inner concrete lintel or beam
10. Pressed steel lintel
11. Steel angle
12. Metal coping
13. Precast concrete cill
14. Damp proof course (DPC)
15. Brick cill
16. Movement joint
17. Ground floor slab
18. Steel cavity wall tie
19. Foundation

Masonry cavity walls: Brick



3-D exploded view of opening in cavity brick wall facade



Details

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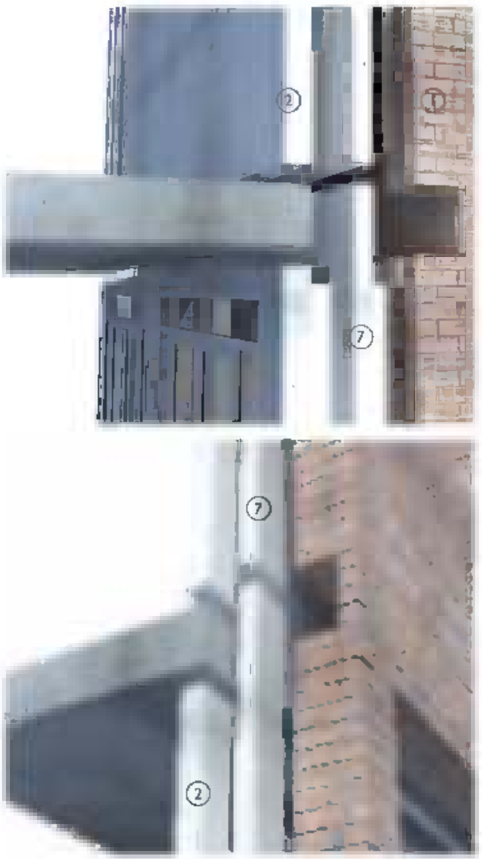
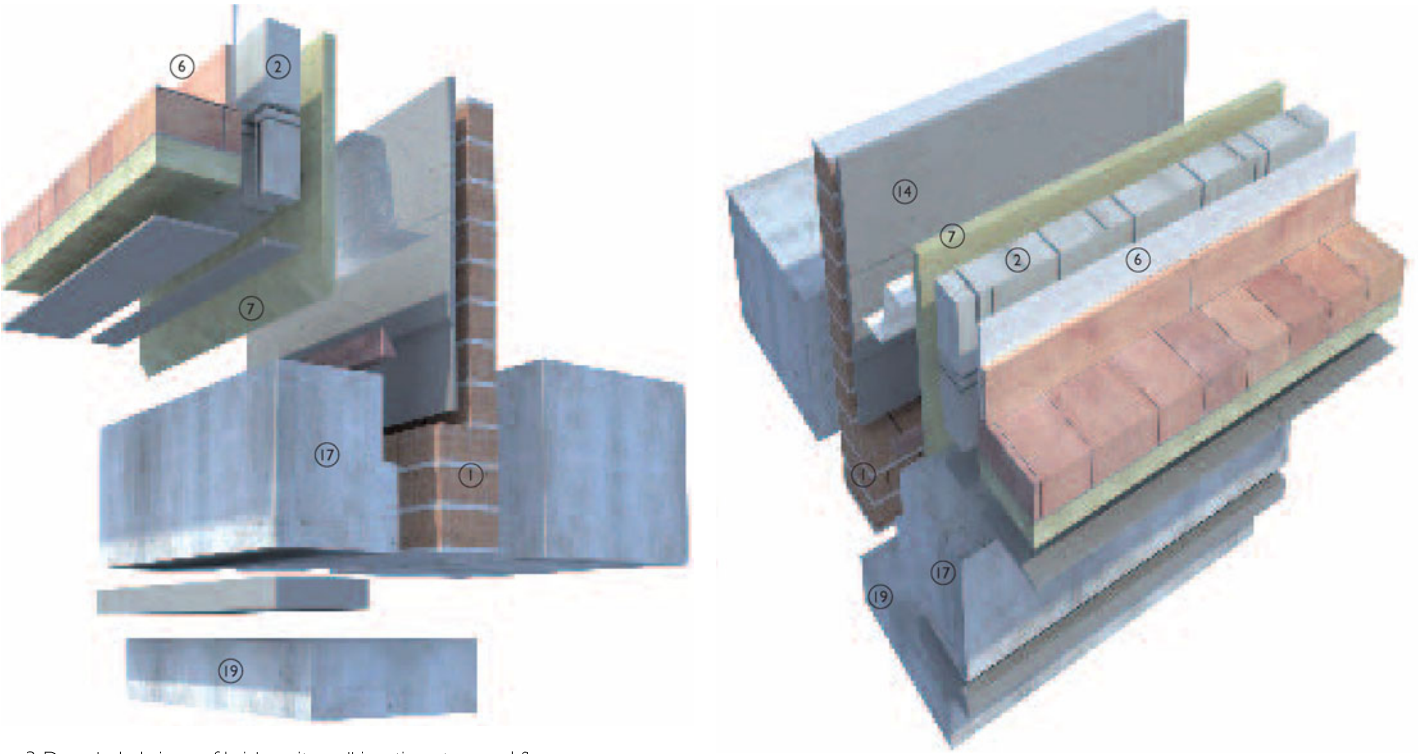
10. Pressed steel lintel
11. Steel angle
12. Metal coping
13. Precast concrete cill
14. Damp proof course (DPC)
15. Brick cill
16. Movement joint
17. Ground floor slab
18. Steel cavity wall tie
19. Foundation

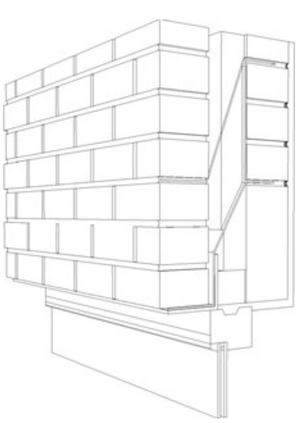
3-D exploded view of cavity brick wall assembly



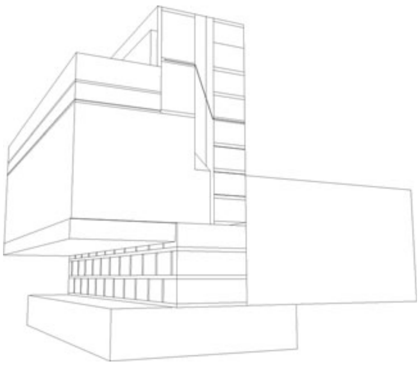
3-D exploded views at upper floor junction



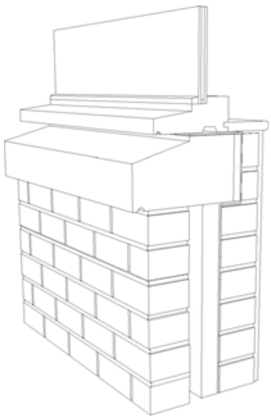
3-D exploded views of brick cavity wall junction at ground floor



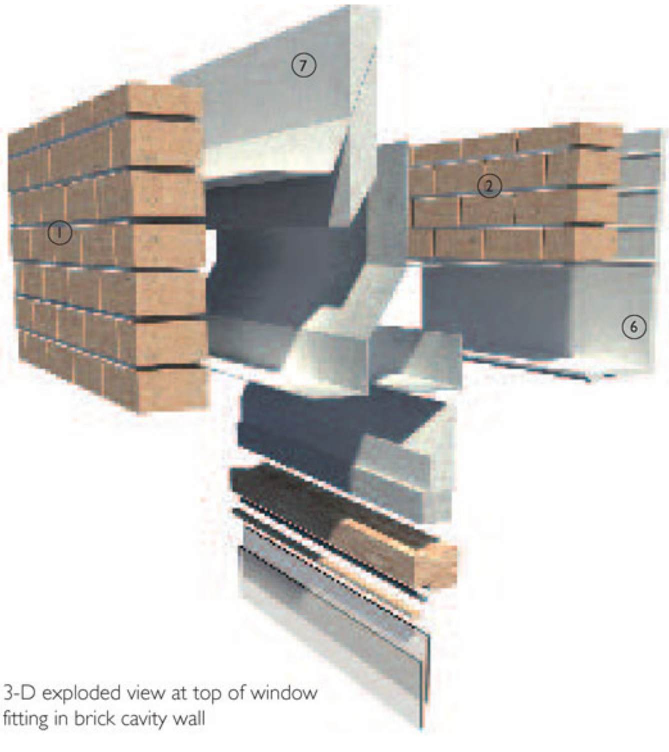
3-D view at top of window opening in brick cavity wall



3-D view at ground floor junction

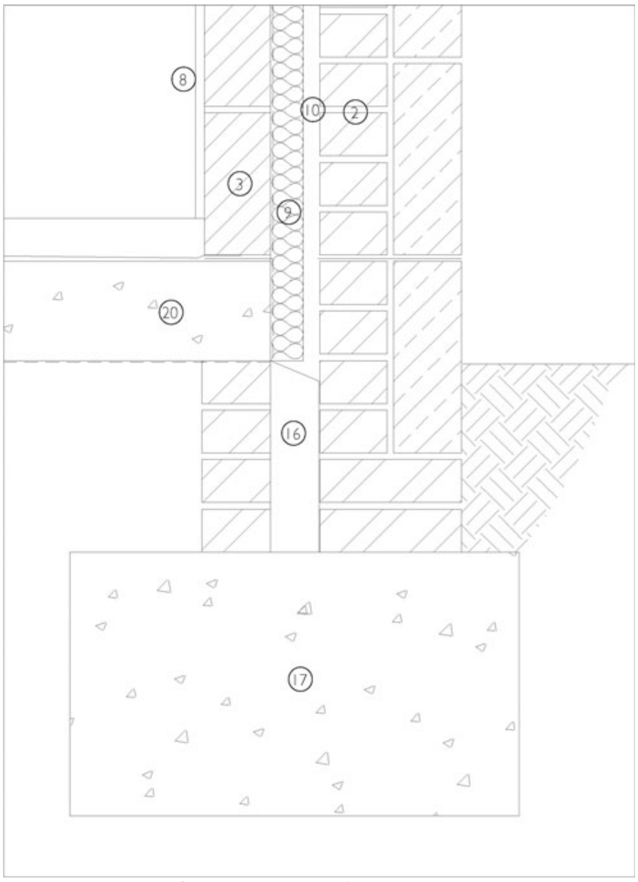


3-D view at bottom of window opening in brick cavity wall

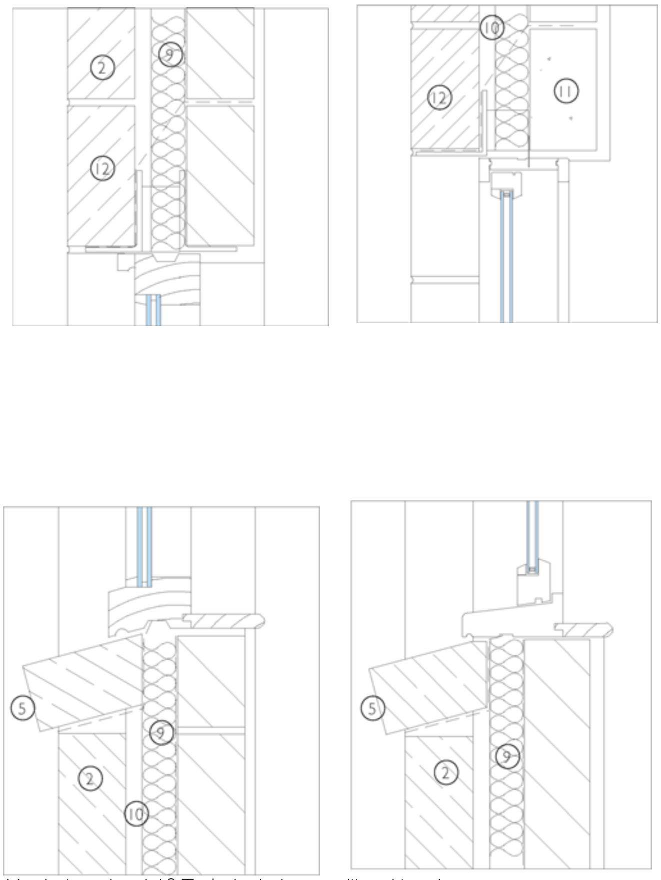


3-D exploded view at top of window fitting in brick cavity wall

3-D exploded view at bottom of window fitting in brick cavity wall



Vertical section 1:10. Junction at ground floor level



Vertical section 1:10. Typical window at cill and head

Details

1. Stone or concrete coping
2. Outer stone skin with brick backing shown to create deep window reveals or where required structurally
3. Inner block skin
4. Timber framed window / door
5. Stone or precast concrete cill
6. Timber inner cill
7. Cavity closer
8. Internal plaster finish or dry lining/dry wall
9. Thermal insulation in cavity

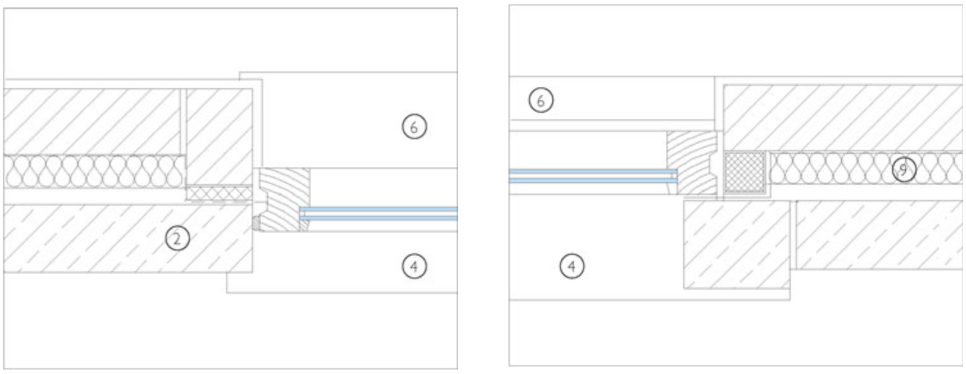

3-D view of cill detail on a blockwork cavity wall

The principles of cavity wall design are set out in the previous text on brick cavity walls. The same principles can be applied for use when stone and concrete blockwork are used to form an outer skin.

When stone is used, it can be used either as an outer skin approximately 100mm/4in thick, or with thinner stone that is bonded to brickwork that together forms a 'composite' outer skin. When used as a 100mm/4in thick skin in order to be self-supporting, the stone becomes expensive, so sandstones and limestones are most commonly used. Composite-type outer skins suit stone that is 40mm to 50mm thick (1.5in-2.0in), bonded to a 100mm/4in wide brick skin. This method suits granites and denser limestones.

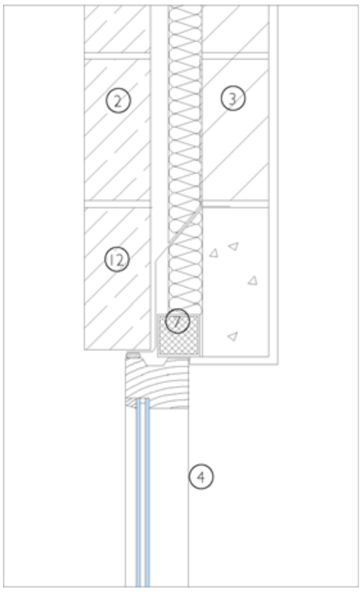
In single outer skins of stone, the material is ventilated on both sides, allowing it to dry out easily, avoiding a situation where stone would dry from only the outer face, which would draw dirt and dust out into the outside face.

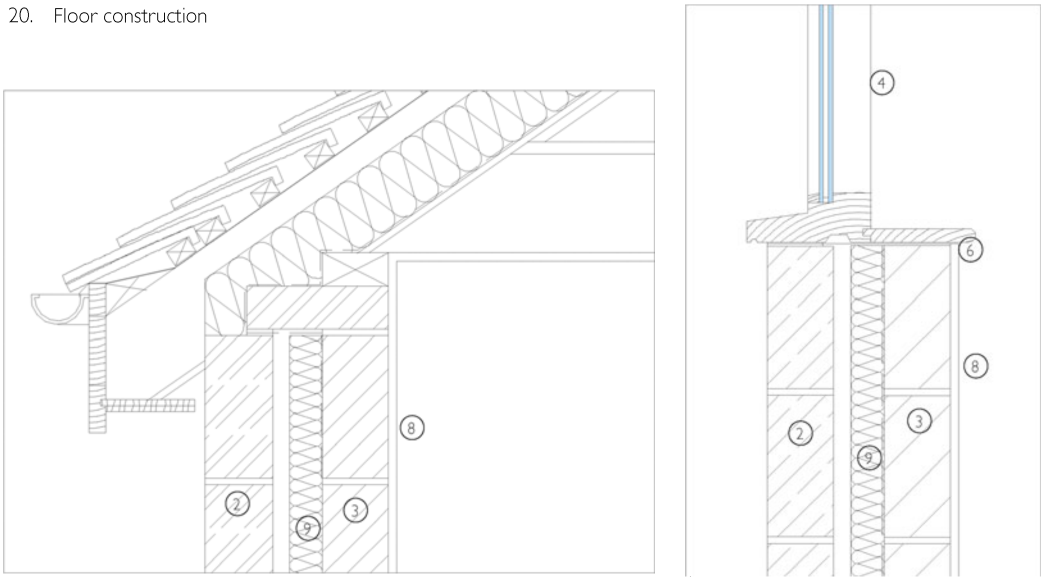
The biggest difference in detailing between brick cavity walls and stone / block cavity walls is that there are fewer joints in stone / block due to their large size. This means that there are fewer opportunities to design a damp proof course (DPC) with floor slabs, for example, particularly where shelf angles are used. The smaller unit size of brick makes it a very flexible material when detailing; stone / block requires careful co-ordination of stone / block size and floor to floor heights to allow for windows to be suitably placed. For this reason, alternating bands



Horizontal section 1:10. Typical window jamb

10. Air cavity (sometimes omitted where insulation fills cavity)
11. Inner precast concrete lintel
12. Outer precast concrete lintel or stone flat arch
13. Damp proof course (DPC)
14. Movement joint
15. Timber framed inner skin with quilt insulation
16. Cement fill
17. Foundation
18. Vertical DPC
19. Structural column
20. Floor construction



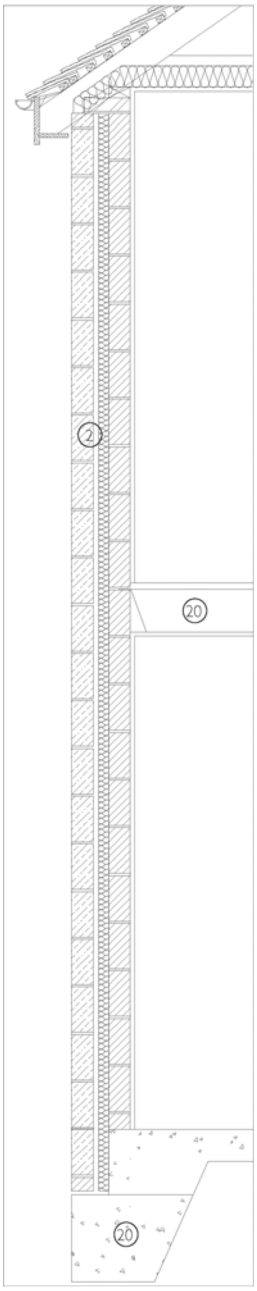


Vertical sections 1:10. Typical Window at cill and head, parapet and eaves to pitched roof

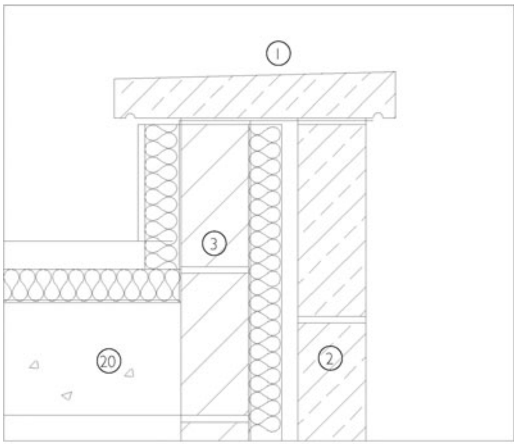
of thick and thin stone are used in coursing. This allows horizontal joint lines to be provided at shelf angles, cavity trays and DPCs at ground level without disturbing the stone pattern with additional horizontal joints. Unlike open jointed stone cladding, where the mortar is omitted, the mortar and joint profile have a big visual impact.

Wall structures

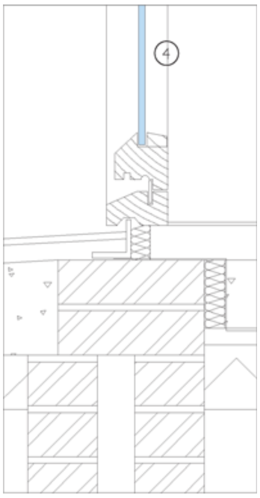
Loadbearing cavity walls used to support two storey structures on their inner skins are very common in housing construction in Europe and North America. Vertical movement joints are provided at around 7500mm/25ft centres, or else are avoided altogether in the construction by keeping lengths of wall within these dimensions. When cavity walls are used with large scale building frames in either steel or concrete, the inner leaf is no longer loadbearing and instead the complete wall construction forms a cladding to the frame. When reinforced concrete frames are used, the junction between inner skin, typically concrete block or terracotta block, is straightforward with a gap between the two to allow for structural movement in the frame. Stainless steel sliding anchors are used either in the sides of the inner skin panel where it meets the column, or at the head where it meets the floor slab. The outer skin runs continuously in front of it. The situation is more complicated with a steel frame, where the column needs to be protected from corrosion from water vapour in the cavity. Typically the column is painted to form a protective

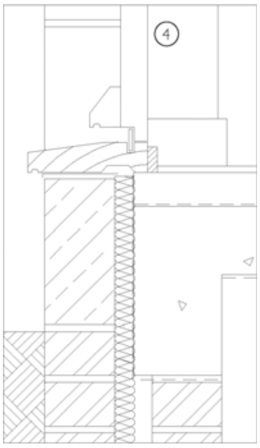


Vertical section 1:25. Wall assembly

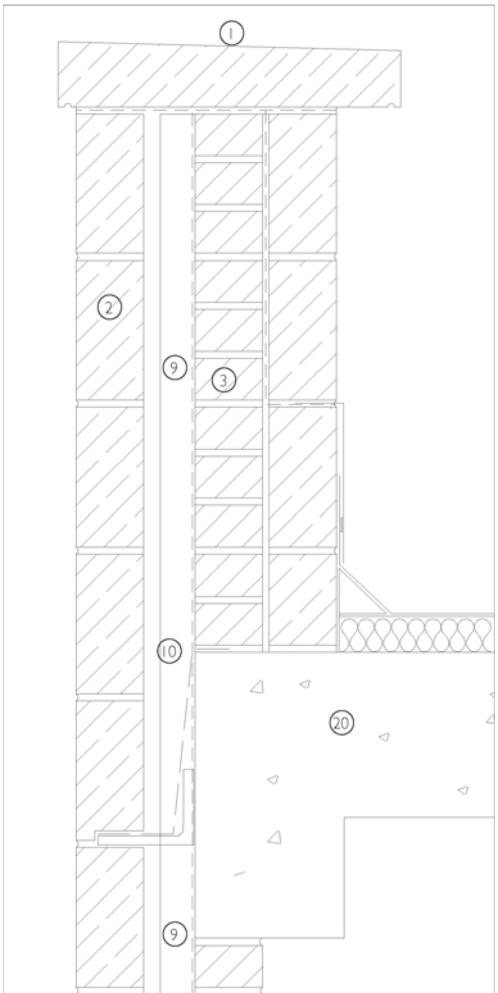


Vertical section 1:10. Typical parapet





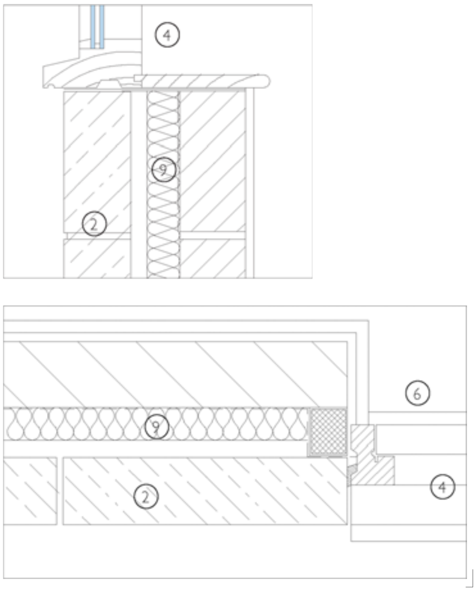
Vertical section 1:10. Typical threshold



Vertical section 1:10. Typical parapet

Details

1. Stone or concrete coping
2. Outer stone skin with brick backing shown to create deep window reveals or where required structurally
3. Inner block skin
4. Timber framed window / door
5. Stone or precast concrete cill
6. Timber inner cill
7. Cavity closer
8. Internal plaster finish or dry lining/dry wall
9. Thermal insulation in cavity
10. Air cavity (sometimes omitted where insula tion fills cavity)
11. Inner precast concrete lintel
12. Outer precast concrete lintel or stone flat arch
13. Damp proof course (DPC)
14. Movement joint
15. Timber framed inner skin with quilt insulation
16. Cement fill
17. Foundation
18. Vertical DPC
19. Structural column
20. Floor construction



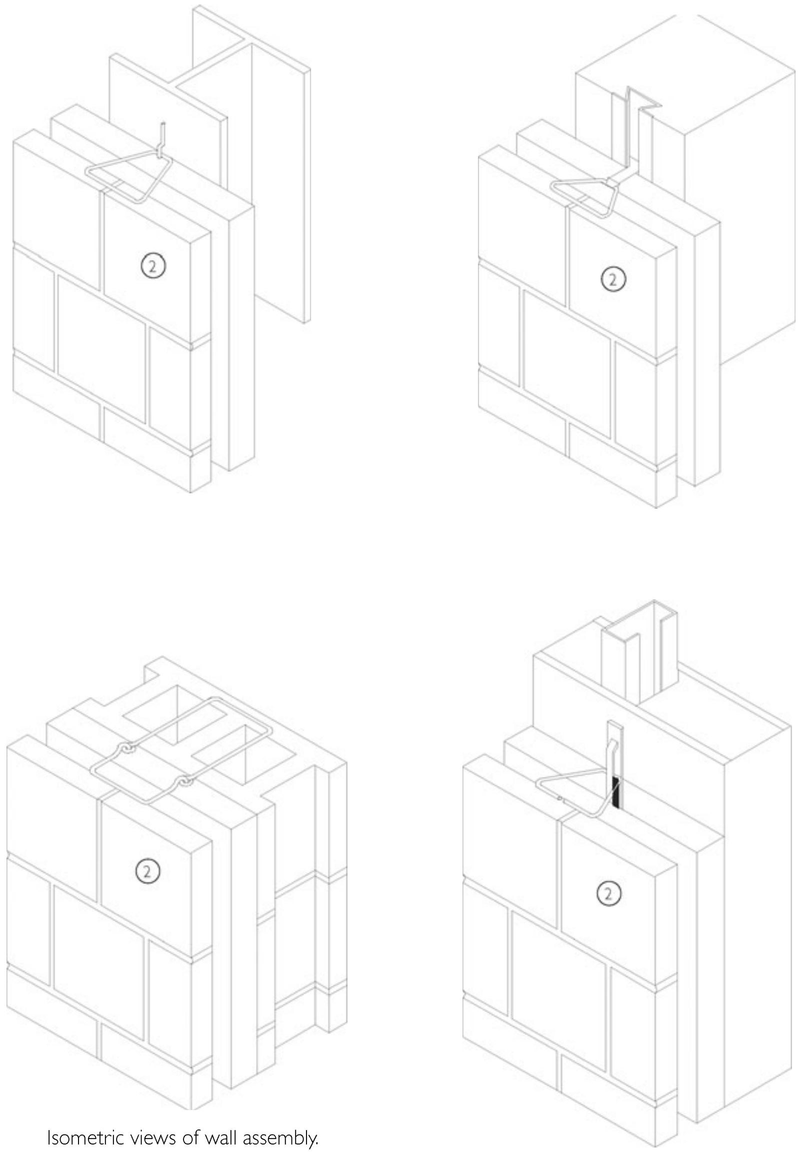
Vertical & horizontal sections 1:10. Typical window at cill

coating and thermal insulation is set across the face of the steelwork to provide a continuity of thermal insulation. Sometimes the outer skin is restrained with cavity ties fixed to the face of the reinforced concrete or steel column. This is particularly useful when forming a movement joint in lengths of brickwork, or movement joints that form part of the building structure which typically occur at columns in the building frame. The vertical movement joint is filled with two part polysulphide sealant that also matches the colour of the mortar as closely as possible and provides a seal that can accommodate the structural movement within the cavity wall.

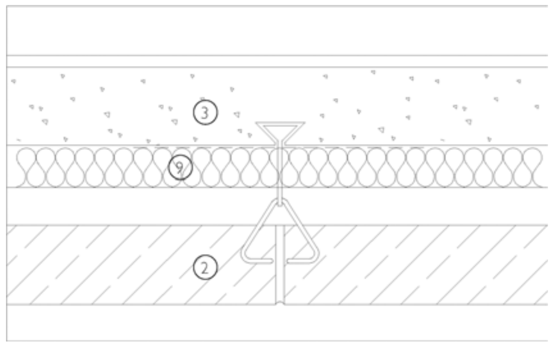
Ground level

An essential design consideration at ground level is to provide a DPC at a minimum 150mm/6in above ground floor level with a horizontal joint that can be accommodated within the design. Granite is often used below DPC level to avoid staining from rain splashing from the adjacent ground and from dust and damage in urban locations. The granite, usually 30mm to 40mm thick (1.2in to 1.5in), is bonded to brickwork or concrete blockwork to make up the difference in thickness of the outer skin to a minimum of 100mm (4in).

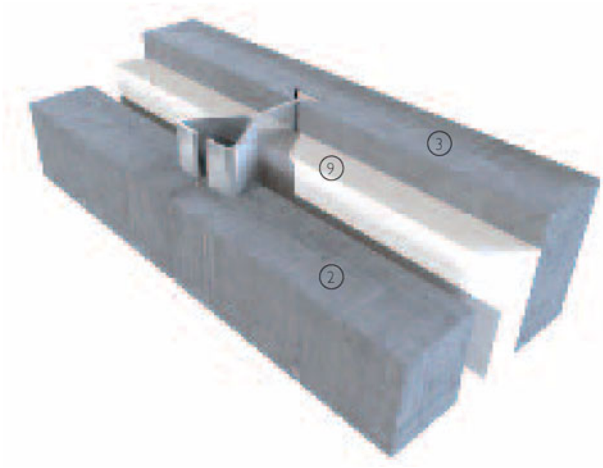
In order to avoid dampness reaching the inside of the building, a mixture of DPCs is used that provides a continuity between DPC and the damp proof membrane for the floor slab. Different combinations of DPCs are used for entry into the building at the same level as outside when the floor level is a minimum of 150mm (6in) above external level. When internal and external levels are



Isometric views of wall assembly.



Horizontal section 1:10. Blockwork cavity wall construction



3-D view of blockwork cavity wall construction

almost the same, the DPC is set at ground level and is continuous with the DPM rising from below. An additional stepped DPC is set 150mm (6in) above external level to drain the cavity above. When internal and external levels are very different, a first DPC steps down from internal floor level to a horizontal joint in the outer skin, 150mm (6in) above external level, where a second DPC on the inner skin extends down the internal face of the wall down to join the DPM.

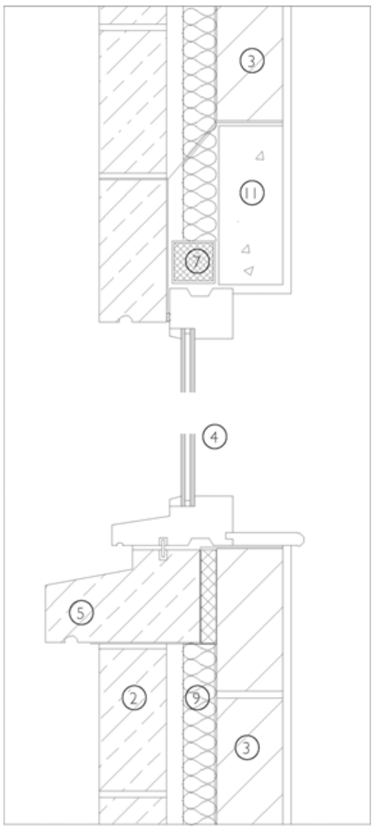
The cavity below ground level is filled to avoid water building up in any voids, particularly where foundations for pads for steel or reinforced concrete columns are continuous with the cavity wall. Foundations need to be filled to ground level.

There is always a difficulty in providing a continuity of thermal insulation down the cavity and under the slab due to the need to build the masonry skins directly off the foundation. The thermal insulation in the cavity is taken down as far as possible to overlap with the insulation under the floor slab to reduce the thermal bridge to a minimum.

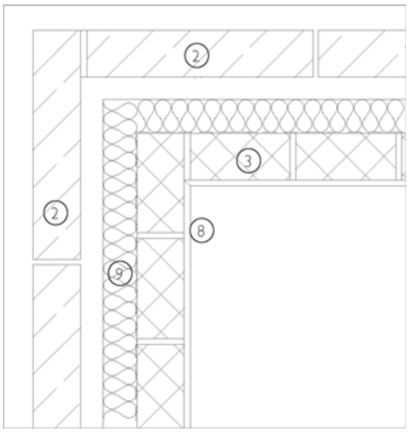
Openings in walls

This section discusses variations and details additional to those set out in the previous section on brick cavity walls and focuses on different materials for the inner skin.

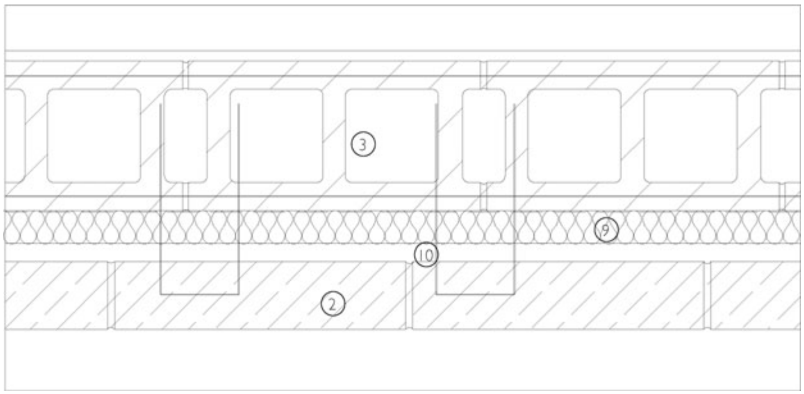
When a timber framed inner skin is used, the window is usually an integral part of that inner skin so that a complete enclosure is formed in timber with masonry used as an outer skin providing some lateral stability. The outer masonry skin can be returned to form a reveal up to around 125mm (5in) depending on the thickness of insulation in the cavity. Alternatively the timber window can be set



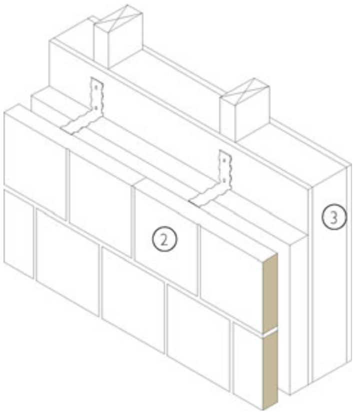
Vertical section 1:10. Typical window at cill and head

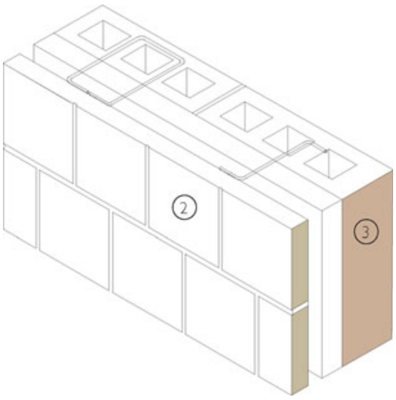


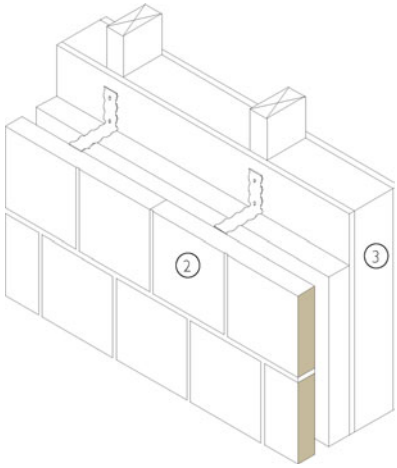
Horizontal section 1:10. Blockwork cavity wall construction



Horizontal section 1:10. Blockwork cavity wall construction







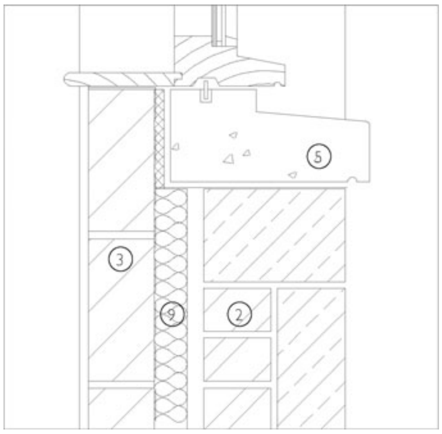
Isometric view of wall assembly.

Details
1. Stone or concrete coping
2. Outer stone skin with brick backing shown to create deep window reveals or where required structurally
3. Inner block skin
4. Timber framed window / door
5. Stone or precast concrete cill
6. Timber inner cill
7. Cavity closer
8. Internal plaster finish or dry lining/dry wall
9. Thermal insulation in cavity
10. Air cavity (sometimes omitted where insulation fills cavity)
11. Inner precast concrete lintel
12. Outer precast concrete lintel or stone flat arch
13. Damp proof course (DPC)
14. Movement joint
15. Timber framed inner skin with quilt insulation
16. Cement fill
17. Foundation
18. Vertical DPC
19. Structural column
20. Floor construction

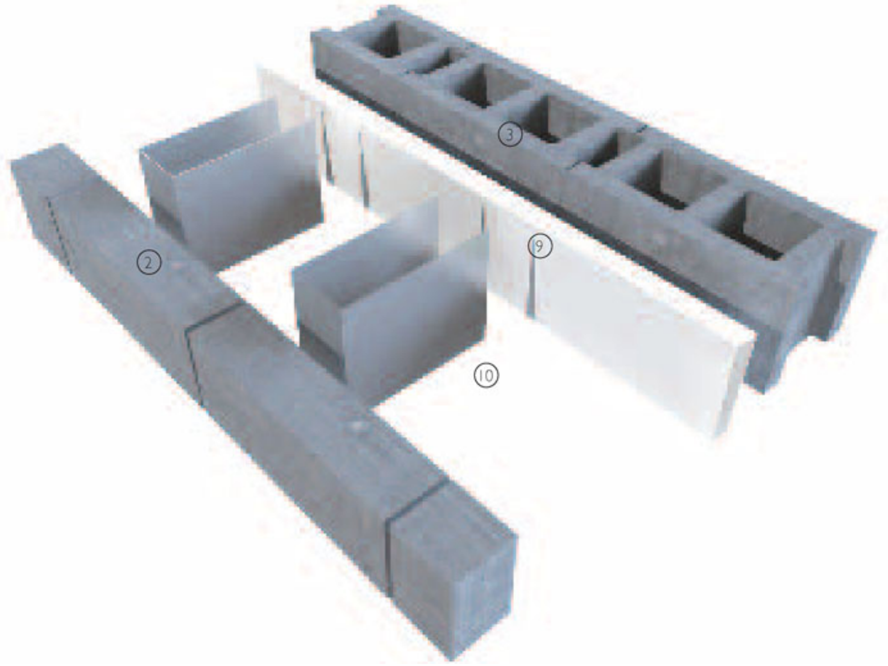
forward close to the line of the outer face with a timber cill projecting forward of the wall. This gives the outer wall an appearance of a brick texture, giving a planar look to the material.

With reinforced concrete inner skins, it is difficult to set wall ties into the material to restrain the outer material. Since it is not practical to cast in wall ties in the precise location where they are needed, which does not allow for later adjustment, a set of narrow stainless steel channels are post fixed to the concrete. Wall ties are then fixed to these channels, which provide the adjustment required. In recent years, outer masonry skins have been made as prefabricated panels on some projects when fixed back to a reinforced concrete wall. Panels of stone, terracotta or even brick are bonded together with mortar and then held in a steel edge frame, which is fixed to the inner skin. The concrete inner skin is waterproofed with bituminous paint and thermal insulation set on the outside face of the inner skin. The steel angle on the bottom edge forms a closer to the window below, while the steel on the top edge forms a cill to the window above. The vertical steel angles are usually concealed within the cavity to give a continuous masonry appearance. The masonry is sometimes restrained within the panel by vertical stainless steel rods which are tensioned against the frame to form lightly prestressed panels. Vertical joints between panels are sealed, typically with a polysulphide sealant.

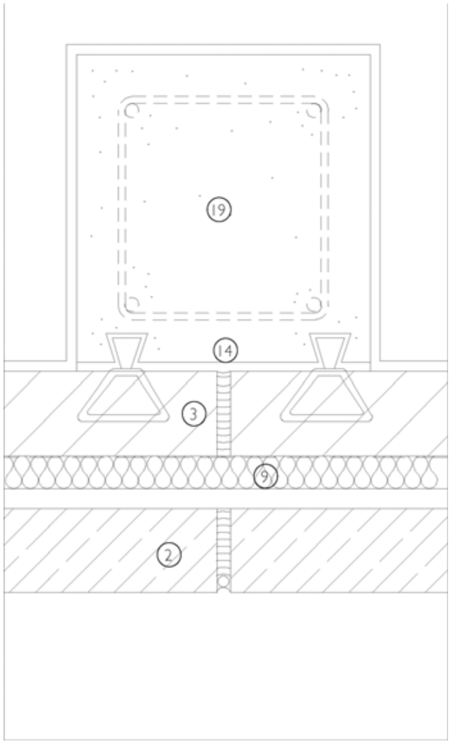
3-D view of blockwork cavity wall construction



Vertical section 1:10. Typical window at cill



3-D exploded view of blockwork cavity wall construction

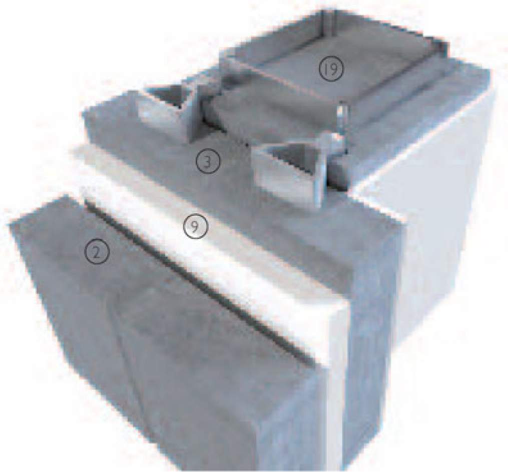


Horizontal section 1:10.
Typical connection or restraint to primary structure

Eaves and parapets

Eaves to cavity walls in stone and block are generally to either a reinforced concrete slab or to a timber pitched roof. When a reinforced concrete slab is used and is visible from the outside, both inner and outer skins need a joint for expansion at the head. A compressible durable seal is used, recessed from the face of the outer skin to avoid a colour clash with the mortar below. Stainless steel angles with slotted connections are also used to restrain masonry at the head, or even a stainless steel channel if the underside of the concrete is revealed. When the concrete slab soffit is concealed with additional cladding, a horizontal joint in the outer skin is usually placed to align with the cladding to avoid the appearance of the stone disappearing behind the soffit. The outer skin continues with another course to close against the slab soffit. Where a downstand beam is used to support the concrete roof slab above, the beam is usually aligned with the inner skin of the cavity wall. A stepped DPC is set the other way round from its usual position, draining from the outer leaf to the inner leaf, but water running down the underside of the DPC is drained harmlessly down the outer face of the inner skin. If timber is used in a projecting flat roof the DPC is set on top of the wall, on which roof timbers are supported. A continuity of thermal insulation is provided. The timber roof structure can also be ventilated to allow it to be kept dry while maintaining thermal insulation.

For parapets the inner skin is thickened



3-D view of blockwork cavity wall construction

Details
1. Stone or concrete coping
2. Outer stone skin with brick backing shown to create deep window reveals or where required structurally
3. Inner block skin
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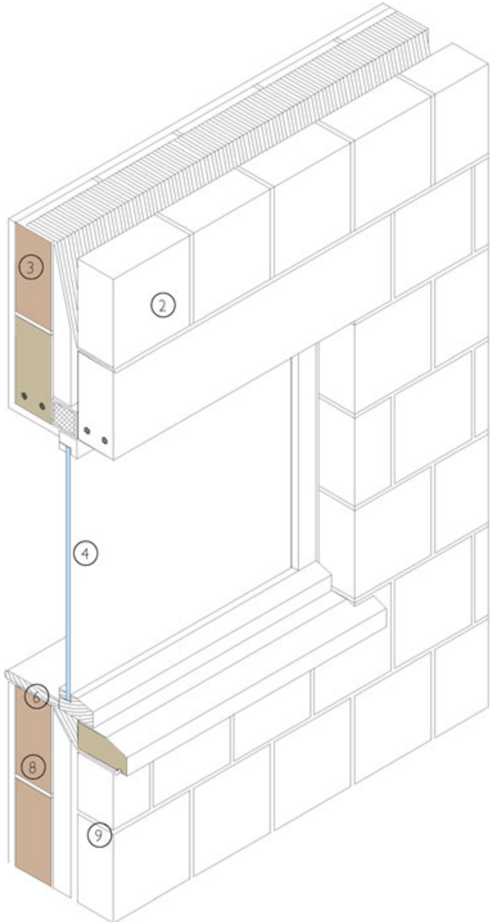
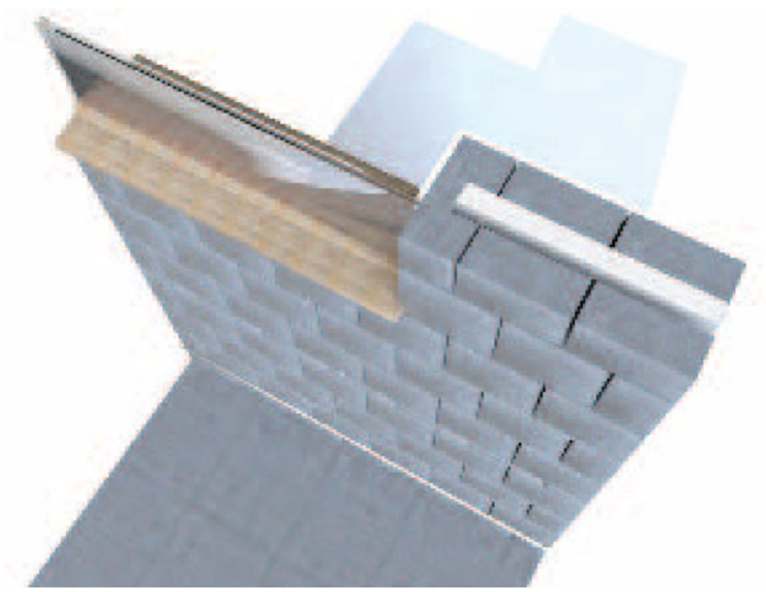
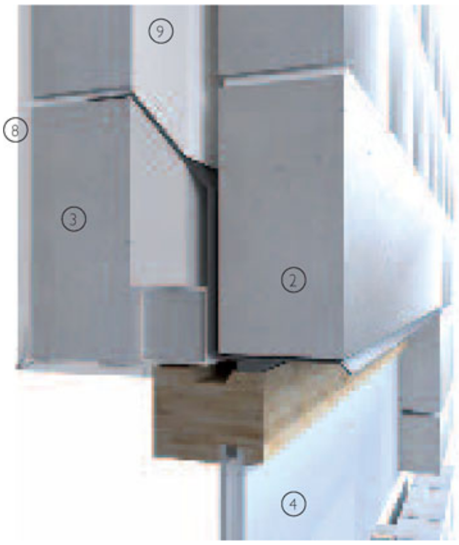
15. Timber framed inner skin with quilt insulation
16. Cement fill
17. Foundation
18. Vertical DPC
19. Structural column
20. Floor construction



Isometric view of wall assembly.

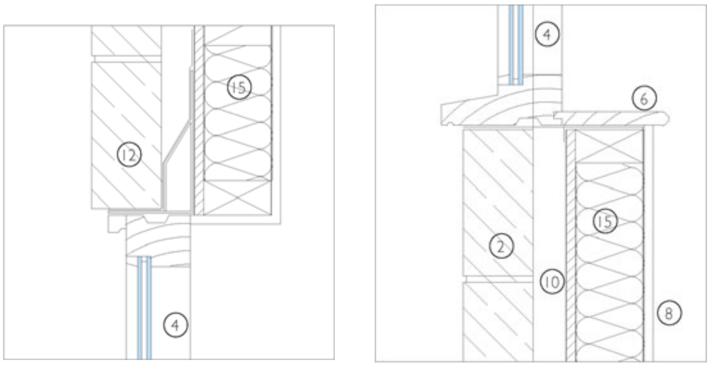
up when used as a balustrade. A handrail on top of the coping is fixed by drilling through the top and bolting it to the inner skin beneath. The coping is cut to receive the balustrade or handrail, unless the uprights supporting the handrail pass between the joints. The adjacent area of flat roof or gutter usually has a waterproofing layer returning up the wall, regardless of the roof finish. The waterproofing layer is set into horizontal joints in outer masonry skin. A metal flashing is set into the same horizontal joint and is set over the top of the waterproofing to protect it from damage. Metal copings are used increasingly on parapets in order to match the appearance of windows and doors, particularly where metal cills are used. The same principles apply as for concrete copings, with a DPC set on top of the masonry wall. Drips are formed on either side of the vertical face to ensure that water is thrown clear of the wall. For all parapets, the waterproofing layer is continued up the wall to become continuous with the DPC in low parapets. For high parapet walls, a stepped DPC is used to drain water back to the inner skin to ensure that water inside this part of the cavity wall is drained immediately, especially in very exposed conditions. A stepped DPC is used instead of a regular flat DPC under the coping.


3-D view of section through blockwork cavity wall and window

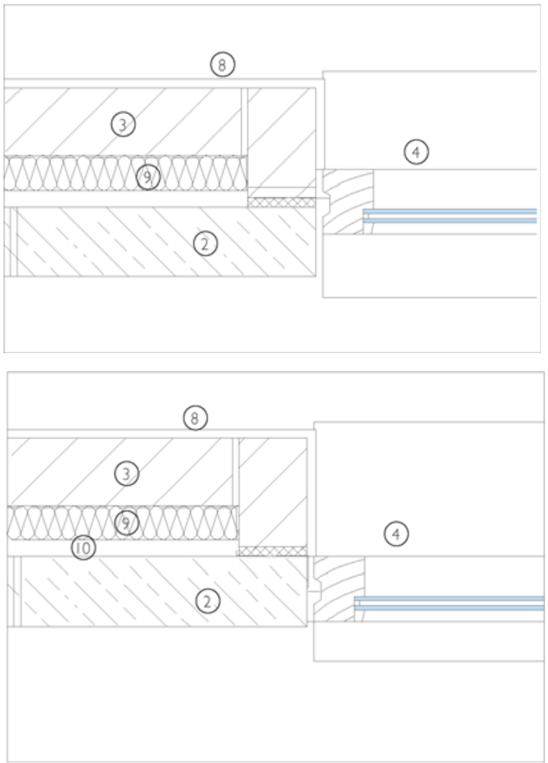


3-D view of window head detail

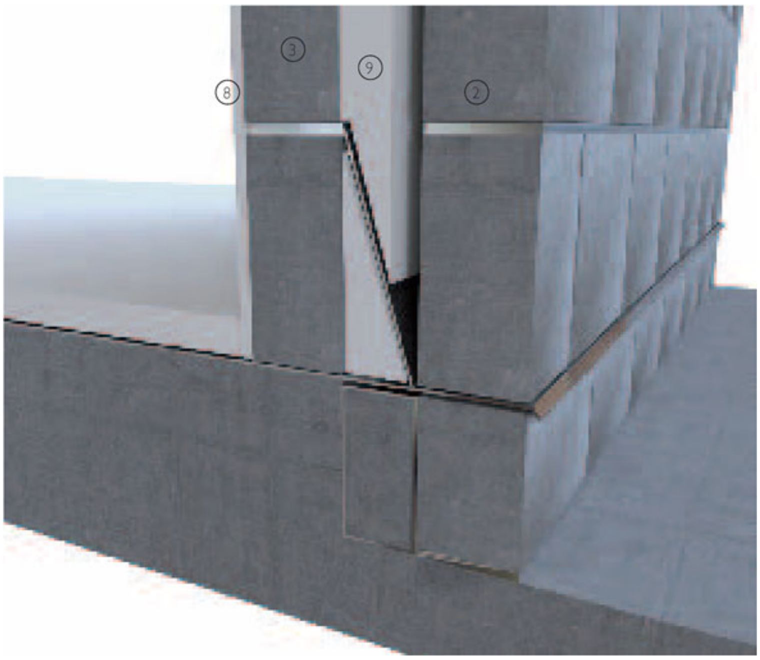
3-D view of window cill detail



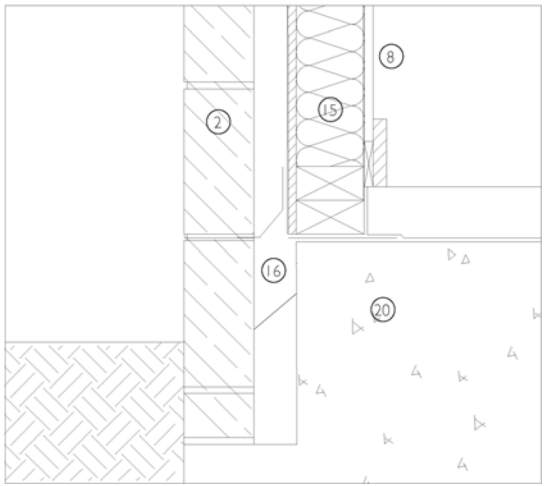
Vertical sections 1:10. Typical window at cill and head



Horizontal sections 1:10. Window jambs



3-D view of junction at ground floor level



Vertical section 1:10. Junction at ground floor level

Masonry cavity walls: Stone and concrete block

3-D view of blockwork cavity wall construction

Details

1. Stone or concrete coping
2. Outer stone skin with brick backing shown to create deep window reveals or where required structurally
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4. Timber framed window / door
5. Stone or precast concrete cill
6. Timber inner cill
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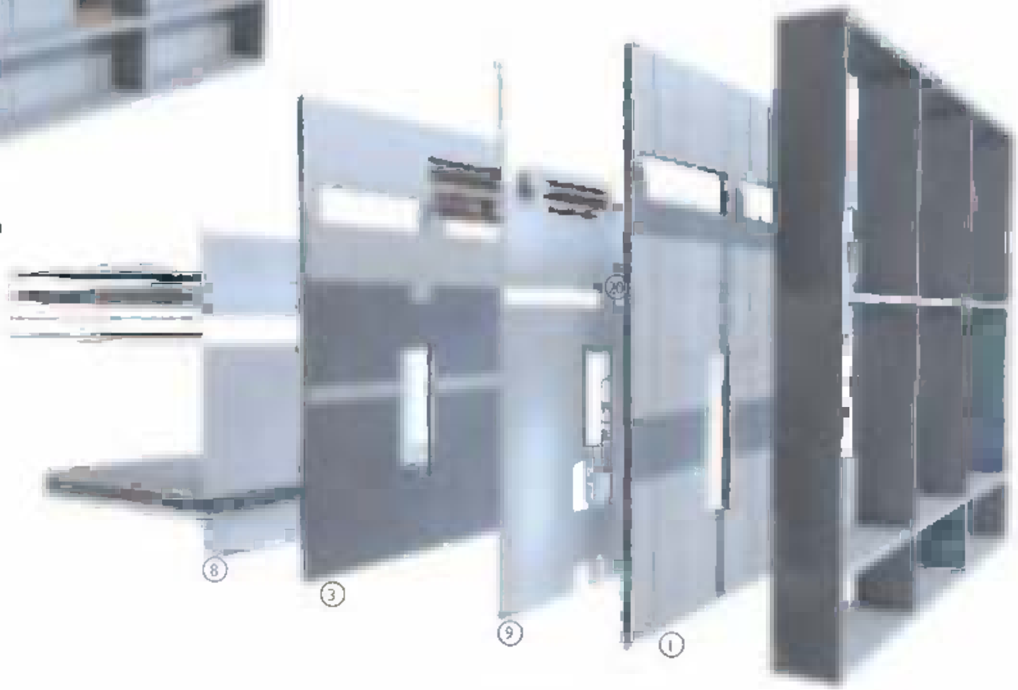
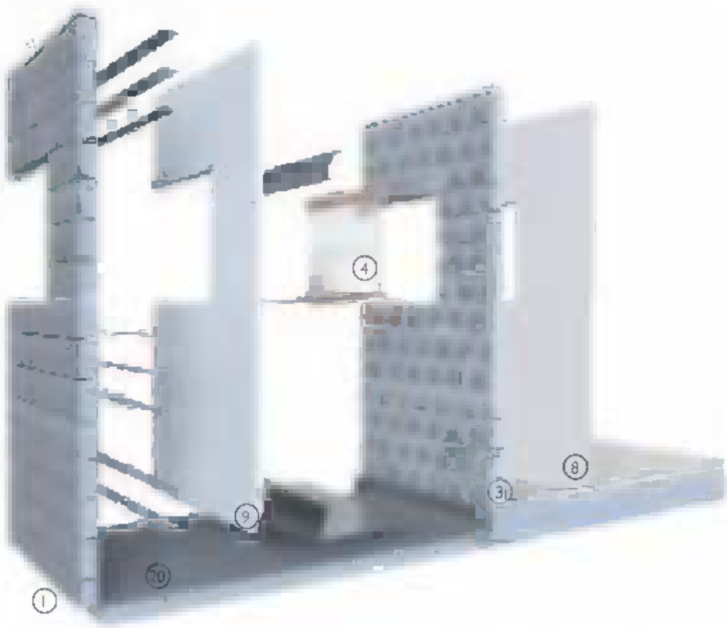
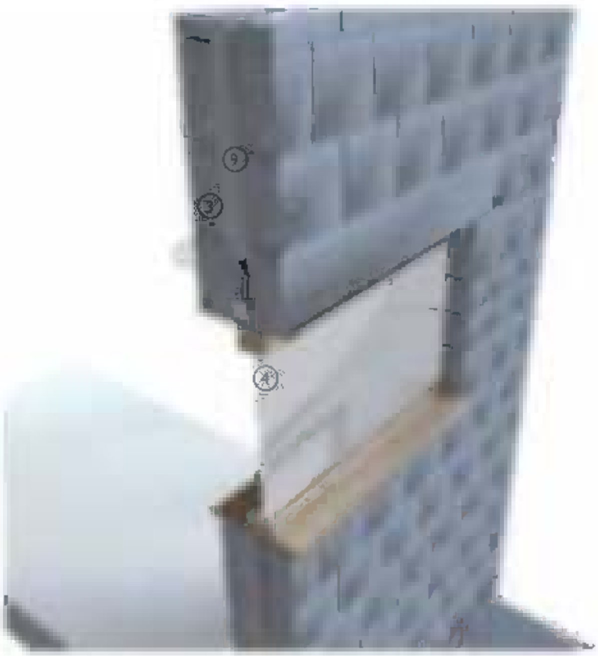
15. Timber framed inner skin with quilt insulation
16. Cement fill
17. Foundation
18. Vertical DPC
19. Structural column
20. Floor construction



3-D exploded view of blockwork cavity wall construction

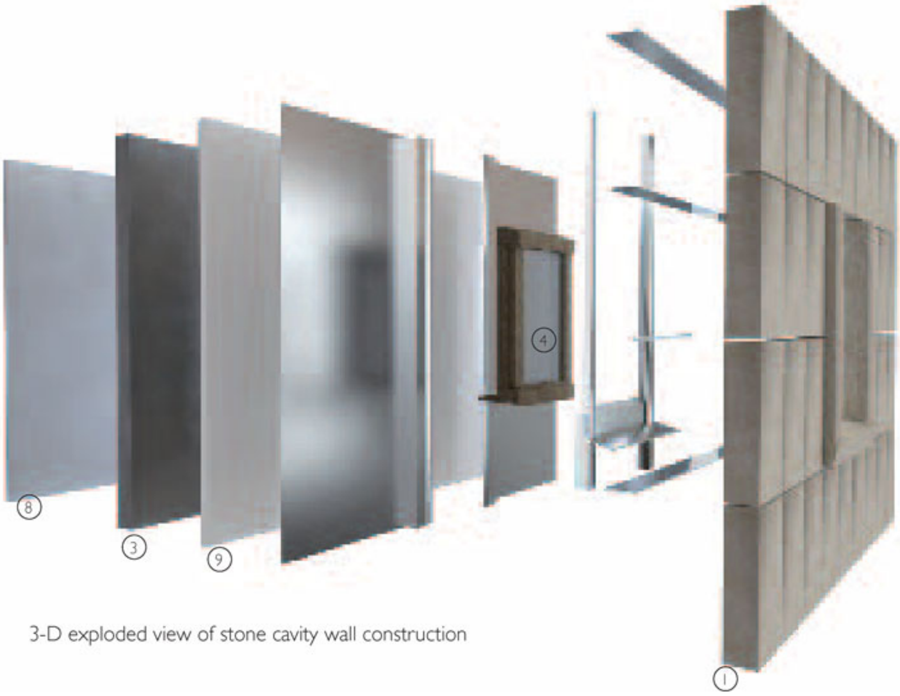


3-D exploded view of blockwork cavity wall construction

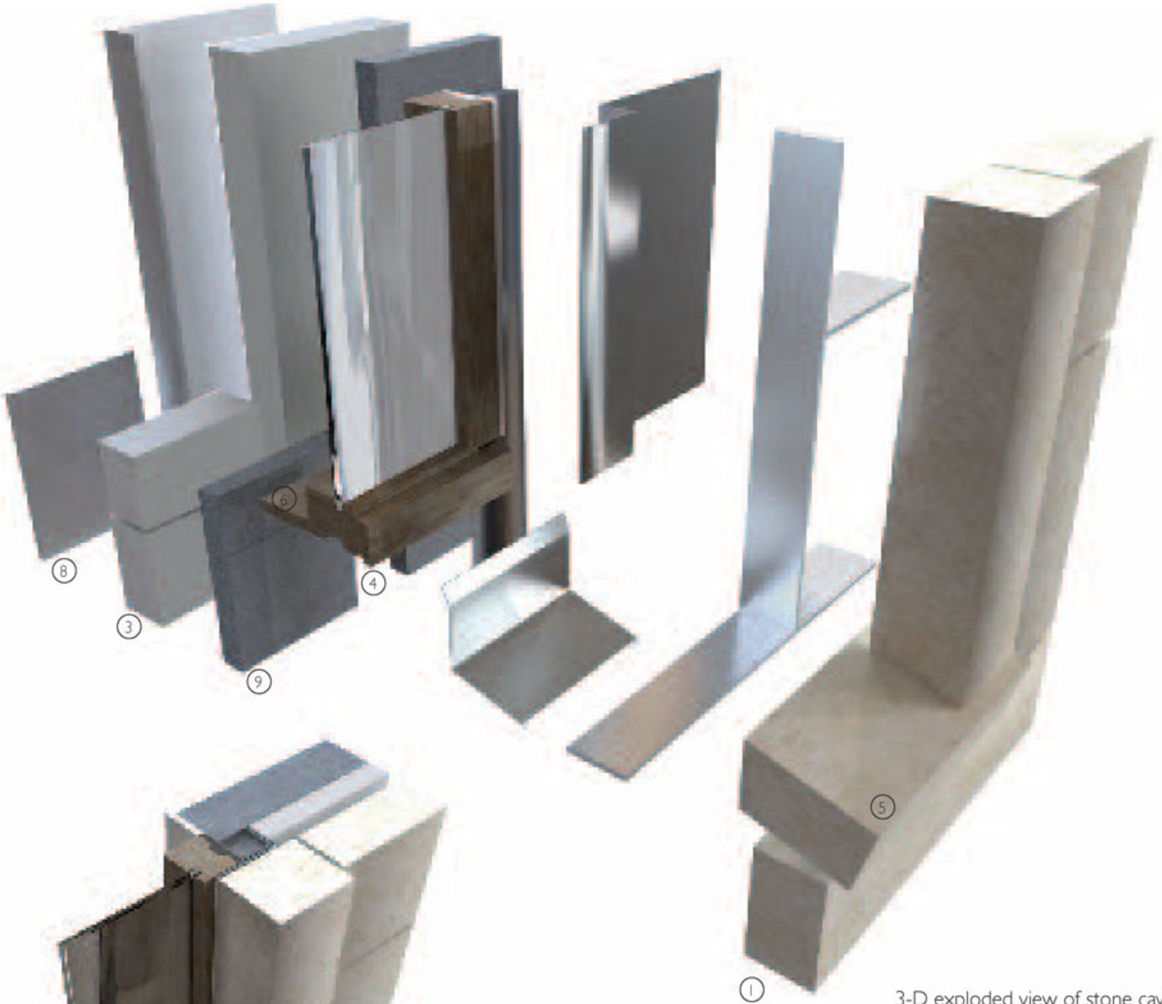


3-D view of blockwork cavity wall with window

3-D view of stone cavity wall construction

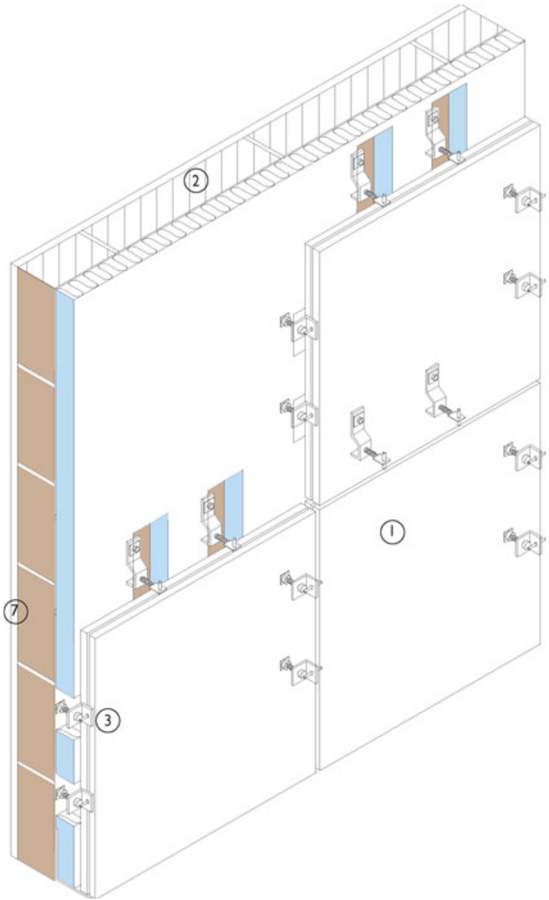


3-D exploded view of stone cavity wall construction

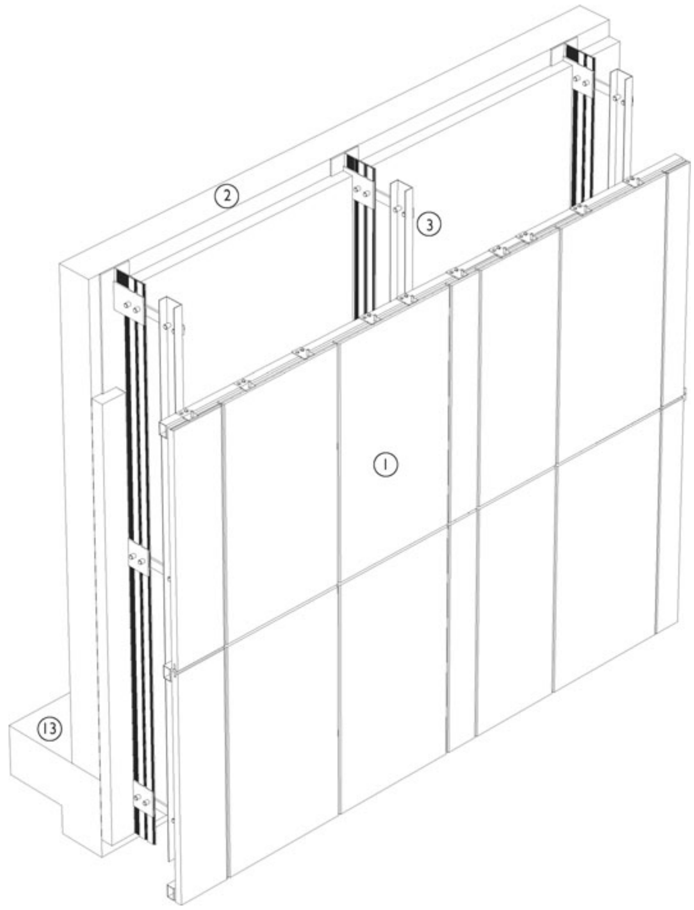


3-D exploded view of stone cavity wall window detail

3-D view of stone cavity wall construction with window



Isometric view of stone cladding on individual fixings



Isometric view of stone cladding on extruded aluminium carrier system

Cut stone used for wall cladding can be either sealed with mortar or sealant or, alternatively, be open jointed following rainscreen principles. In both cases the stones are fixed to an insulated backing wall. The stone types used in cladding are granites, sandstones, limestones and slates. Marbles are sometimes used, but are not generally considered to be as durable as the other stone types. Their weights vary from 2500kg/m2 for limestone to 2750 kg/m2 for granite.

An essential difference between stone and other cladding materials is that the material may still not be cut from the quarry at the time the material is chosen for a building project, particularly for larger projects. The use of stone for cladding requires considerable planning, from setting the range of colours, tone and surface marks that will be used for the cladding, to establishing the physical properties for the stone from the actual quarry chosen, to using this data to complete a structural design to establish stone panel sizes and thicknesses.

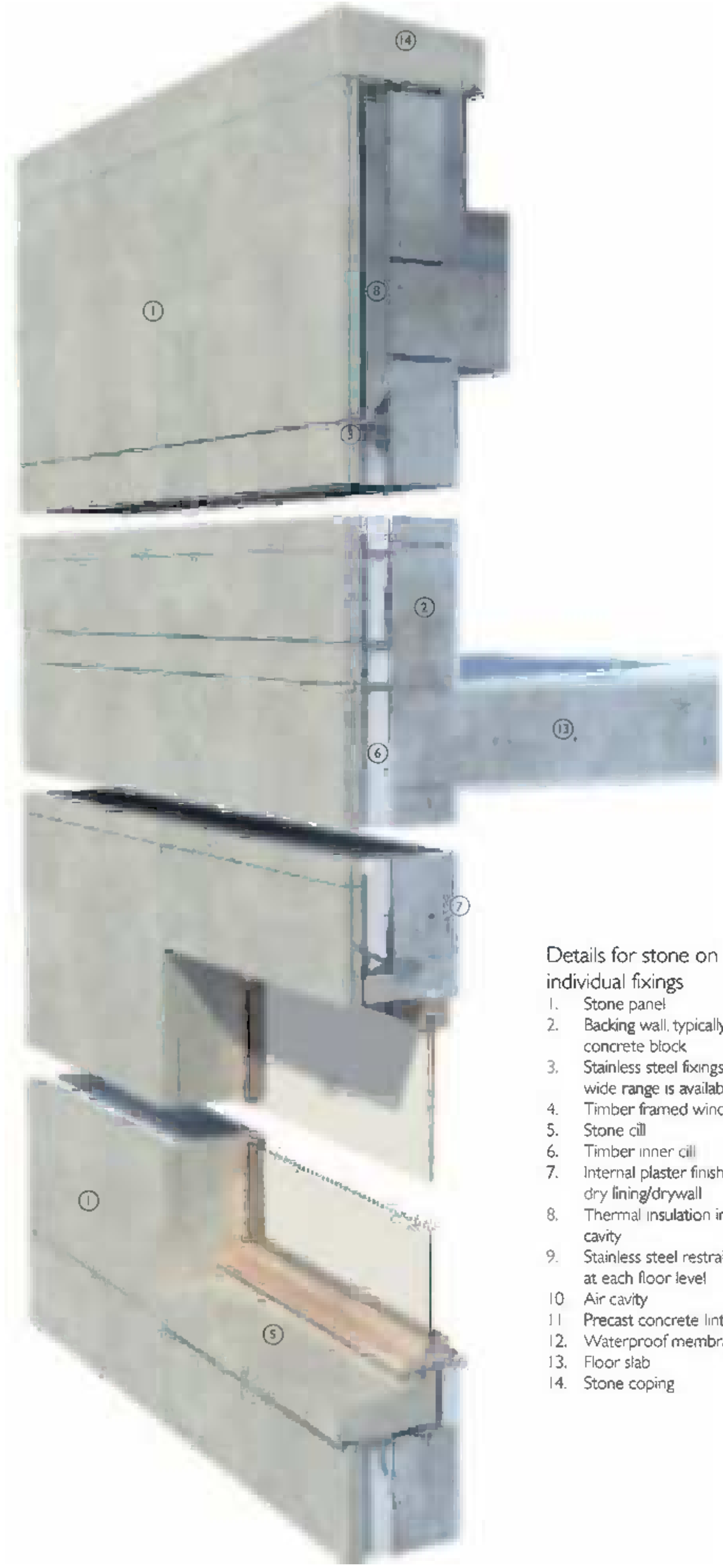
Stone is varied in its durability and strength due to variation in the bed of the stone. Some quarries have consistent stone, while in others its properties may vary considerably. Test data on the physical properties of the stone in each quarry are obtained, particularly its strength, in order to establish the panel size and thickness that will be used. The thickness of stone for a facade application is usually established by structural calculation. Flexural strength, also called the modulus of rupture, is usually the most important structural consideration. Codes of practice often set out minimum thicknesses for different panel sizes in different stones, but this is only a general guide and calculation is usually undertaken for facade applications.

Samples are usually chosen to set the range of colour and texture that are to be used in a facade. Because the stone required for a particular project is not always cut before construction starts, the quarry confirms the amount of time needed to cut and finish the stone panels, which can take considerably longer than cladding panels in other materials. Because the material is natural, care is taken to avoid defects such as cracks and holes in the material that will affect its durability as a cladding material. For slates, natural markings are a part of the nature of the stone and the material is judged for its particular application.

Fixings

Stainless steel is most commonly used for fixings rather than other materials because of its resistance to corrosion combined with high strength and rigidity. Stone fixings allow for a three-way adjustment to ensure a proper fit vertically, horizontally and laterally (in or out from the facade). Where anchor slots or inserts are cast into the floor slab or reinforced concrete wall, these are needed to be accurately positioned even though they provide adjustment for the final position of the stone. The type of fixing used is dependent mainly on the stone thickness.

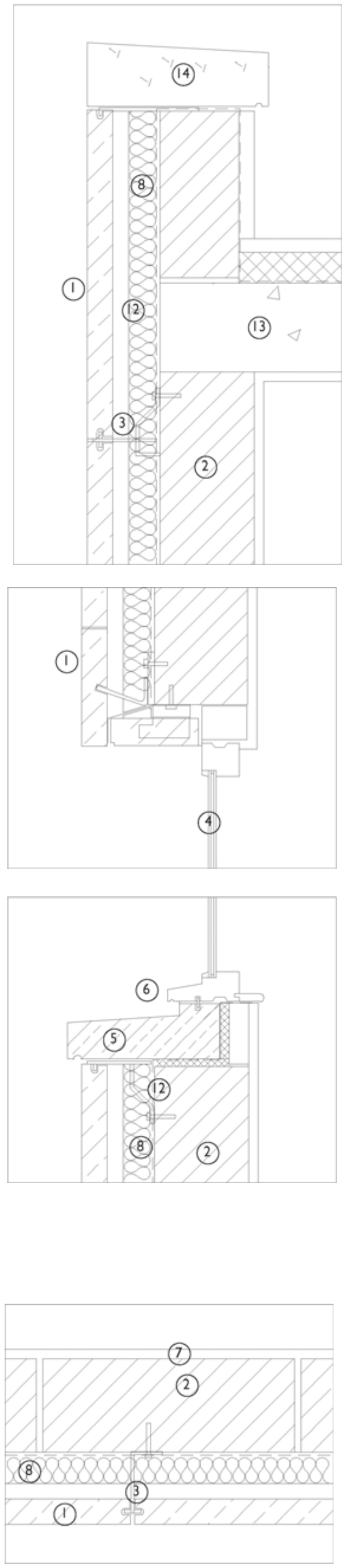
Loadbearing fixings, supporting the stones, are usually set on the bottom edge of the stone panel, though side fixings are sometimes used, depending on the weight and



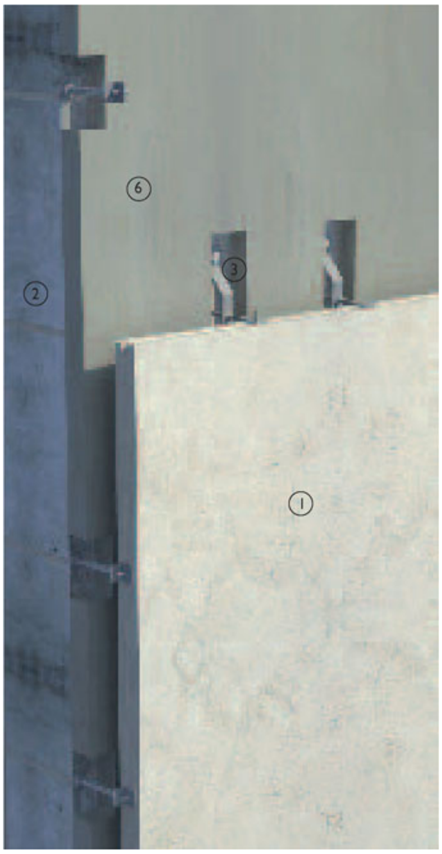
3-D view of typical stone carrier system made from individual stone fixings

Details for stone on individual fixings

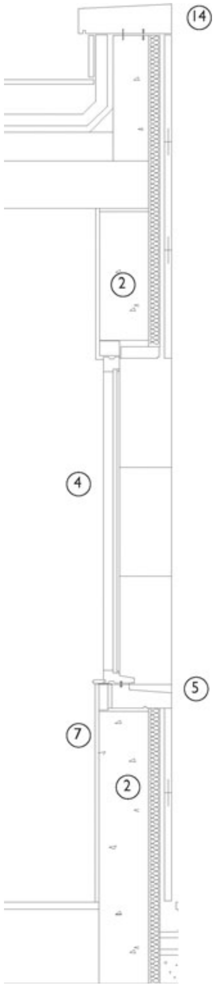
1. Stone panel
2. Backing wall, typically concrete block
3. Stainless steel fixings (a wide range is available)
4. Timber framed windo
5. Stone cill
6. Timber inner cill
7. Internal plaster finish o dry lining/drywall
8. Thermal insulation in cavity
9. Stainless steel restraint at each floor level
10. Air cavity
11. Precast concrete lintel
12. Waterproof membran
13. Floor slab
14. Stone coping

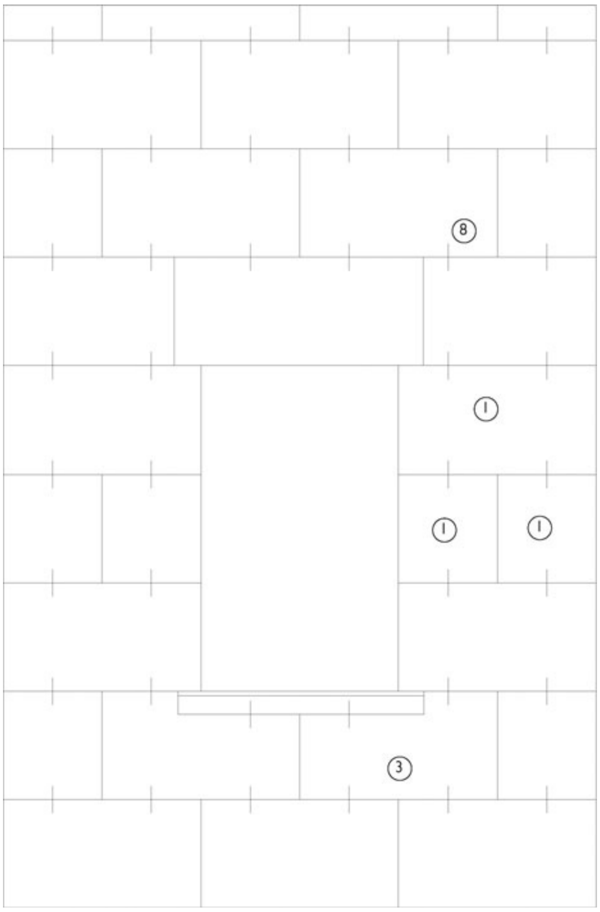


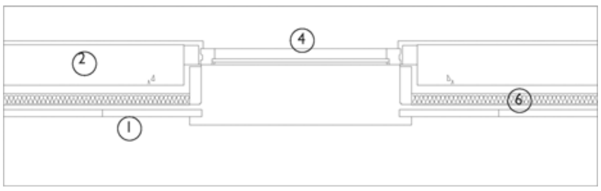
Horizontal & vertical sections 1:10. Typical stone carrier system made from individual stone fixings



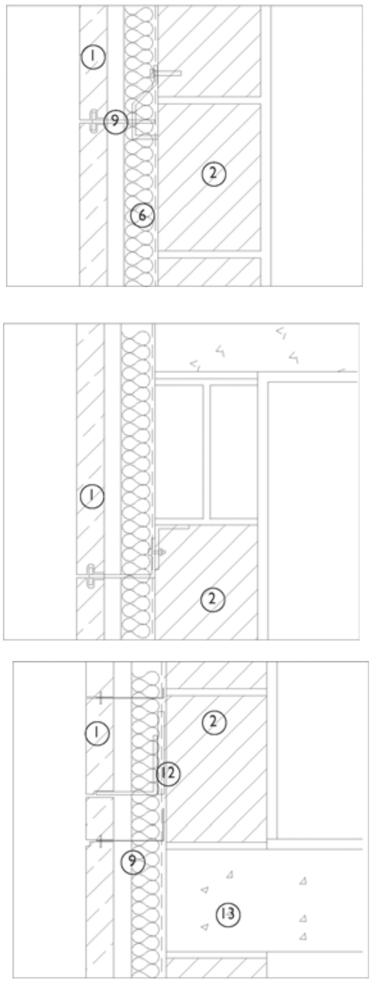
3-D view of stone carrier system made from individual fixings







Horizontal, vertical sections and elevation 1:25.
Typical stone carrier system made from individual stone fixings



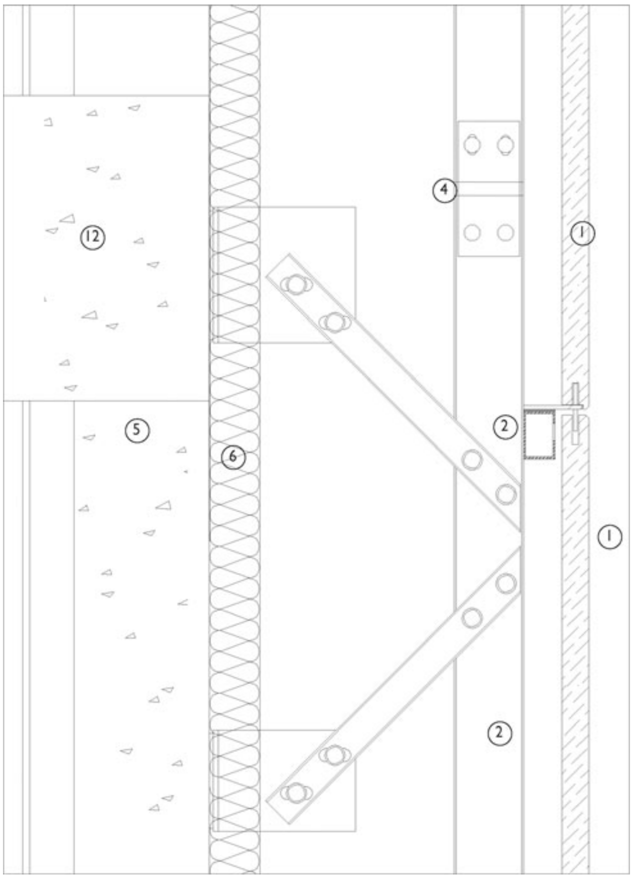
Horizontal & vertical sections 1:10. Typical stone carrier system made from individual stone fixings

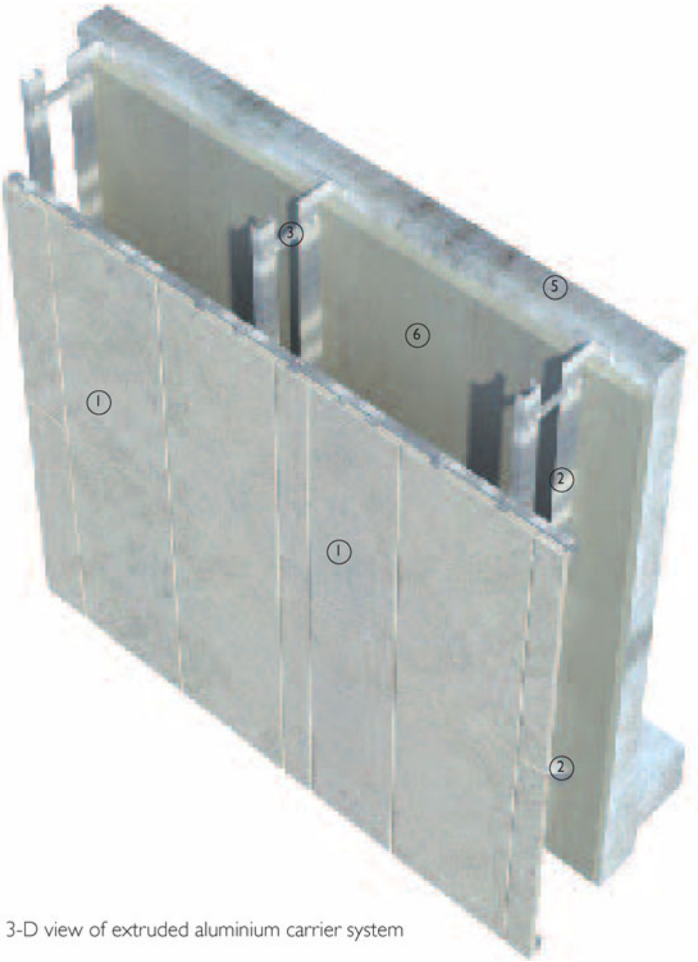
strength of the panels. Two brackets at the bottom of the stone are used, with not more than four brackets in total. Triangular panels usually have one fixing in each corner. At vertical movement joints, adjacent stones are carried on separate supports, each side of the movement joint. The end of the fixing supporting the stone is around 50mm wide.

Restraint fixings are used to resist positive and negative wind loads as well as imposed loads from maintenance equipment. The slot in the stone is either a hole, slot or rebate that is not visible from the stone face. These are usually located at 1/5 points for stack bonded stones and ¼ points for ½ bonded stones, and at least 75mm (3in) from the corner. A maximum of four restraint fixings per stone is used. Restraint fixings typically consist of a stainless steel pin, or dowel, set into a stainless steel flat section in an 'L' shape. The pins are typically 3mm (0.118in) diameter for stone up to 30mm (1.2in) thick and 5mm (0.2in) for stone of greater thicknesses.

Face fixings are normally used with marble and granite. The bolts function as both loadbearing and restraint fixings and are set away from the corners in the manner of bolt fixed glazing. A bolt is fixed in each corner, usually at a distance equal to three times the stone thickness but to a maximum distance of around 75mm (3in) from the corner. Smaller stones are fixed with fewer fixings, and triangular panels usually have a fixing in each corner only.

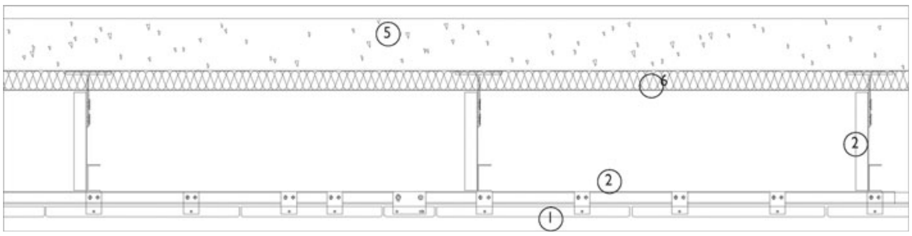
Fixings used to support stones that clad soffits, such as the underside of a concrete slab, are suspended from bolts or hangers





3-D view of extruded aluminium carrier system

Horizontal & vertical sections 1:10.
Typical stone carrier system made from extruded aluminium



Details for stone supported on carrier system

1. Stone panel
2. Extruded aluminium carrier system
3. Stainless steel fixing pins
4. Stack joint
5. Backing wall. Concrete shown.
6. Thermal insulation
7. Adjacent wall. Rainscreen panels shown.
8. Open joint configuration as shown
9. Support brackets
10. Restraint brackets
11. Joint between stone panels
12. Floor slab

which slide into anchorages cast into the supporting structure.

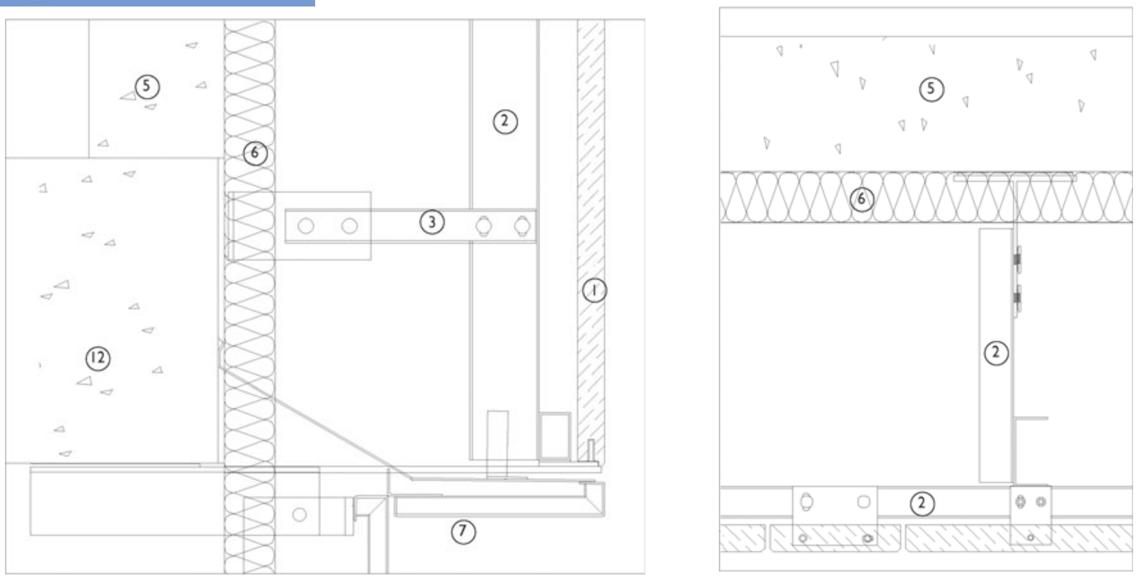
Cladding to precast concrete panels

Any of the stones listed at the beginning of this section can be used as a facing to precast concrete panels, but granite is most commonly used due to its higher strength, allowing it to be used relatively thinly. Thicker sandstones and limestones are also used, however. Stone is fixed to concrete panels with dowel pin fixings which are inclined at 45° to 60° to suit the size of stone and holding it in place. Pins are usually set at around 200mm (8in) centres both vertically and horizontally with a pin thickness of around 5mm. 50% of dowels are set in each direction to provide a balanced support. Each dowel has a flexible rubber-based washer around 3mm (0.118in) thick to allow for the movement between stone and the concrete background. The dowel penetrates 2/3 the thickness of the stone and around 60mm - 75mm into the concrete (2.3in-3in).

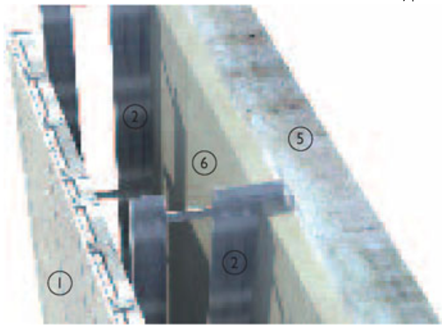
Joints

Joints are either of closed or open type. Closed joints use either mortar or proprietary sealant. Closed joints are used where the cladding is supported at each floor level on stainless steel angles with jointed stones. With open jointed stones, each panel is individually supported in a rainscreen construction, where rainwater passing through the joints is drained away down either the back of the stones or down the face of the backing wall.

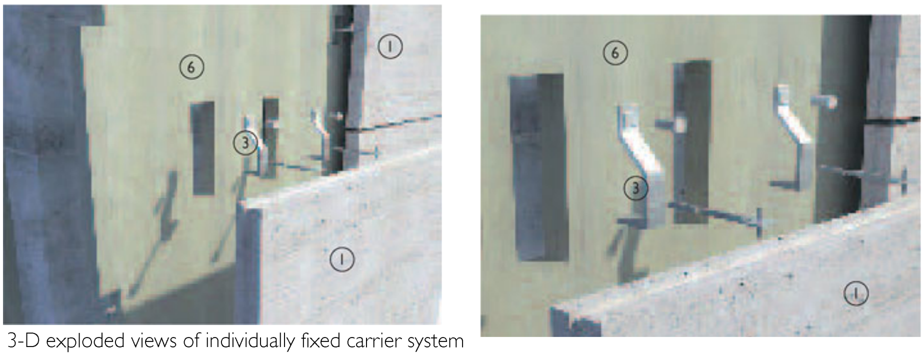
3-D view of extruded aluminium carrier system



Vertical & horizontal sections 1:10. Typical stone carrier system made from extruded aluminium



3-D view of extruded aluminium carrier system



3-D exploded views of individually fixed carrier system

Closed joints

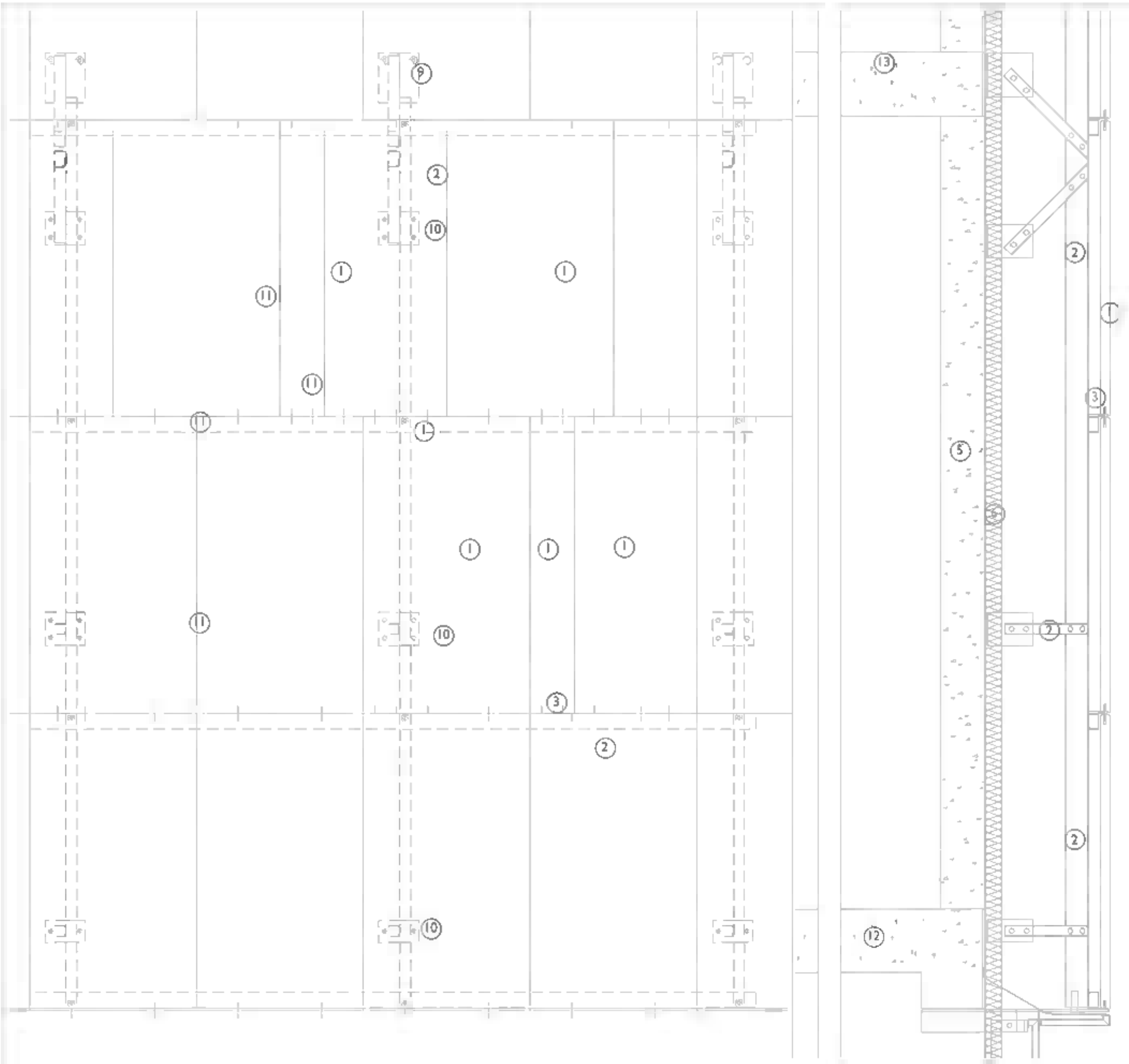
Closed joints need to be loadbearing and watertight and must also accommodate relative movements of cladding and supporting building structure. The types of jointing or pointing (the outer finish of mortar or sealant) will depend on the type, size, thickness and surface finish of cladding units. Stones are not usually butted up against one another, since any movement of the unit or of the structure cannot be accommodated, causing damage to the stones.

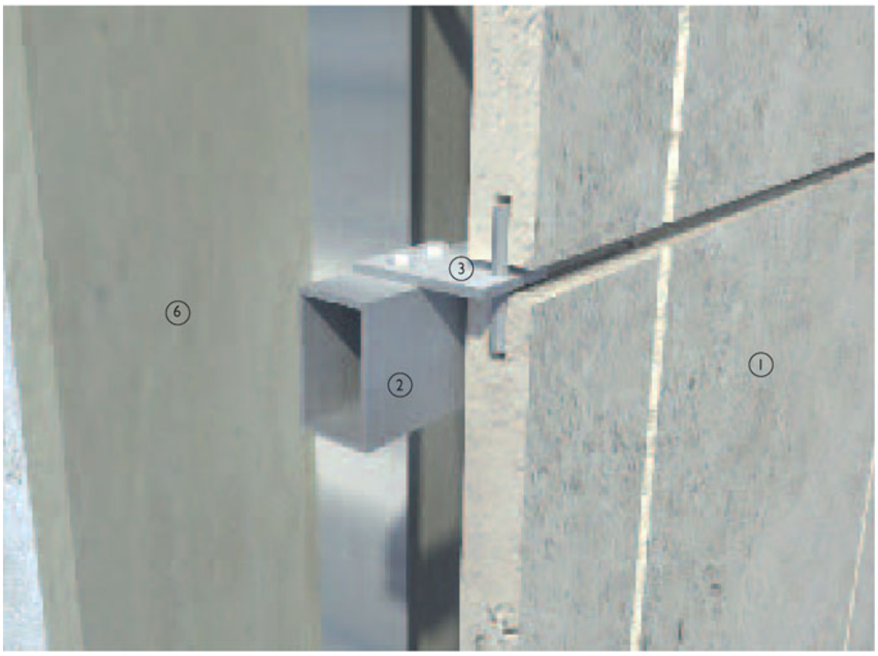
Joints in sandstone and limestone are usually filled with cement/sand mortar or cement/sand/lime mortar. Granite and slate typically use proprietary sealant, such as two-part polysulphide. Mortar used for pointing is made frost resistant when used in temperate climates, and of similar strength to the jointing mortar, which is the structural mortar behind. Neither mortar should be stronger than the stone. For limestone and sandstone a mortar of 1/1/5 for cement/lime/sand is typically used, or 1/2/8 for cement/lime/crushed stone particles, where the colour of the mortar is blended with the crushed stone.

For narrow joints used with granite or slate, a high cement-to-sand ratio is used. Joints wider than around 4mm are filled with a weaker mix to reduce shrinkage cracks. The maximum widths of mortar filled joints are around 12mm (0.5in) but sealant filled joints can be up to around 30mm (1.2in), depending on the proprietary product used. Joint widths are usually a function of the cutting tolerance of the stone, around 2mm difference in the cut line of the stone, depending on stone type and the cutting machine used. Modern machines can cut stones to within 1mm accuracy. Joint widths of 4mm are common, but this can rise to a maximum of 12mm when required for visual reasons, particularly when the joint is recessed. Granite, slates and hard limestones and sandstones can have a joint width at a minimum of 3mm, while soft sandstones and limestones can be laid with a minimum 5mm joint. When a proprietary sealant is used, the minimum joint width for all stone types is usually around 5mm.

Movement joints

Horizontal movement joints are used to deal mainly with floor slab deflections, and to a lesser extent vertical shortening, in the structural frame. This horizontal joint is usually provided at slab level, where the stone cladding is supported from either short lengths of stainless steel angle, or a continuous shelf angle. The joint occurs immediately below the stainless steel angle, where vertical deflection will occur. Horizontal movement joints can be set at intervals of two storeys if the stone and support brackets or frame can be designed to span the height. The joint width is usually a minimum of 15mm, but 20mm to 25mm (0.8in-1in) are common with reinforced concrete structures. The joint is formed either as a sealant or as a step in the stone, where the upper stone projects forward of the stone below to conceal the wider joint. In both joint types the joint is made watertight, for closed joints and for open joints, where rainscreen cladding principles are used.



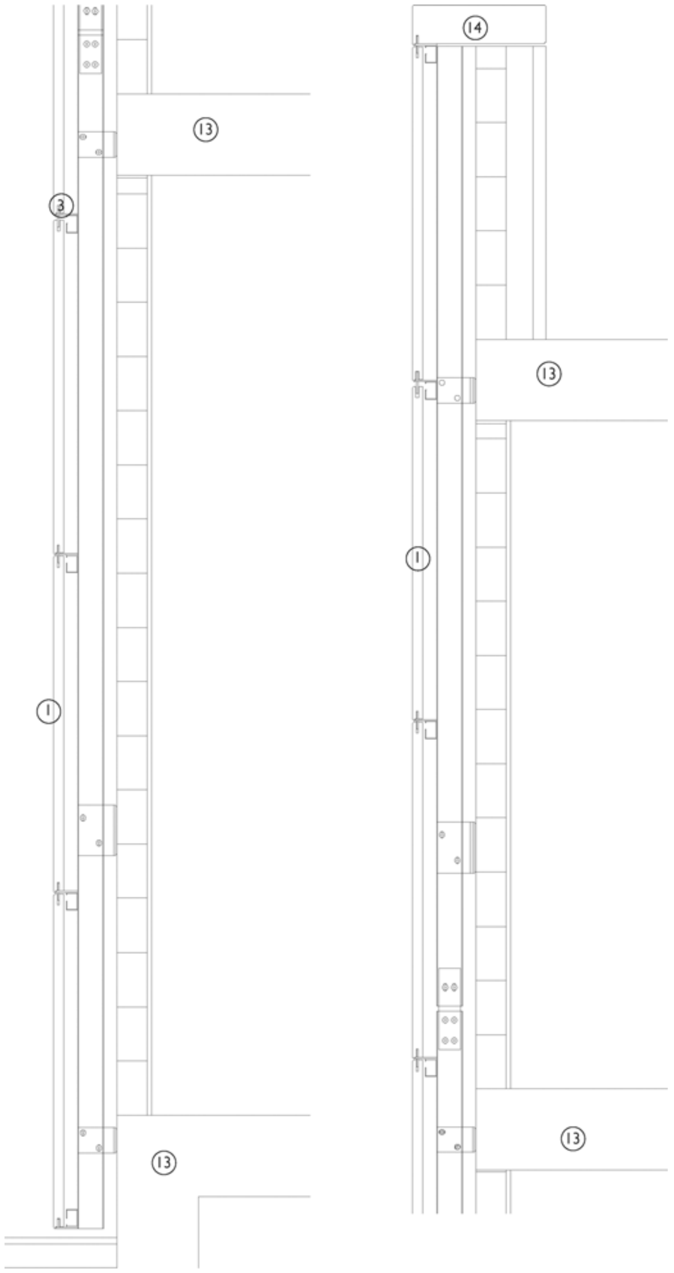


3-D view of stainless fixing method for extruded aluminium carrier system

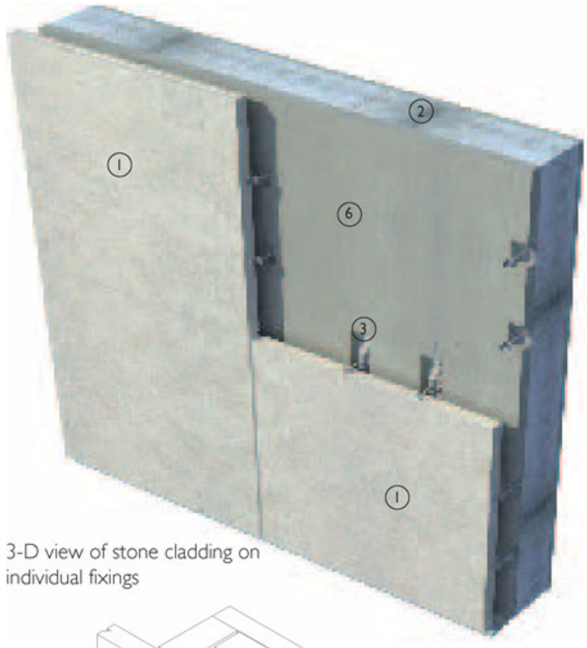
Vertical section and elevation 1:25.
Typical stone carrier system made from extruded aluminium. Stone joints with both straight and staggered joints to show flexibility of carrier systems

Details for stone supported on carrier system

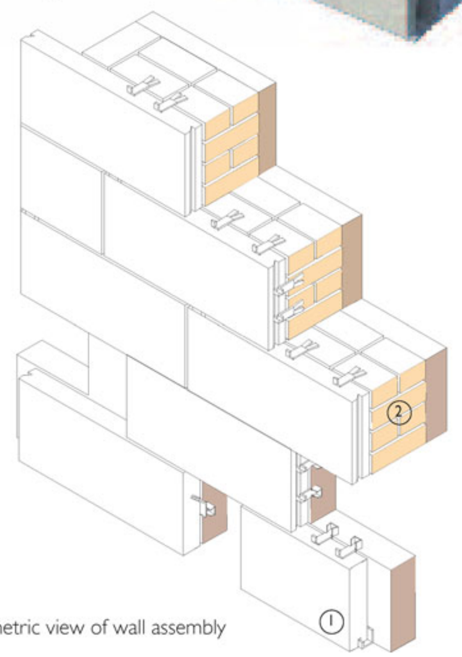
1. Stone panel
2. Extruded aluminium carrier system
3. Stainless steel fixing pins
4. Stack joint
5. Backing wall. Concrete shown.
6. Thermal insulation
7. Adjacent wall. Rainscreen panels shown.
8. Open joint configuration as shown
9. Support brackets
10. Restraint brackets
11. Joint between stone panels
12. Floor slab



Vertical section 1:25.
Typical stone carrier system



3-D view of stone cladding on individual fixings



Isometric view of wall assembly

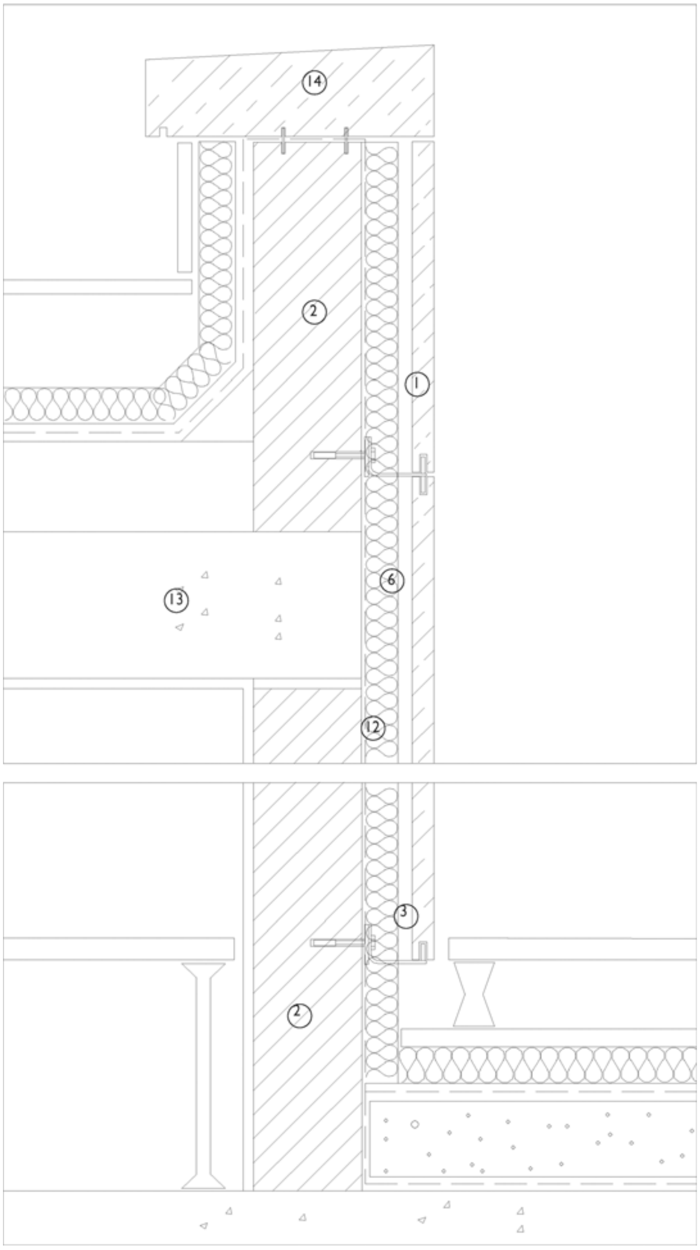
Details for stone on individual fixings

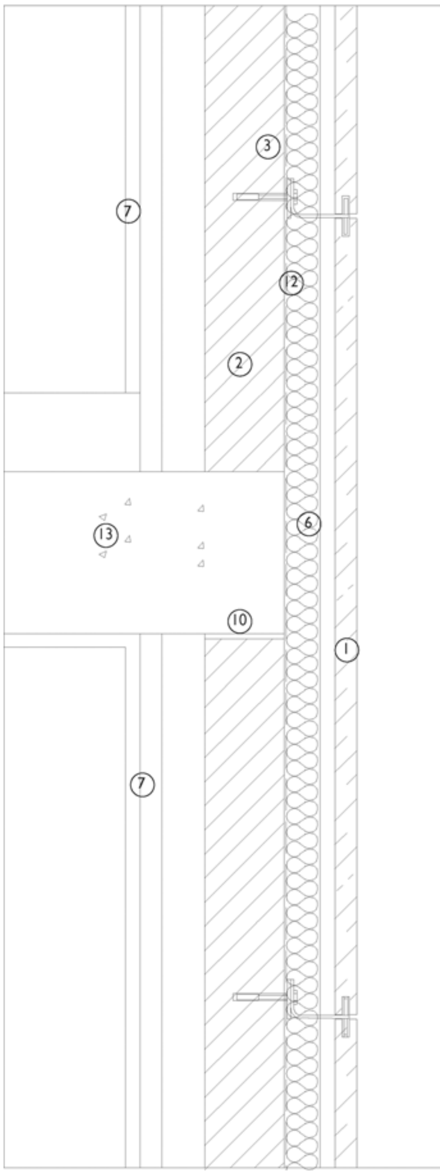
1. Stone panel
2. Backing wall, typically concrete block
3. Stainless steel fixings (a wide range is available)
4. Timber framed window
5. Stone cill
6. Thermal insulation in cavity
7. Internal plaster finish or dry lining/dry wall
8. Timber inner cill
9. Stainless steel restraint at each floor level
10. Air cavity
11. Precast concrete lintel
12. Waterproof membrane
13. Floor slab
14. Stone coping

Vertical movement joints are provided to deal with racking in the structure as well as movements in the cladding itself. Where movement joints occur in the building structure, usually following a continuous vertical line where it intersects with the facade, a vertical movement joint is provided in the facade in the same location. The distance between joints is typically at around 6 metres in a continuous run of stone cladding with closed joints. The joint width corresponds to the expected movement in the cladding, but where sealed joints are used, the joint width is dependent on the amount of movement that the sealant is required to accommodate. Minimum widths of vertical movement joints are around 10mm (0.5in). Vertical movement joints are extended into parapets and copings.

Stone finishes

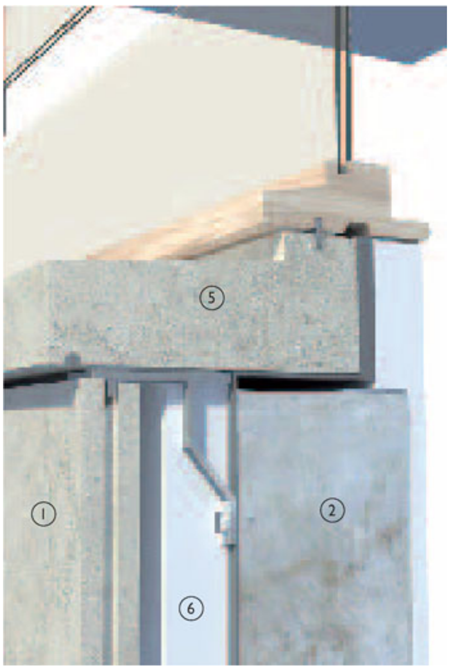
Granites, limestones, sandstones and slates are using an increasingly wide range of finishes, with finishes associated with one stone type being used for another. The main finishes are as follows: A rubbed finish is a smooth finish made by rubbing stone with an abrasive material (typically used for limestone and sandstone); a honed finish has a dull polish (used for all types); a polished surface has a high gloss (typically used for granite and hard limestone); a flamed finish is obtained by passing a hot flame over the stone surface



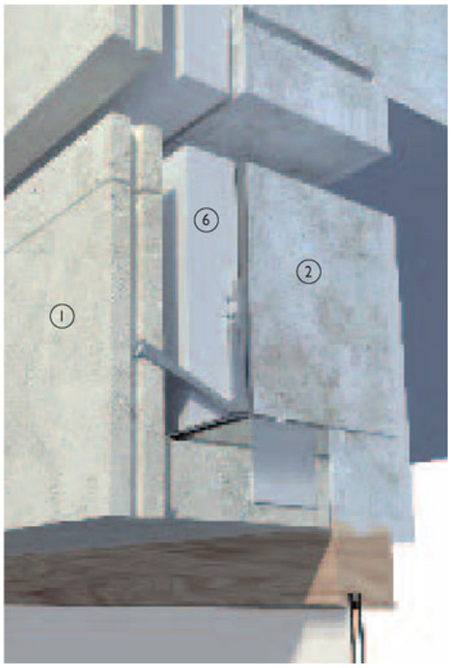


Vertical sections 1:10. Typical stone carrier system made from individual stone fixings. Parapet detail (top left), and floor junctions (bottom left and above)

(typically used for granite and slate), a riven finish, where the stone is cut on its cleavage plane (typically used for slate, sandstone or limestone) and tooled, where the material is worked, leaving tool marks and is used mainly on sandstone or limestone. In addition, stones can be filled with cements or proprietary fillers to conceal natural voids in the stone. The surface is then coated or polished.

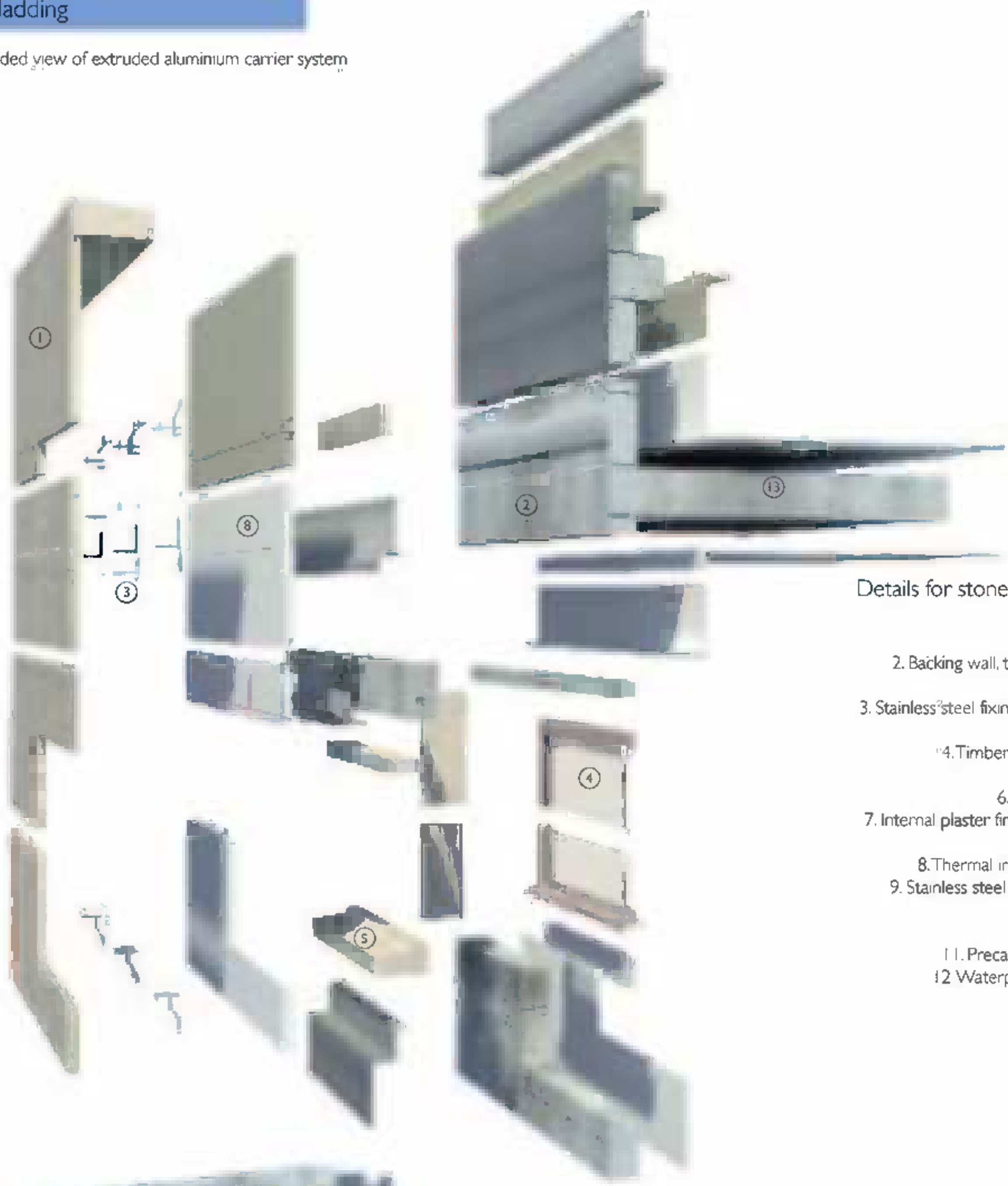


3-D view of bottom of window opening in stone cladding system made from individual stone fixings



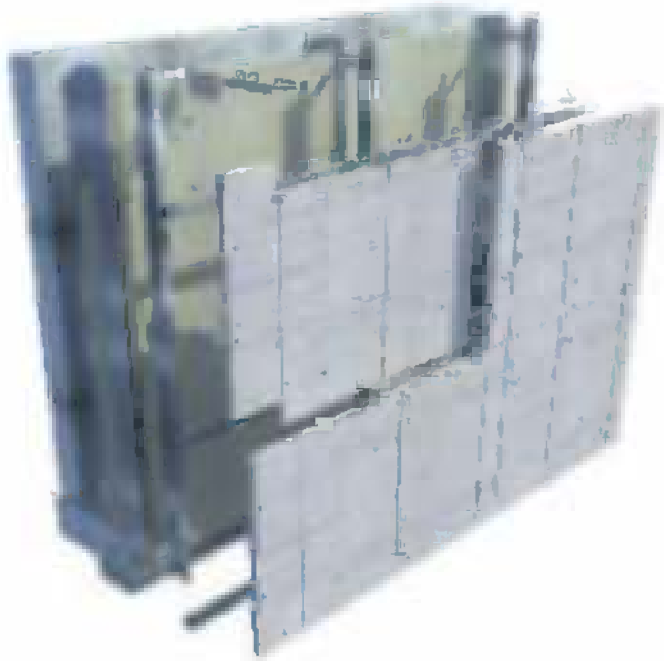
3-D view of top of window opening in stone cladding system made from individual stone fixings

3-D exploded view of extruded aluminium carrier system

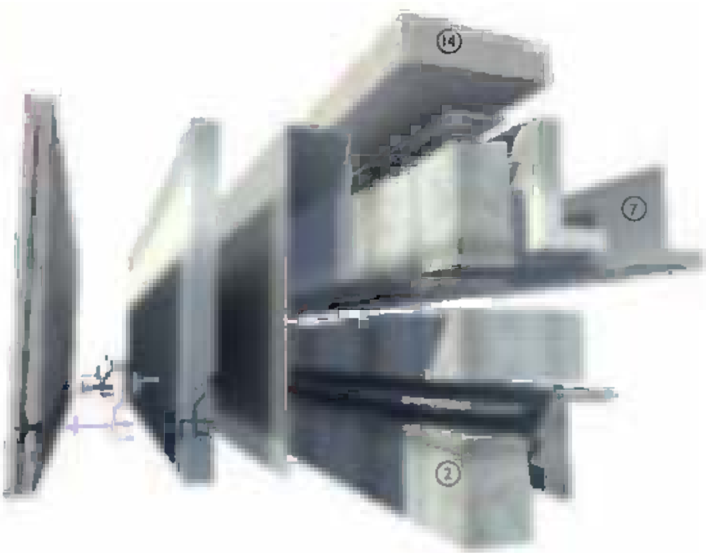


Details for stone on individual fixings

1. Stone panel
2. Backing wall, typically concrete block
3. Stainless steel fixings (a wide range is available)
4. Timber framed window
5. Stone cill
6. Timber inner cill
7. Internal plaster finish or dry lining/ dry wall
8. Thermal insulation in cavity
9. Stainless steel restraint at each floor level
10. Air cavity
11. Precast concrete lintel
12 Waterproof membrane
13. Floor slab
14. Stone coping

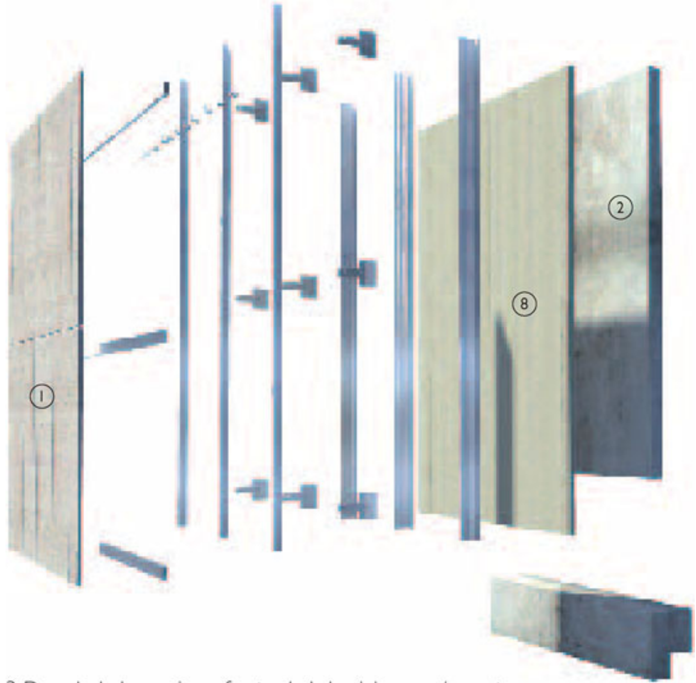


3-D exploded overview of extruded aluminium carrier system

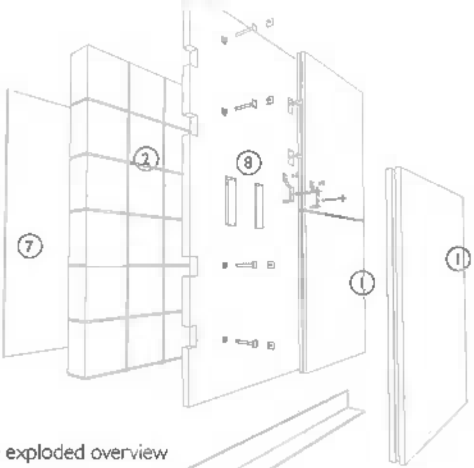


3-D exploded detail view of parapet for stone cladding system fixed with individual fixings

3-D exploded detail view of extruded aluminium carrier system



3-D exploded overview of extruded aluminium carrier system



-D exploded overview
f stone cladding
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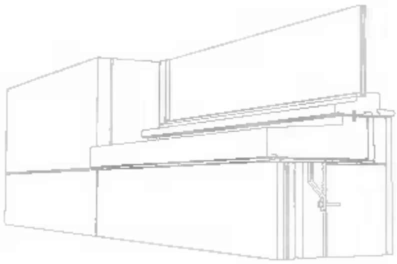
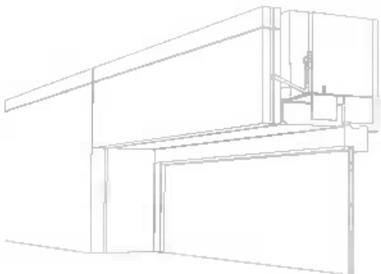
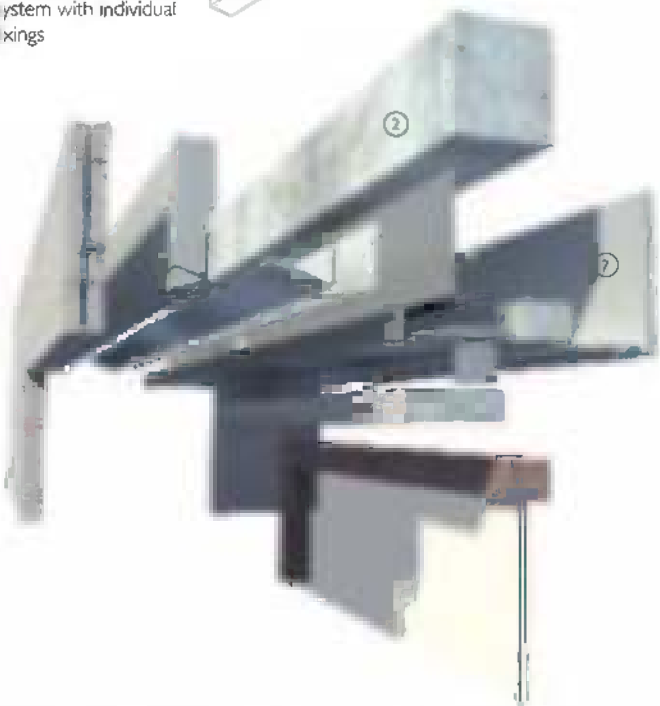


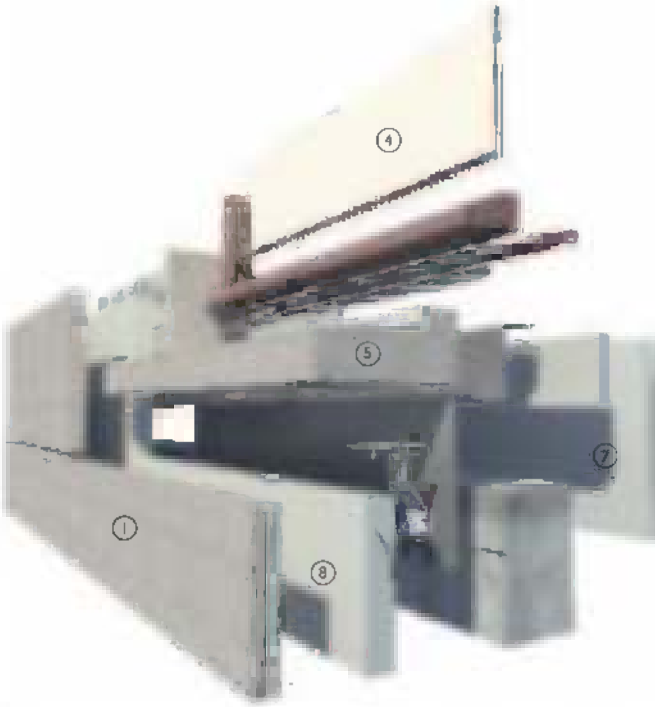
3-D view of bottom of window opening in individually fixed stone cladding system



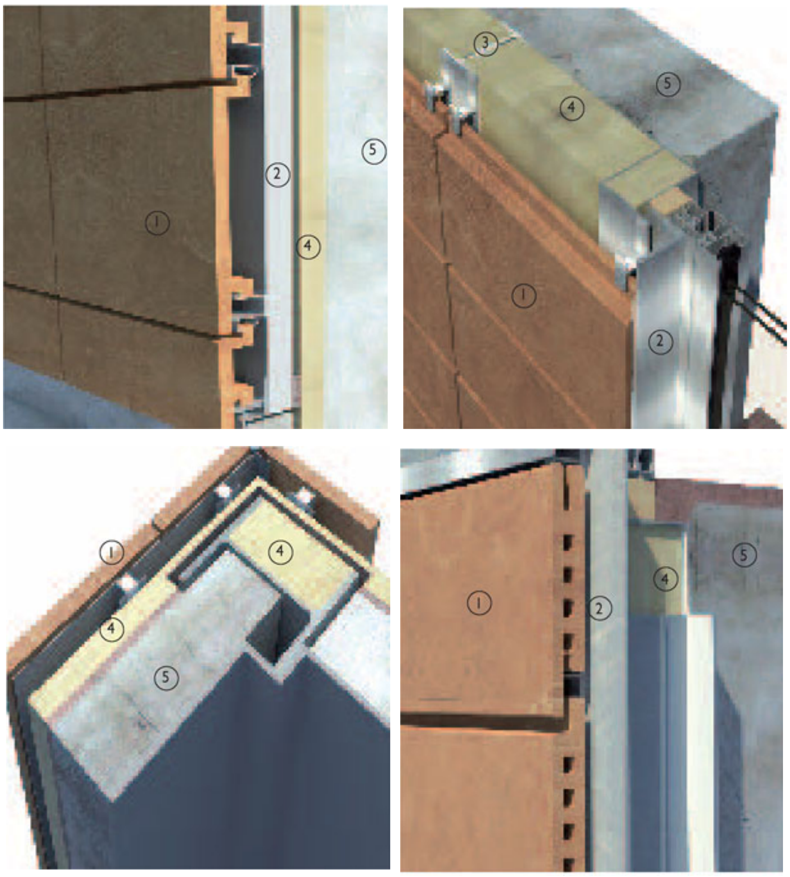
3-D view of top of window opening in individually fixed stone cladding system



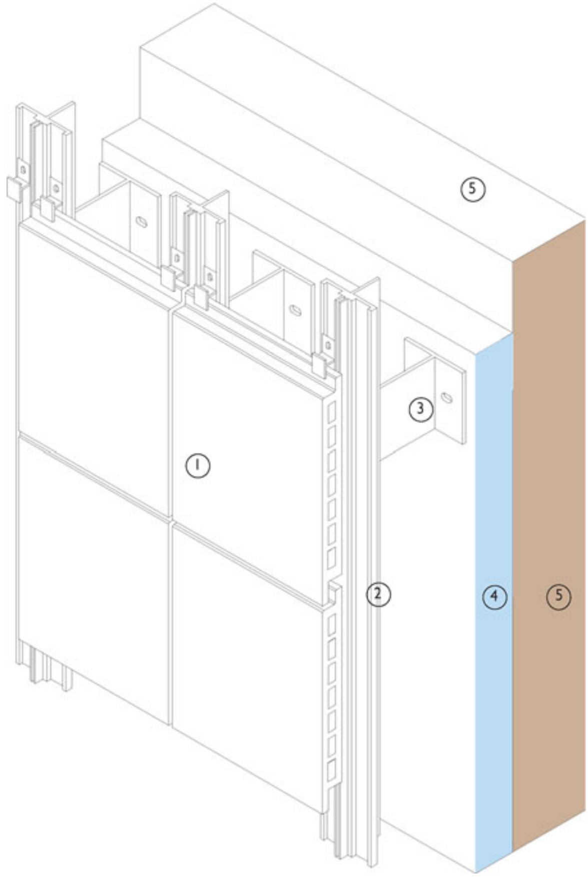
3-D exploded view of top of window opening in individually fixed stone cladding system



3-D exploded view of top of window opening in individually fixed stone cladding system



Examples of terracotta rainscreen fixing methods



Isometric view of vertically set wall assembly

The essential principles of rainscreen cladding are discussed in the section on metal rainscreens. Terracotta rainscreens have developed into patented proprietary systems from prototypes within the last ten years. Over that time the sizes of terracotta panels have increased and fixing systems have developed for use as solar shading screens to glazed walls as part of an overall rainscreen system for a building facade. Hollow terracotta sections are reinforced with aluminium sections set into them to form louvred screens that can match with adjacent areas of cladding. Terracotta is fixed either on rails, into aluminium or stainless steel panels, or on individual brackets like masonry cladding with concealed fixings. Vertically-set or horizontally-set rails are used to suit a range of joint arrangements that imitate traditional masonry bonds, or can be stack bonded in the manner of wall tiling or glass blocks. Terracotta has been developed for use in rainscreens both from building blocks and bricks, as used in loadbearing masonry construction, and from decorative tiles, where many of the glazed finishes are derived. Recently developed systems have interlocking panels, to provide crisp joints, and double wall sections to provide long spanning tiles with high flexural strength, or modulus of rupture, combined with lightness in weight. The range of glazed finishes has developed considerably in the past few years to give a very wide range of textures and colour mixes derived from contemporary pottery.

Manufacture of panels

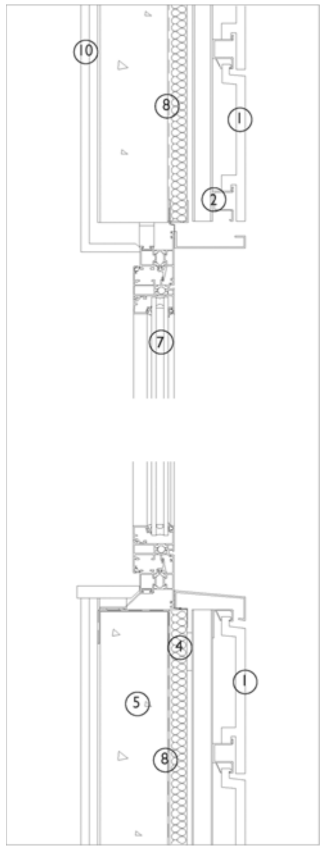
Terracotta is made from natural clay that is extruded and fired in a kiln. Powdered clay is mixed with water in the factory to achieve a controlled level of water content. It is then extruded through dies that draw the material along a conveyor belt where it is wire cut to the required length. The use of dies makes the manufacture of terracotta panels very flexible, giving it the ability to make new shapes and sections for each new project with relative ease. The die creates different heights and depths of block, with hollowing out of the interior to keep the material relatively light and easy to handle, allowing it to be made in long pieces if required. The extruding process gives flexibility to the material that is similar to the creation of aluminium sections for glazed walls and windows. When the material is extruded and cut it is dried and fired in kilns of different types depending on the tile size and shape. Some terracotta panels are machined for firing in order to provide the precise profile needed for the fixing system as well as to provide precise smaller joint widths between panels.

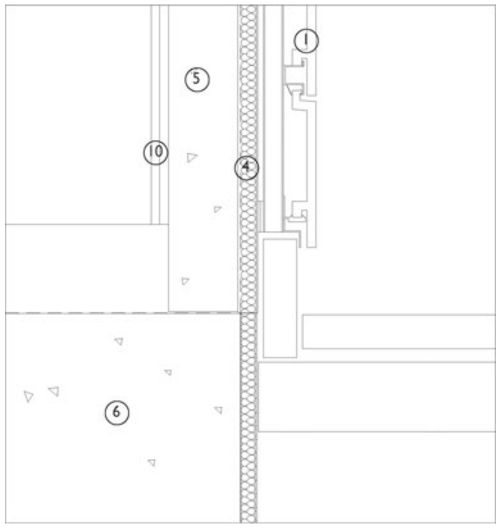
Because terracotta panels have two extruded edges and two cut edges, it is important in arranging panels to avoid a cut edge being revealed at a corner. This is because the surface finish and colour of the end face will not match that of the front face. The ends of extruded terracotta differ from terracotta and fired clay bricks in this respect. The ends of panels are usually concealed with aluminium trims, sometimes at the corners but typically around window openings.

Corner pieces

Special shapes can be formed by hand to match with the standard extruded tiles, such as corner pieces and decorative elements.

Vertical sections 1:10. Windows at head and cill



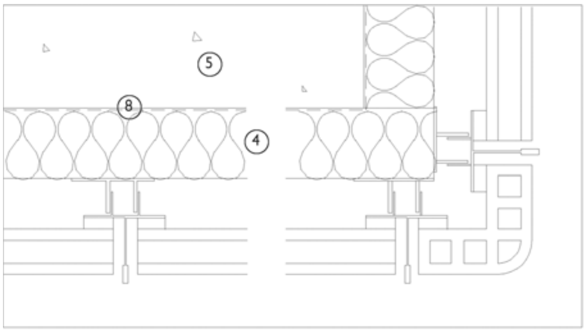


Vertical section 1:10. Junction with ground

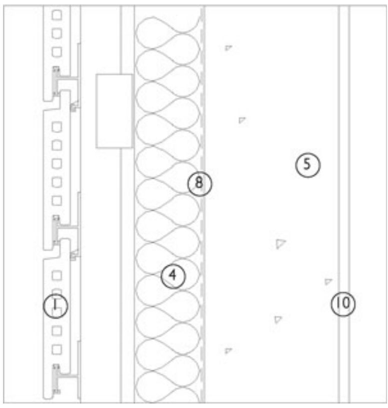
3-D view of terracotta rainscreen assembly, hung from individual aluminium clips and horizontally-set support rails

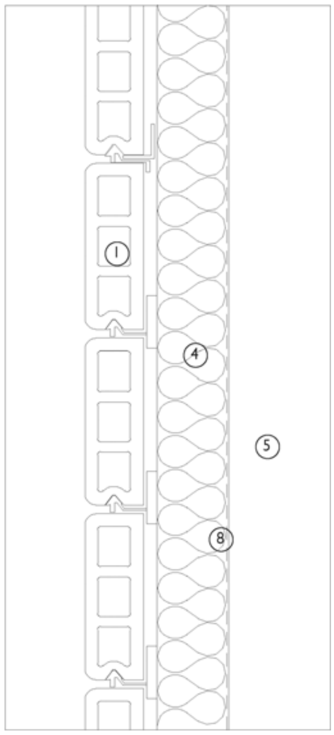
Details

1. Terracotta rainscreen
2. Extruded aluminium carrier frame
3. Support brackets, typically aluminium
4. Thermal insulation
5. Backing wall
6. Floor slab
7. Metal framed window
8. Waterproof membrane
9. Structural column
10. Internal finish

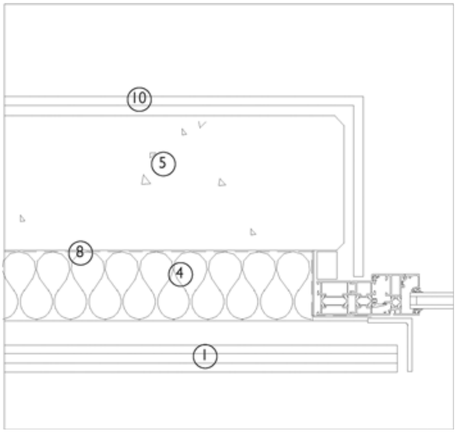


Horizontal section 1:10. Corner conditions





Vertical section 1:10. Panel-to-panel junctions

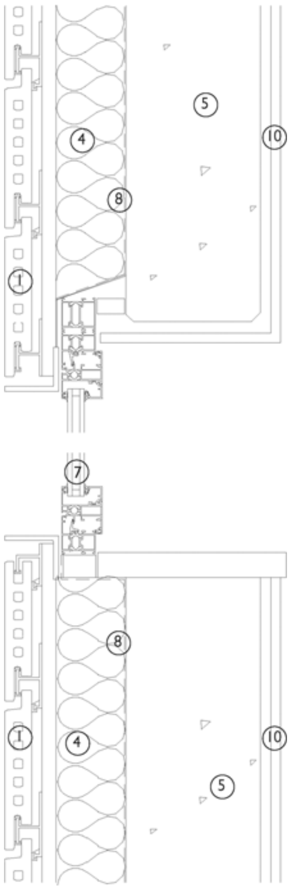


Horizontal section 1:10. Window jamb

3-D view of terracotta rainscreen fixed with individual clips to vertically-set support rails

Details

1. Terracotta rainscreen
2. Extruded aluminium carrier frame
3. Support brackets, typically aluminium
4. Thermal insulation
5. Backing wall
6. Floor slab
7. Metal framed window
8. Waterproof membrane
9. Structural column
10. Internal finish

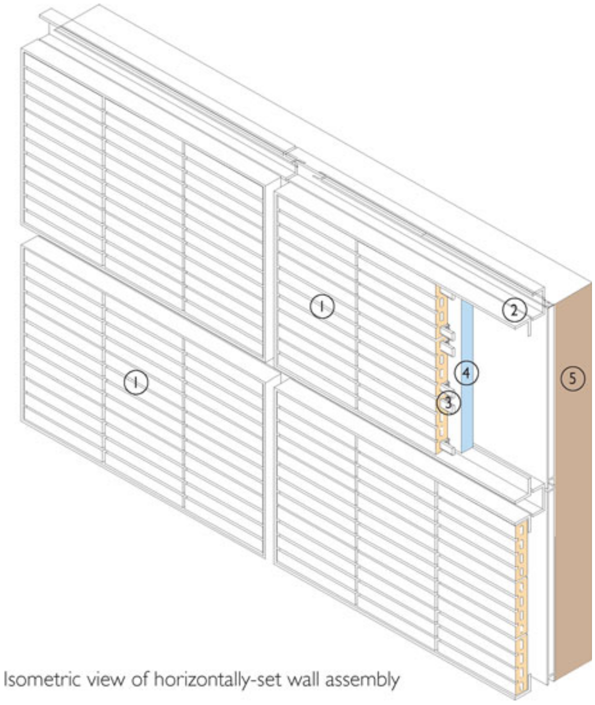


Vertical section 1:10.
Window at head and cill, junction with ground

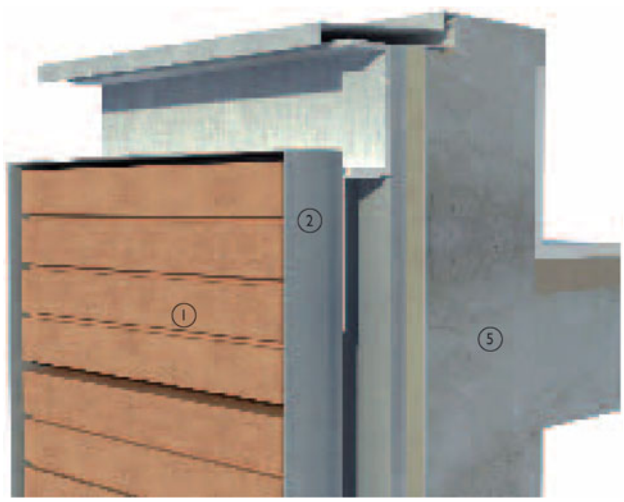
Corner pieces are made by pressing, usually with a maximum length of 150mm (6in) on one leg and 300mm (12in) on the other leg. Large corner pieces are made by hand by joining two sections together, but these currently produce less reliable results that can lack a straight and crisp edge. Manufacturers often provide extruded cill sections for parapets and window sections to suit wall constructions of 300mm to 500mm (12in-20in) wide. These have slopes to either one side or to both sides from the middle of the extrusion. The fired terracotta is either left in its natural colour or is glazed with a wide range of glazes. A glazed finish can give the material more visual sparkle by making the material more reflective, which also provides better durability from staining. However, water absorption of regular terracotta panels is between 3% and 6%, with a density of around 2000kg/m3, making the use of glazes not very important in excluding rainwater but important more for visual reasons.

Fixing systems

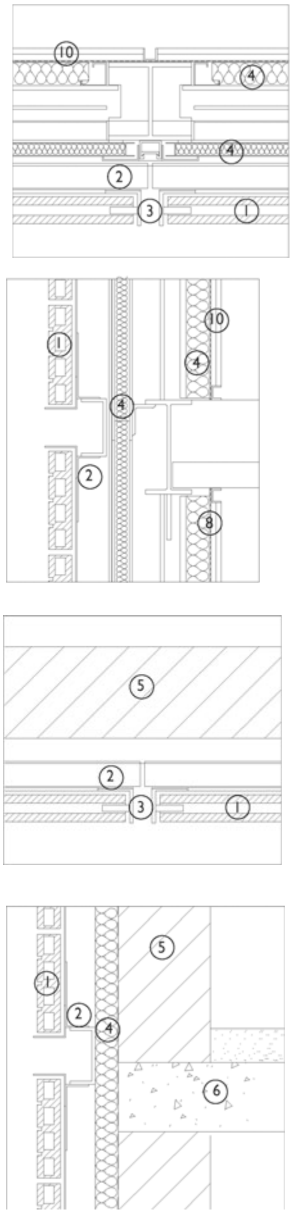
Terracotta tiles have been used in traditional construction for a long time, but their use as extruded panels in open jointed rainscreen construction is relatively new and has been undergoing considerable development over the past 10 years. The extruded nature of the material used for cladding allows it to be supported on clips from both behind and inside the material. Depending on panel size and thickness, the material can be made solid or hollow to suit a range of fixing systems.



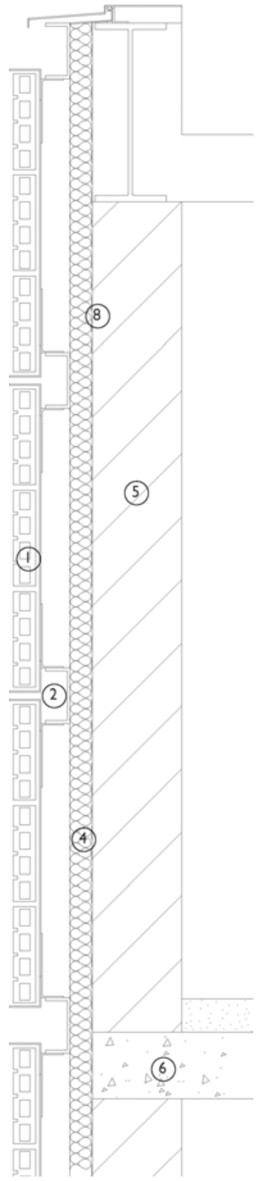
Isometric view of horizontally-set wall assembly



3-D view of parapet detail on terracotta rainscreen facade



Vertical & horizontal sections 1:10. Panel-to-panel junctions



Vertical section 1:10. Panel-to-panel junctions

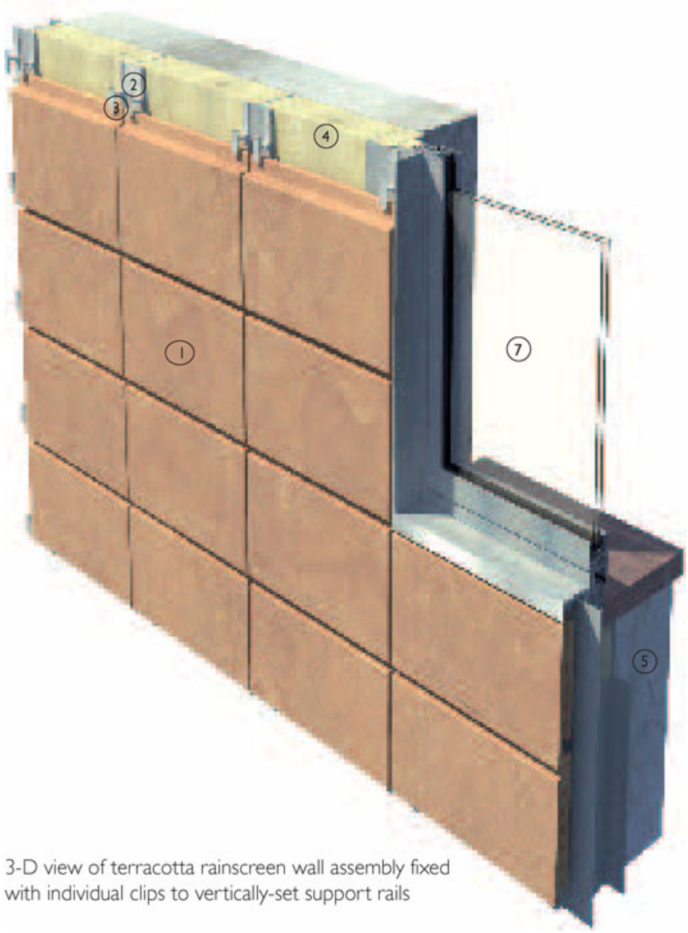
Smaller, solid panels have continuous support clip profiles on the top and bottom at the back of the panel which forms part of the material when extruded. Some manufacturers use the hollows of the extrusion to hold fixing pegs at their ends to provide a fully concealed fixing system.

The panel is then fixed back to support rails which are set either vertically or horizontally, made from aluminium for their ability to be formed precisely as extrusions for ease of fixing. Vertical rails are well suited to 'stack bonded' terracotta, where joints form a rectilinear grid of continuous vertical and horizontal joints. Horizontal rails are well suited to staggered bonds of panels that imitate the stretcher bond used in masonry cavity wall construction. Because vertical joints are not continuous, at least twice as many vertical rails would be needed as those needed for a stack bond arrangement. Since horizontal joints are continuous, horizontal rails are used to fix courses of terracotta.

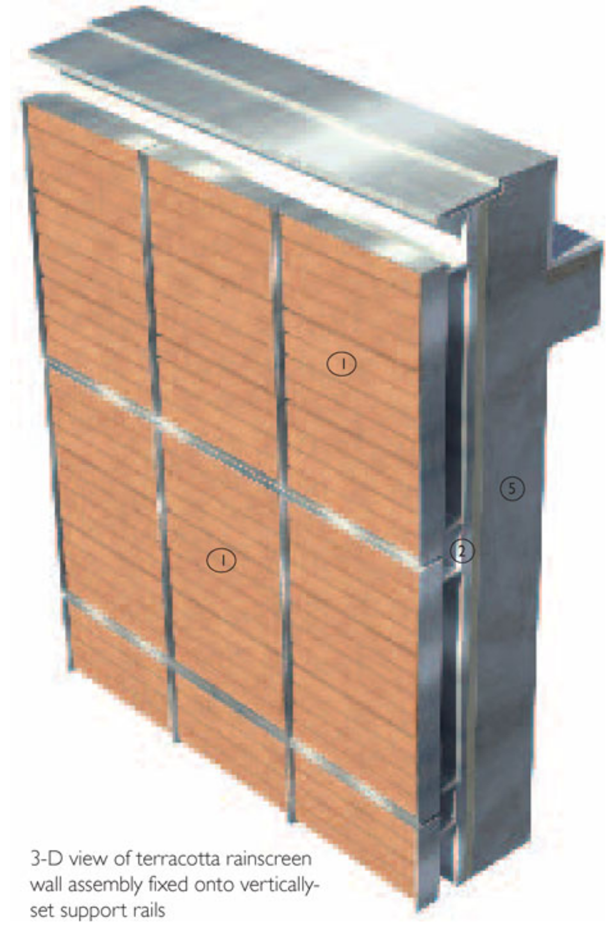
Vertical rails are continuous, and form a setting-out grid for stack bonded tiles, which are fixed back to rails with extruded aluminium clips. Each manufacturer has a proprietary fixing system which makes easier the process of fixing panels to form even joints around the terracotta panel edges.

Horizontal rails are not continuous in order to allow water to run down the backing wall without being impeded by the brackets. An alternative method of fixing horizontal rails is to set them forward of the backing wall on brackets to allow water to pass

3-D view of terracotta rainscreen facade with horizontally-set support rails



3-D view of terracotta rainscreen wall assembly fixed with individual clips to vertically-set support rails



3-D view of terracotta rainscreen wall assembly fixed onto vertically-set support rails

between the rails and the backing wall. Some manufacturers use stainless steel components mixed with aluminium components since the former material is considered to be more durable.

Horizontally supported systems usually have extruded aluminium sections which, like vertically supported systems, are fixed back to a continuous backing wall such as concrete blockwork. Aluminium brackets are fixed to the backing wall from around 1000mm to 2000mm (3ft 3in to 6ft 6in) horizontal centres, depending on rail size. The use of a horizontal clip ensures that most of the rainwater is excluded at horizontal joints by clipping the panels together in a way that ensures most of the water runs back out of the joint. Terracotta tiles used in horizontally supported systems have a stepped edge that projects into the cavity that clips into the aluminium profile. The bottom edge of the terracotta panel above laps over the front of the horizontal support profile in order to conceal it. A continuous lip is formed in the back of the panel, as part of the terracotta extruding process, which serves as a support bracket to take the load of the panel onto the supporting rail. Vertical joints are either left open or have a plastic or black coated aluminium strip as a baffle to prevent most of the rainwater from entering the joint. The baffle also serves as a visual screen to the cavity behind where there is a risk of daylight reflecting back out of the cavity to reveal the backing wall behind. An advantage of keeping vertical joints open is that the gaps allow the void behind to be better ventilated, instead of relying only on ventilation points at the top and bottom of the wall as is the case in masonry cavity walls. Joint widths of terracotta panel rainscreens vary from 2mm to around 10mm (up to 0.5in), depending on the size of panel and type of fixing system chosen.

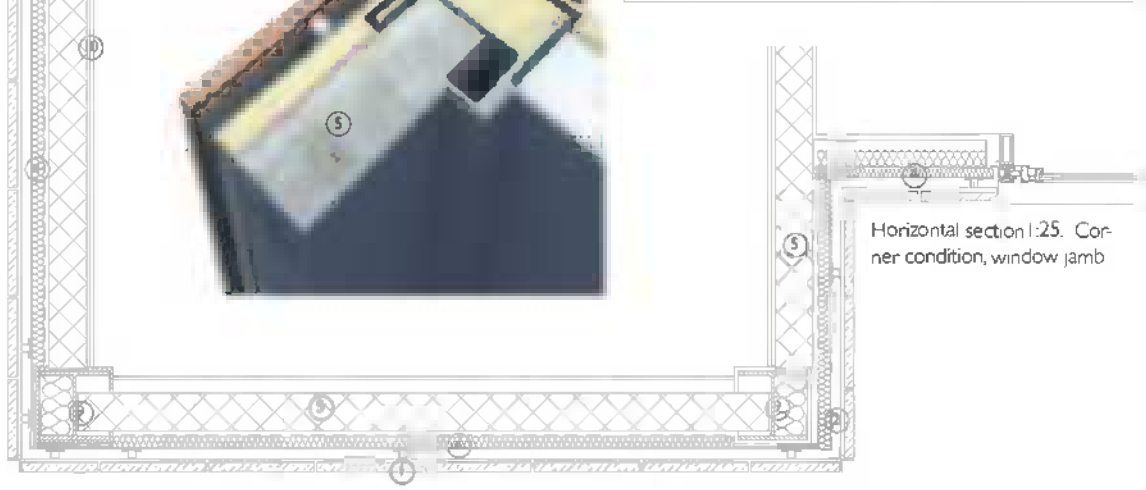
Panel sizes

For the largest tiles, formed as 'planks' up to around 1500mm long x 600mm wide x 40mm thick (5ft x 2ft x 1.5in), a substantial aluminium support section is needed behind the panels. The extrusions, set at the ends of each panel, sometimes project forward of the terracotta in order to provide enough stability in the section. This gives the facade a characteristic appearance of vertical bays of panels, where only vertical backing supports are used, divided by the visible edge of the aluminium support. Corner pieces can be made in sizes of 250mm x 300mm (10in x 12in) high, which often do not match with the maximum size that can be manufactured for the planks, but this constraint will no doubt be overcome in the next few years. Thinner terracotta panels of 30mm (1.2in) thickness are used, in sizes with a maximum length of around 800mm (2ft 8in) and corresponding maximum height of 300mm (12in). These thinner panels have maximum corner panels of 150mm (6in) on one leg and 300mm (12in) on the other leg. The minimum sizes that can be accommodated with the vertical rail system are terracotta panels around 200mm long x 200mm high (8in x 8in), with a thickness of 30mm to 40mm (1.2in-1.6in). All panel dimensions vary with a tolerance of

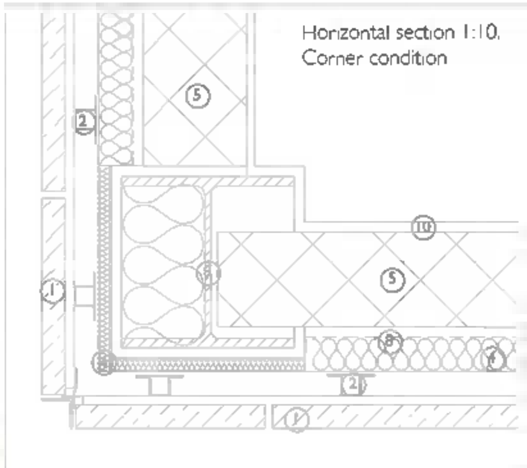
ertical section 1:25
Vindows at head and cill

Details

1. Terracotta rainscreen
2. Extruded aluminium carrier frame
3. Support brackets, typically aluminium
4. Thermal insulation
5. Backing wall
6. Floor slab
7. Metal framed window
8. Waterproof membrane
9. Structural column
10. Internal finish

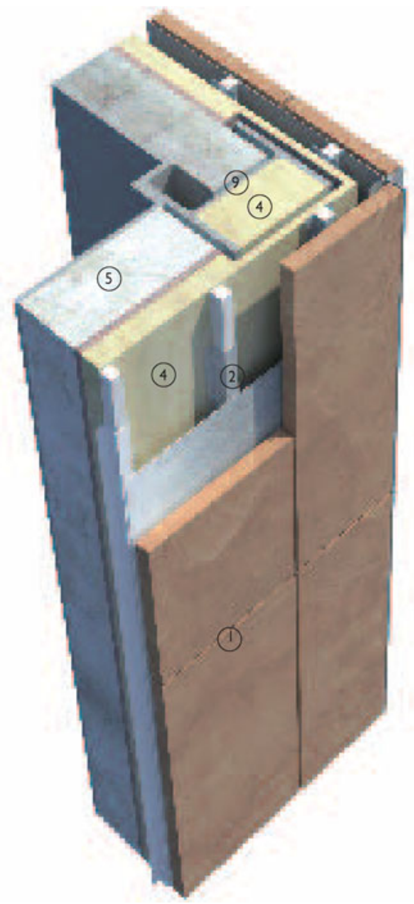


Horizontal section 1:25. Corner condition, window jamb



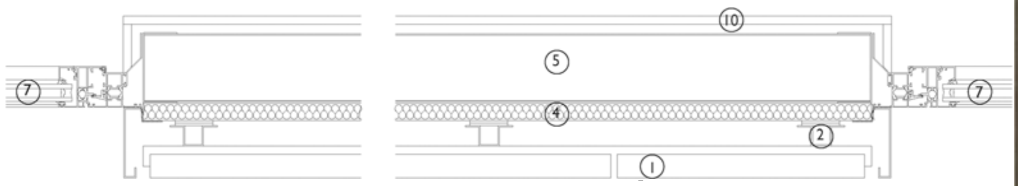
Horizontal section 1:10. Corner condition

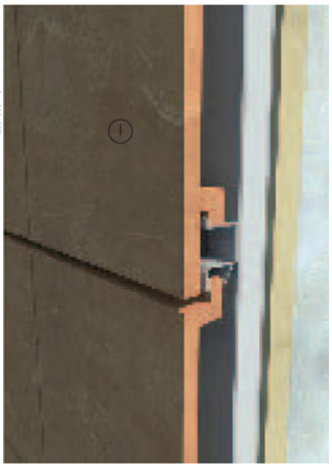
3-D view of bottom of window opening in terracotta rainscreen facade



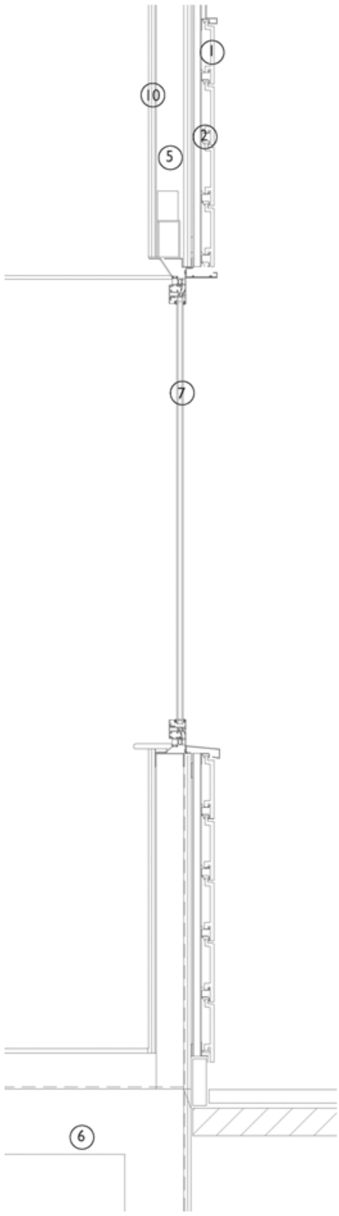
3-D view of corner condition

Horizontal section 1:10. Window jamb

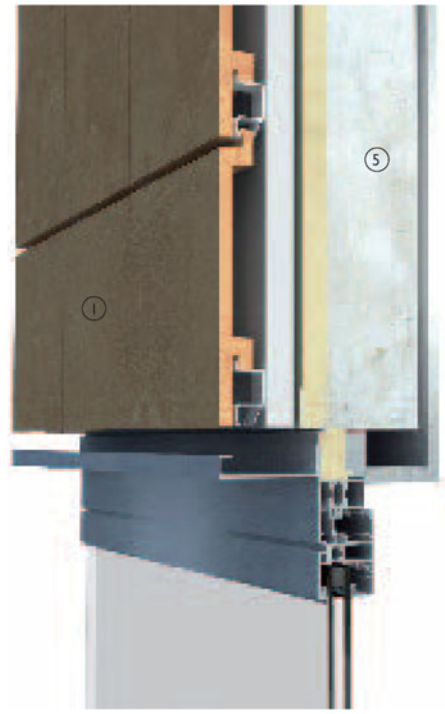




Horizontal section 1:25. Window jamb



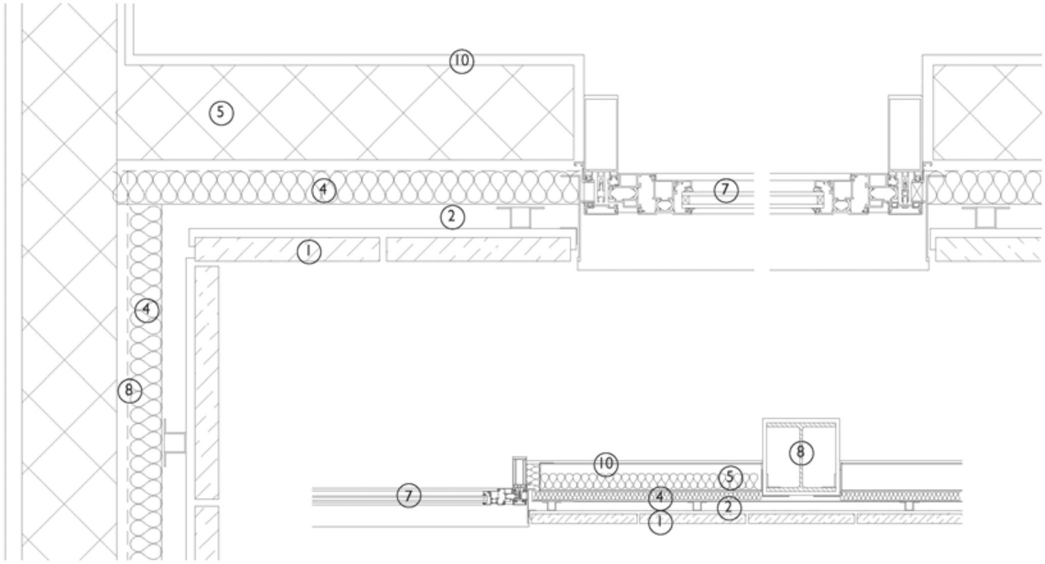
Vertical section 1:25. Window at head and cill



around ±1.0mm in their length, since terracotta is wire-cut as it comes out of the extrusion machine, and is subject to a tolerance of around ±1.5mm in its width due to shrinkage during firing.

Openings

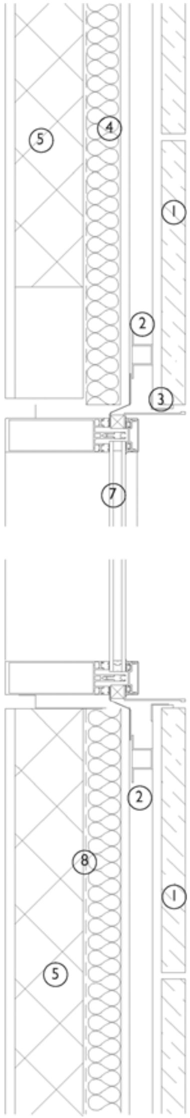
Windows and doors can be set very easily into terracotta rainscreen cladding. Extruded aluminium trims which project from window openings can be used to form a crisp edge to a window when it is set back behind the face of the terracotta, as is typically the case, since the window is usually fixed into the backing wall, to which the rainscreen cladding is fixed. Alternatively, the window frame can form part of a continuous horizontal or vertical metal trim that visually divides the terracotta into panels, typically storey height. The trims are made from either folded aluminium or rolled steel channels. Trims are not continuous with the structure behind in order to avoid thermal bridging. The flat, planar nature of terracotta has led to the increased omission of reveals around window openings by pushing the window frame forward to align with the face of the terracotta panels. Bays of terracotta are also increasingly mixed with other materials such as metal rainscreen panels and metal louvre panels where materials change without the need for any special detailing at the junction, since all panels are in a continuous rainscreen arrangement. Where terracotta reveals are introduced into window openings, corners are mitred with open joints if special corner panels are not used. This principle is also used at internal and external corners in the facade.



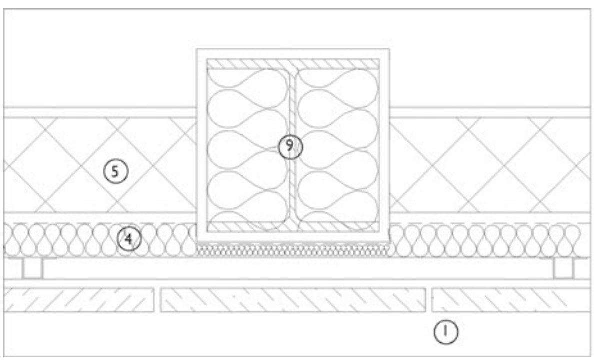
Horizontal section 1:10.
Corner condition, window jamb

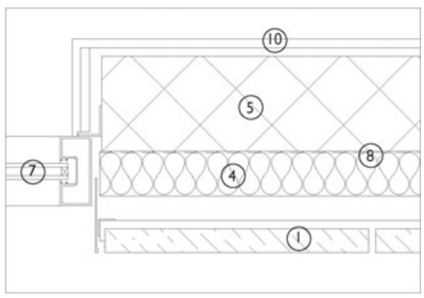
Horizontal section 1:25. Window jamb

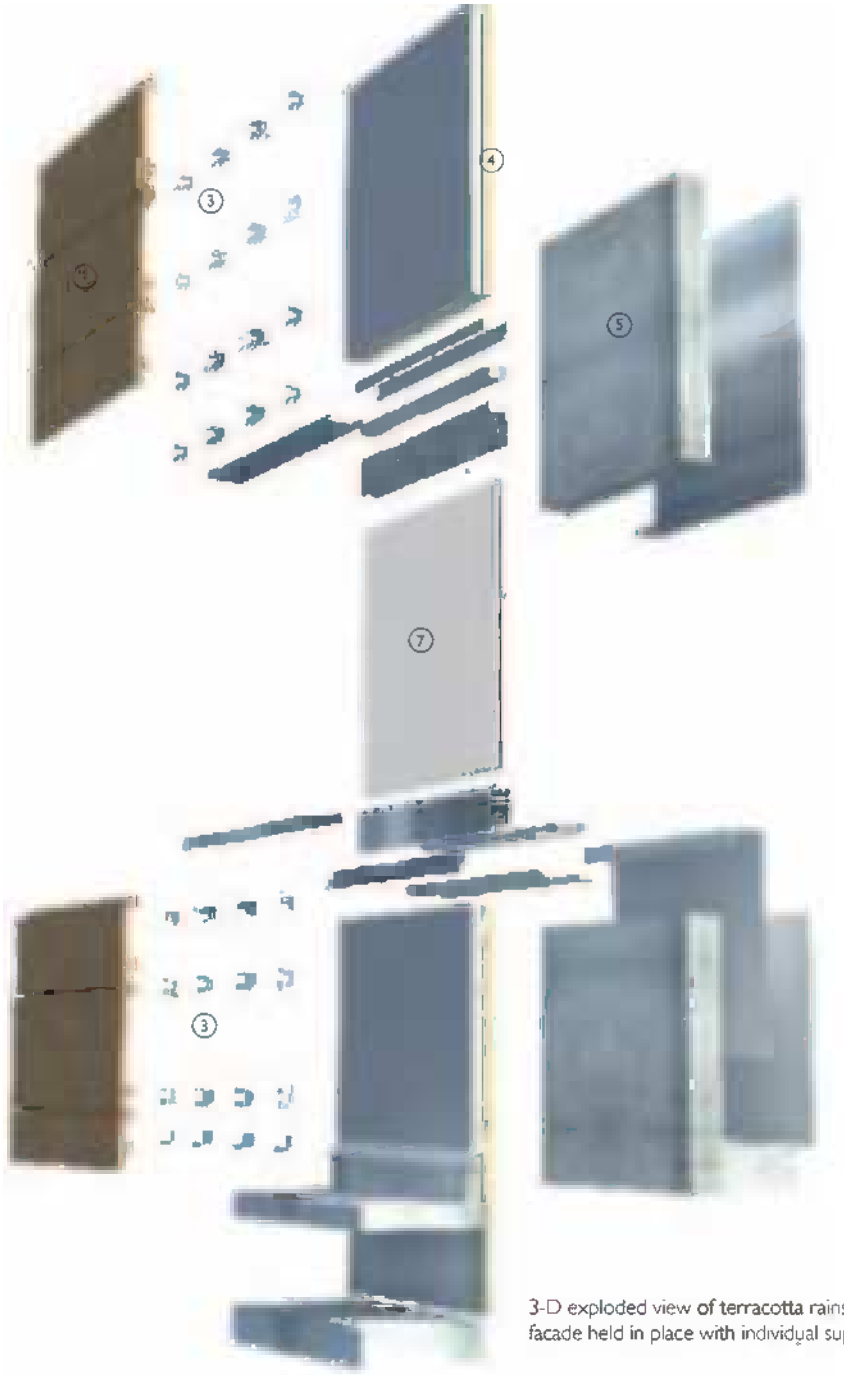
3-D view of top of window opening in terracotta rainscreen facade



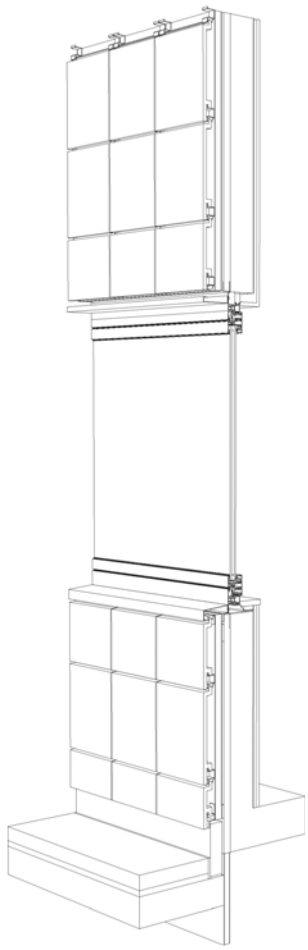
Vertical section 1:10.
Windows at head and cill





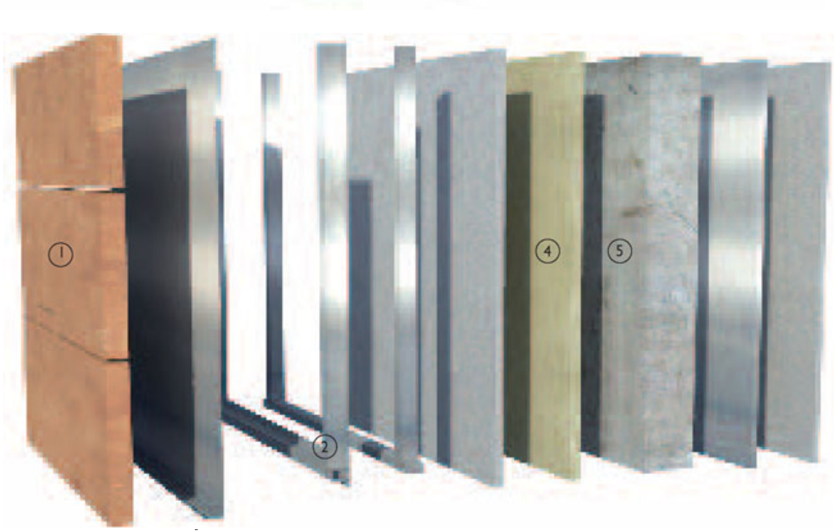


3-D exploded view of terracotta rainscreen facade held in place with individual support clip



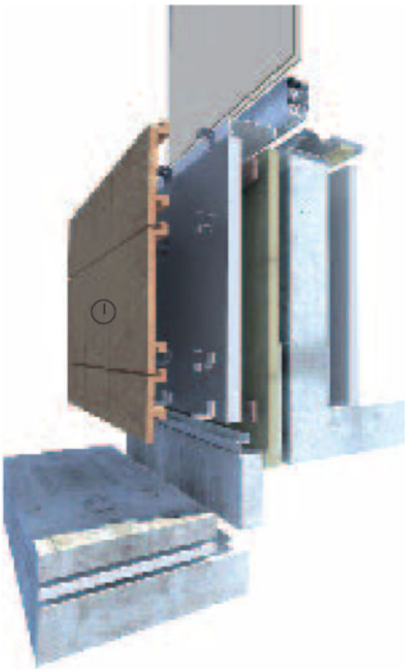
Details

1. Terracotta rainscreen
2. Extruded aluminium carrier frame
3. Support brackets, typically aluminium
4. Thermal insulation
5. Backing wall
6. Floor slab
7. Metal framed window
8. Waterproof membrane
9. Structural column
10. Internal finish



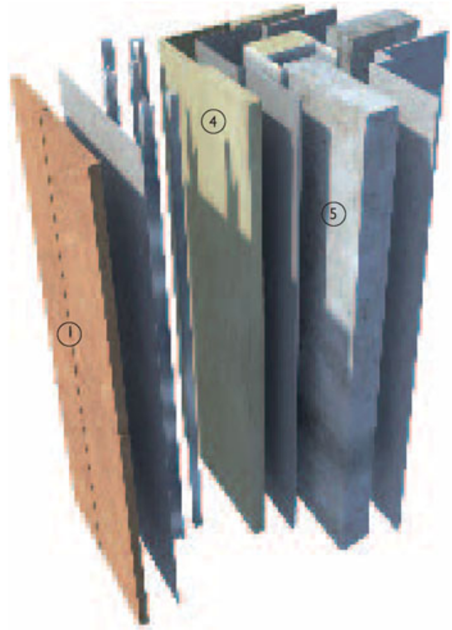
3-D exploded view of wall assembly of terracotta rainscreen supported on vertical and horizontal aluminium rails

3-D exploded view of parapet assembly on terracotta rainscreen facade

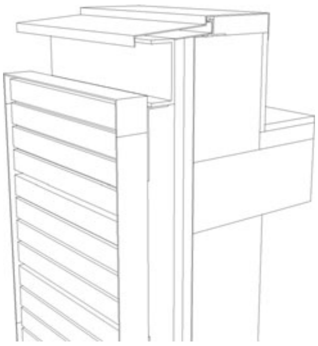


3-D exploded view of ground floor junction

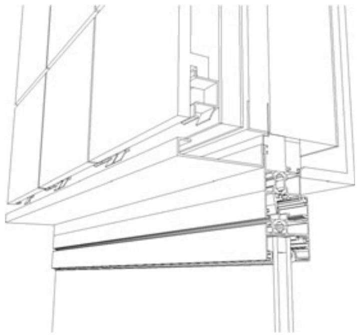
3-D exploded view of top of window opening in terracotta rainscreen wall assembly



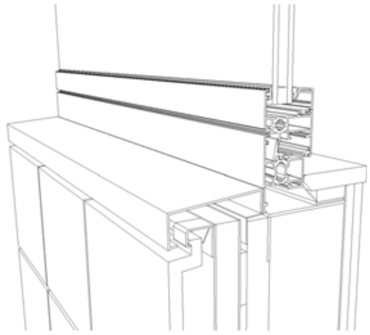
3-D exploded view of top of corner condition in vertically-hung terracotta rainscreen cladding



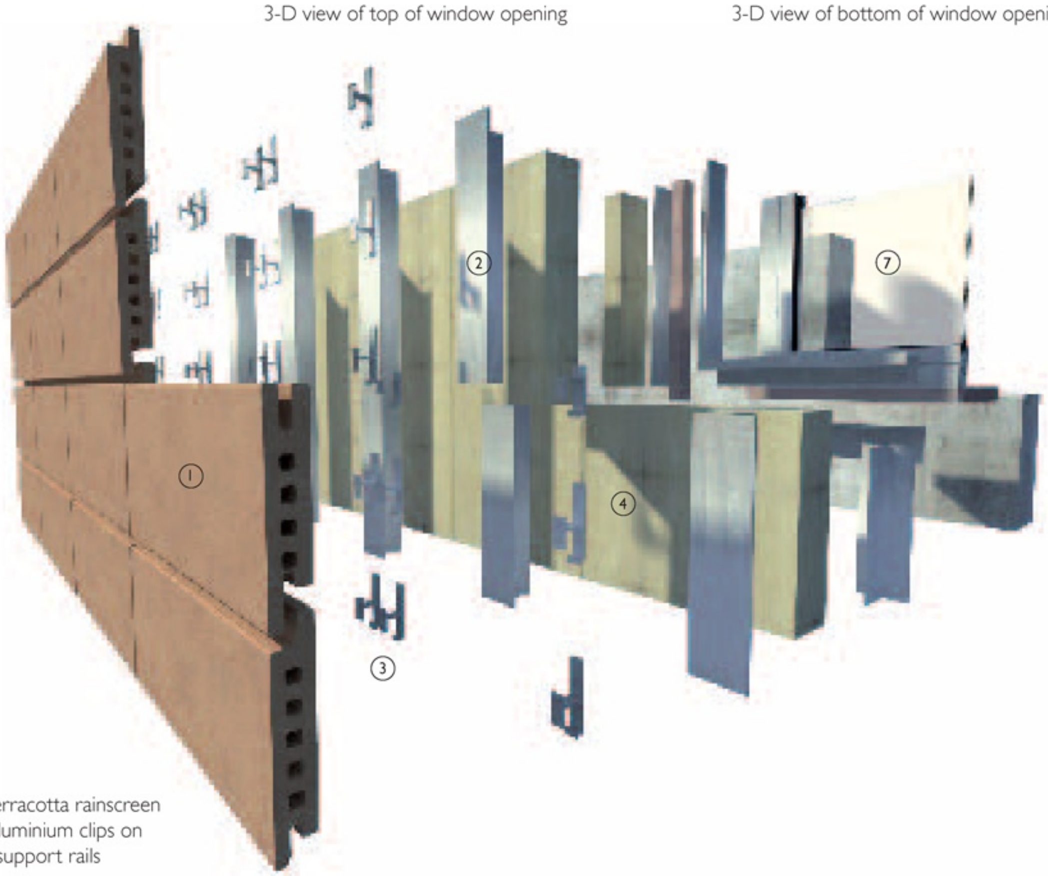
3-D view of parapet



3-D view of top of window opening



3-D view of bottom of window opening



3-D exploded view of terracotta rainscreen mounted on individual aluminium clips on vertically-set aluminium support rails

5

PLASTIC WALLS

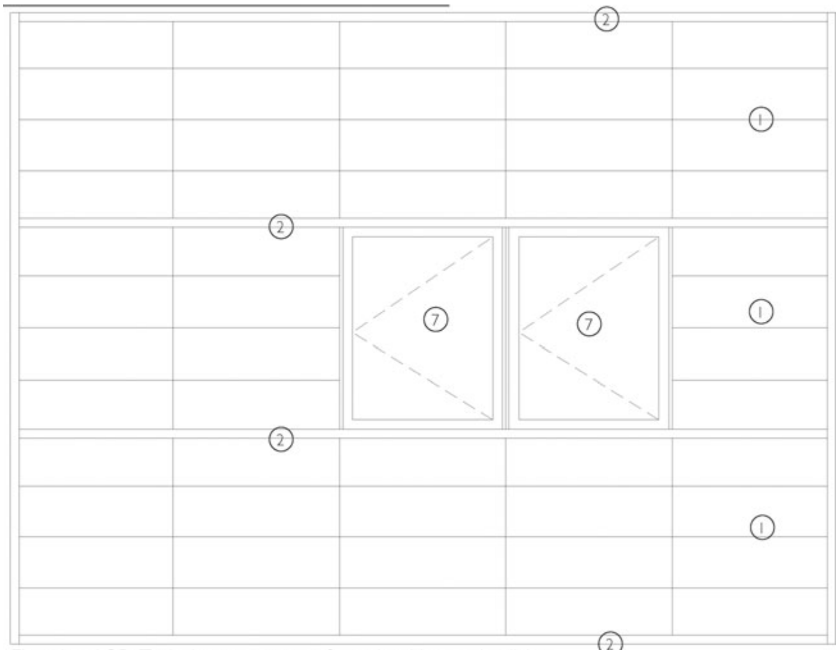
Plastic-based cladding

(1) **Sealed panels:**

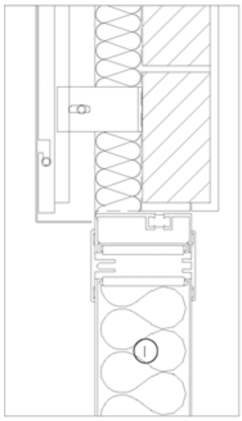
- GRP panels
- Polycarbonate cladding

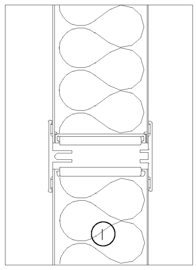
(2) **Rainscreens:**

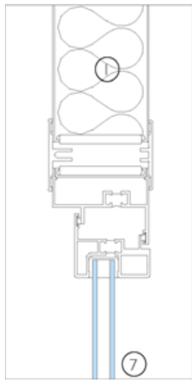
- Flat polycarbonate sheet
- Multi-wall polycarbonate sheet
- Profiled polycarbonate sheet
- Plastic-composite flat panels
- UPVC board cladding
- UPVC windows
- GRP panels

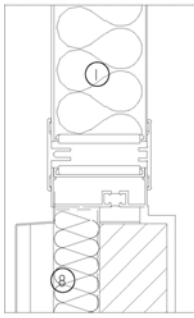


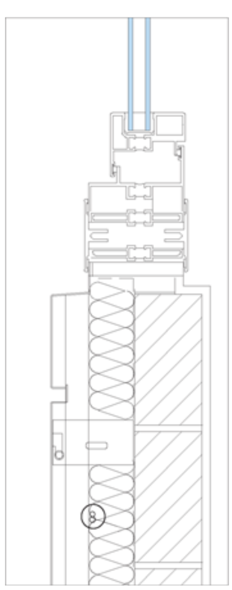
Elevation 1:25. Typical arrangement of panels with opening lights



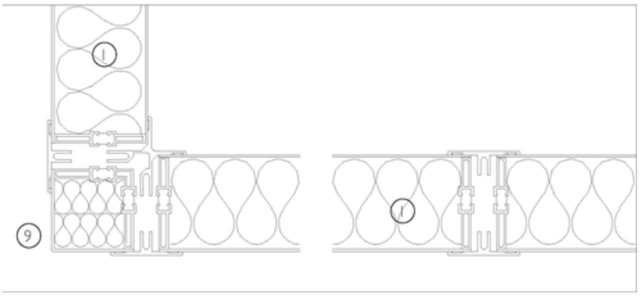


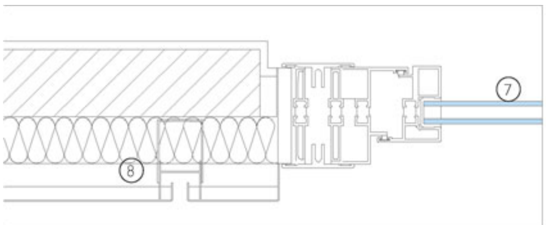


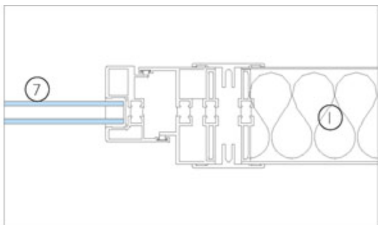




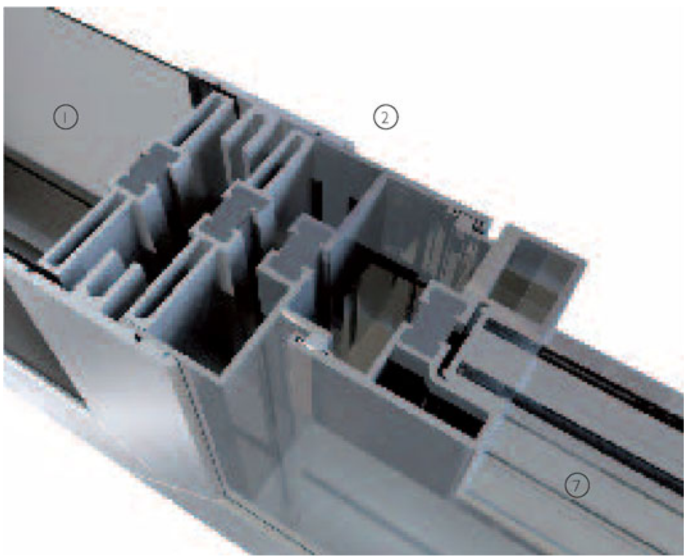
Vertical section 1:10. Junctions at panel-to-panel, window and junction with other wall types at top and bottom



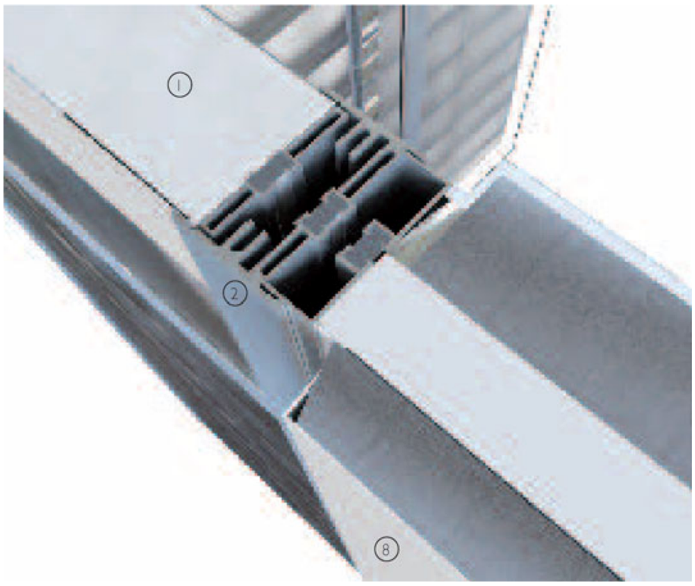




Horizontal sections 1:10. Junctions at panel-to-panel, window and junction with other wall types at top and bottom, corner



3-D detailed view of window and panel junction



3-D detailed view of wall and panel junction

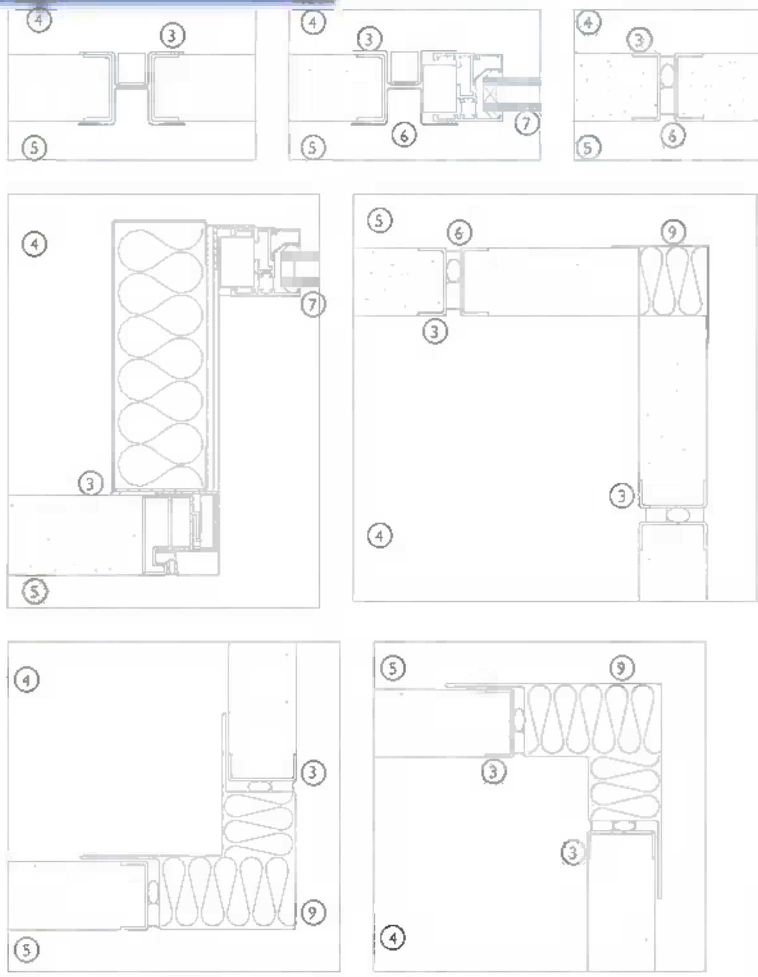
Details

Translucent GRP cladding panel, insulated
Thermally broken extruded aluminium framing
Opaque GRP cladding panel, insulated
Inside
Outside
Recessed cover cap
Window inserted into framing
Adjacent wall. Metal rainscreen shown
Insulated corner panel
0. Metal cover strip
1 Supporting structure

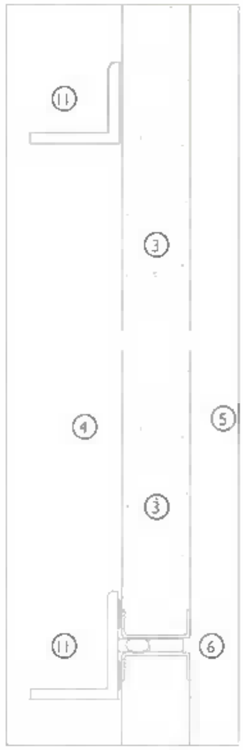
Plastics are resinous, polymer-based materials, and they are used for both sealed cladding and rainscreens, which are discussed in the following two sections. The materials used are principally glass reinforced polyester (GRP), polycarbonate and UPVC. Since the properties of these materials are generally not as familiar to readers as other materials, a brief description of each of these materials is given here.

GRP is a composite material made from thermosetting polyester resins (that set hard and do not melt when re-heated) which are mixed with glass fibre mat. This composite material has high tensile, shear and compressive strength combined with lightness and resistance to corrosion. However, like aluminium it deflects considerably under high loads and requires stiffening, but the material is stiffer than other plastics. GRP is not combustible and can reach one hour fire resistance in some cladding applications. Glass fibre mat is a flexible sheet material made from fibres drawn from molten glass. Its tensile strength is much greater than that of steel. Polyester resin, with which the fibre is combined, forms a solid material when a chemical catalyst is added. GRP panels are formed in a mould where glass fibre cloth is laid into a mould and coated with resin and catalyst. An alternative method is to spray a mixture of glass fibre and resin into a mould. The face of the mould is coated with a releasing agent to allow the GRP to be removed when it has set hard. GRP sections are made by pultrusion, where fibres are pulled through a die drawing strands of the material to form continuous sections in the manner of aluminium extrusions. Pultrusions are beginning to be used as structural components in footbridges, where their durability is considered to be better than painted aluminium or steel structures. Whereas sections are made by an expensive pultrusion method, panels are made by hand as a craft-based activity in a workshop. The production of GRP panels is economic, requiring neither high temperatures for manufacture, nor expensive equipment.

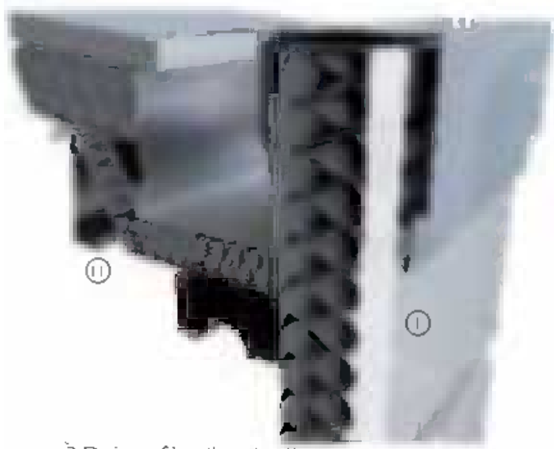
Polycarbonate is a thermoplastic, that is, it melts at high temperatures. It is used in cladding for its translucency and transparency, especially where its high thermal insulation values are needed. Polycarbonate is made by melting a polymer and extruding it into strands which are chopped to produce polycarbonate granules. The granules are then extruded or moulded to form sheet materials. Polycarbonate is extruded in single wall, double wall or triple wall materials. Twin wall sheet is an extrusion of two layers separated by fins, giving the material greater rigidity, combined with an air gap that provides additional thermal insulation. The maximum sheet size is approximately 2000mm x 6000mm. The material has a tendency to yellow with age, which can be overcome with an acrylic coating. The material can also be moulded into complex shapes. It is also used for its high strength, ductility and lightness in weight. Because the material is combustible, its use in facades is limited. An advantage of the material over glass is its impact resistance, which is higher than that of toughened glass or laminated glass. The main disadvantages of polycarbonate over glass are that it is less durable



Horizontal sections 1:10. Panel-to-panel junctions



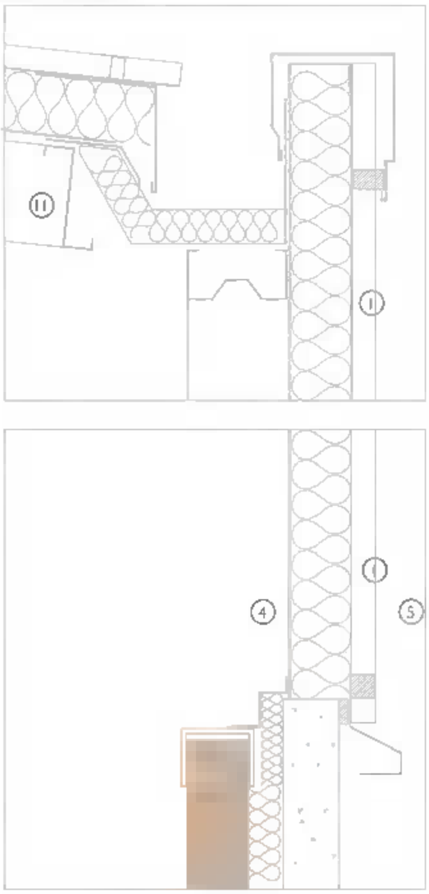
Horizontal section 1:10. Junctions at panel-to-panel, corners



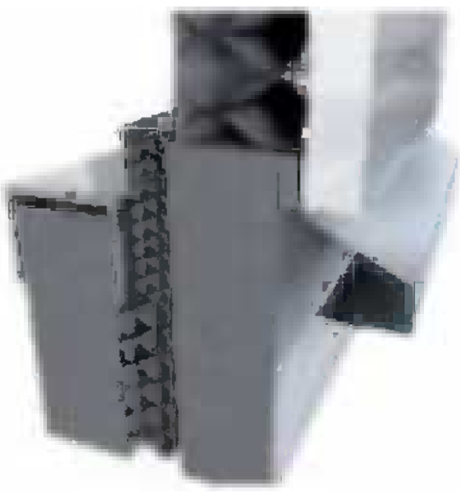
3-D view of junction at gutter

Details

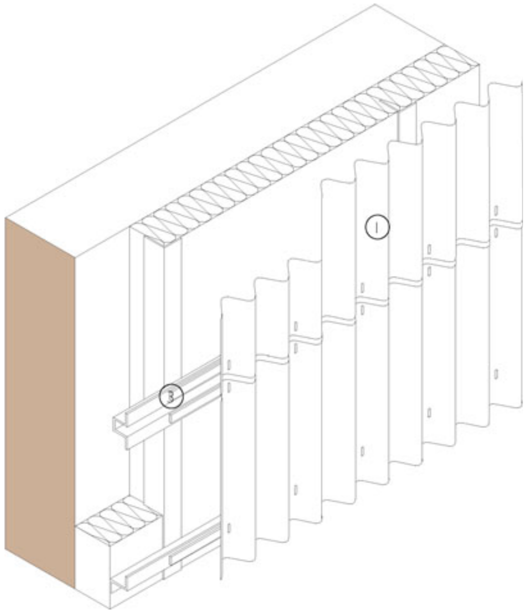
1. Translucent GRP cladding panel, insulated
2. Thermally broken extruded aluminium framing
3. Opaque GRP cladding panel, insulated
4. Inside
5. Outside
6. Recessed cover cap
7. Window inserted into framing
8. Adjacent wall. Metal rain screen shown
9. Insulated corner panel
10. Metal cover strip
11. Supporting structure



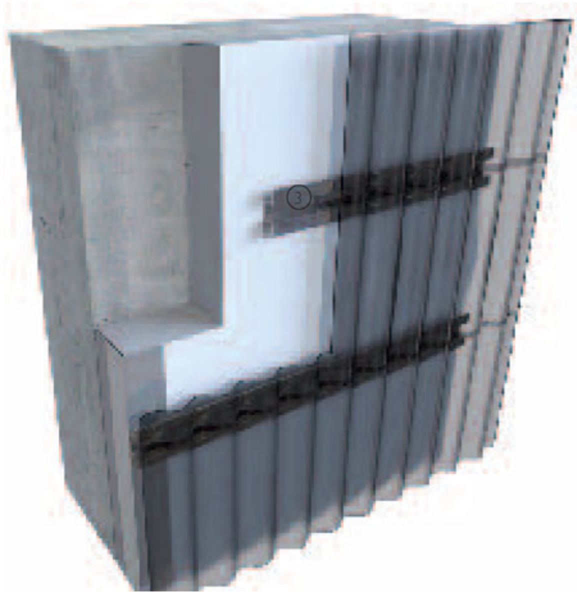
Vertical section 1:10. Junctions at parapet and cill



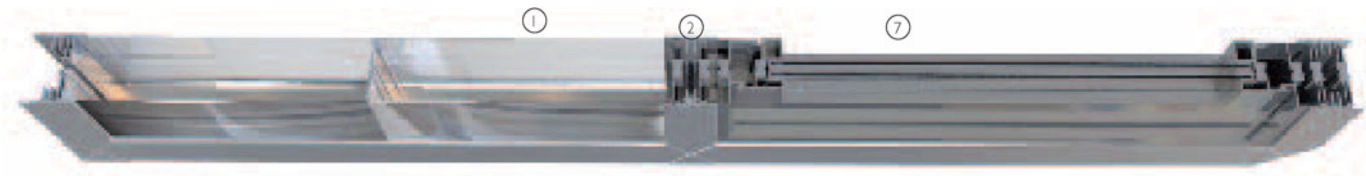
3-D view of junction at ground



Isometric view of wall assembly.



3-D cutaway view of wall assembly.



3-D section of window and sealed panel junction

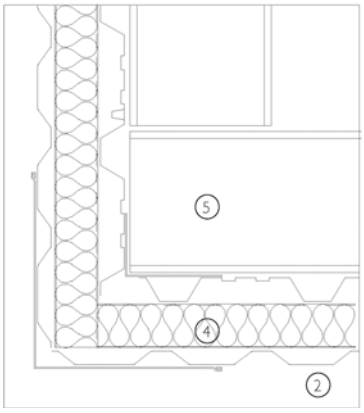
and scratches easily, which makes the surface dull with time, and its high thermal expansion. It expands up to 20% more than glass.

UPVC, or PVC-u is an unplasticised, or rigid PVC, used in plastic-based cladding mainly for window frames and weather-boarding. The material can be easily extruded as complex sections to provide an economic material with low thermal conductivity, making it ideal for window frames where a plastic thermal break would be provided in an equivalent aluminium window. Like polycarbonate it is combustible but is not easily ignited, burning slowly if exposed to a flame source. If the flame is removed, then the flame will self-extinguish. The material will soften if exposed to a direct heat source. UPVC is available in a range of colours, weathering well, but is susceptible to fading, particularly with brighter colours. It is a tough material, but also flexible.

GRP panels

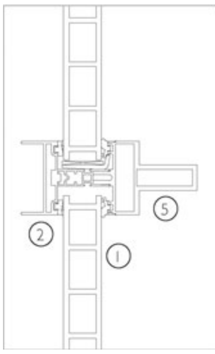
GRP cladding panels can be made either as separate panels glazed into an aluminium pressure plate system with a secondary supporting structure behind, or by forming aluminium extrusions within the panels. An advantage of GRP panels is their lightness in weight, combined with being moulded, allowing them to be made in large panel sizes, up to 6000mm x 1500mm (20ftx5ft). They are more economic than an equivalent insulated glazed wall. Panel thicknesses are usually 70-75mm to provide structural stability and thermal insulation.

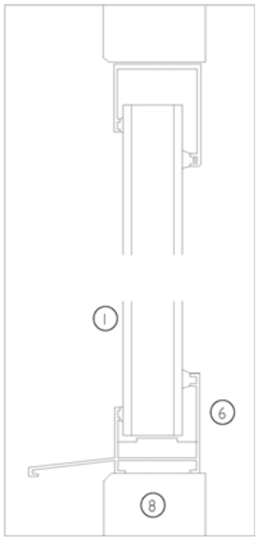
Where panels are fixed into aluminium pressure plates, the cover capping over the face of the plate is also aluminium. This can present a difficulty in colour matching between the capping and the adjacent panel. Where the aluminium is powder coated or PVDF coated, the GRP is coloured with a resin applied to the face of the mould during manufacture. This can lead to colour variation between the cappings and the panels, which can either form part of the design, or else different colours are used for each. GRP panels are glazed in a similar way to glass, with a thin panel edge, which can be compressed, held between EPDM gaskets by an extruded aluminium plate. Panels are made from two moulded GRP skins which are bonded either side of the rigid insulation. In common with metal composite panels, GRP panels have undergone much development in the use of glues to avoid delamination between the outer skins and the insulation core. Edges of the GRP panels are bonded together to form a sealed panel. Windows are glazed in to the pressure plates as separate panels. Windows are rarely glazed directly into GRP panels since it is difficult to provide a drained and ventilated void within a GRP panel. Earlier versions of GRP panels, used in the 1960s and 1970s, used a rubber gasket to seal the joint between window and panel, as was used in car windscreens at that time. But the lack of a second line of defence behind this seal led to the leaks. The same problem was encountered in car windows, which moved on to using silicone bonds. Cills and parapets are formed with GRP or pressed aluminium copings in the same way as stick glazing systems, discussed in the Glass chapter. Copings



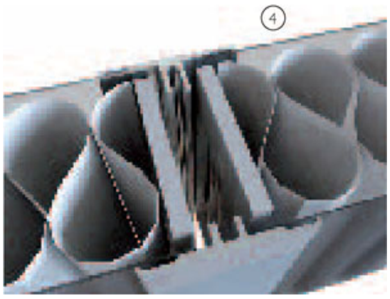
Horizontal section 1:10. Corner condition

Details
1. GRP or UPVC rainscreen panels
2. Twin wall polycarbonate sheet
3. Support rail
4. Thermal insulation
5. Supporting structure
6. Metal drip
7. Floor slab
8. Metal parapet coping
9. Backing wall

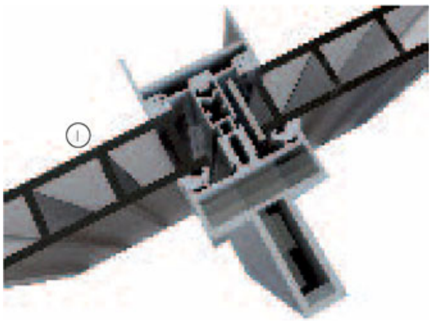




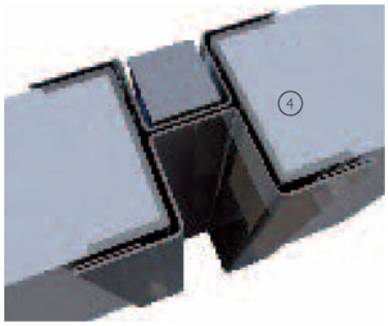
Vertical sections 1:10.
Panel-to-panel junction and head and cill condition



3-D view of panel to panel junction



3-D view of panel to panel junction



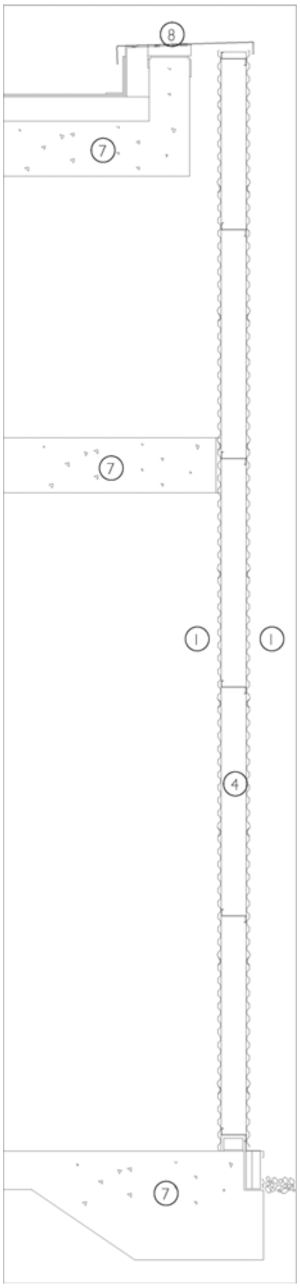
3-D view of panel to panel junction

are glazed in to the pressure plate framing in the same way as a panel.

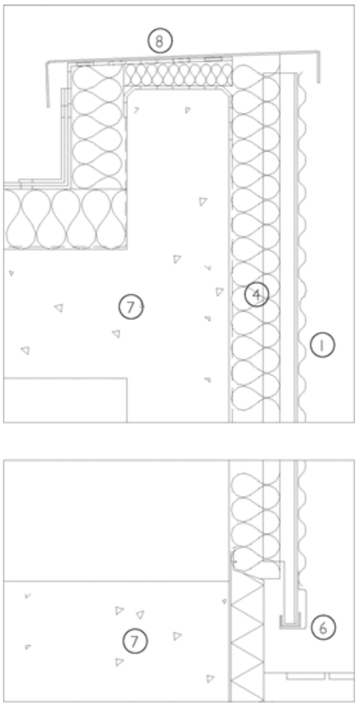
GRP panels can also be fixed together with extruded aluminium sections set within the depth of the panel. This is a more economic solution which is closer to metal composite panels in its approach than the aluminium pressure plate system, which is based on stick-built glazed walls. GRP panels are clipped into aluminium extrusions which have a thermal break set into the section. Panels are also stiffened internally with aluminium I-sections or T-sections where large scale panels are used. Panels can be opaque or translucent, like the previous pressure plate-based systems described. Where panels are transparent, the internal aluminium framing within the panel forms a visible grid, resembling traditional Japanese Shoji screens. These internal ribs are typically set from 300mm x 300mm centres to 300mm x 600mm centres. In these translucent panels the void between the two skins can be filled with translucent insulation quilt to increase thermal insulation, while still allowing a diffused light to pass through the panel. Mineral wool quilt is typically used, but fixing the insulation requires care to avoid the material from later sagging, which is clearly visible through the GRP panel. Light transmission without additional thermal insulation is typically around 15%, with a U-value of 1.5W/m2 °C, which is similar to an argon filled double glazed unit, and a shading factor of 20%, which provides a high level of shading for a 'glazed' wall. Unlike the pressure plate system, windows can be glazed into the panels, giving the possibility of a rich mix of windows, doors and translucent panels without the need for complex framing. Window frames can form part of the T-section extrusion around a window. Integrating the window frame into the extrusion supporting the GRP panels avoids potential leaks associated with silicone-sealed butt joints when a separate window frame and panel frame are fixed together. The integrated window frame allows water to be drained from the frame. GRP panels can be glazed into large structural openings, from floor to ceiling for example, or can form a complete glazed wall, restrained by a secondary steel frame. When glazed into an opening, the edge T-section aluminium profiles are sealed against the adjacent concrete floor slab with silicone, at both top and bottom. When fixed to a secondary support frame, panels are supported at each floor level on metal brackets in either aluminium, mild steel (if internal) or stainless steel (if exposed to the weather). Cills and copings are formed with the methods described in the section on metal composite panels.

Polycarbonate cladding

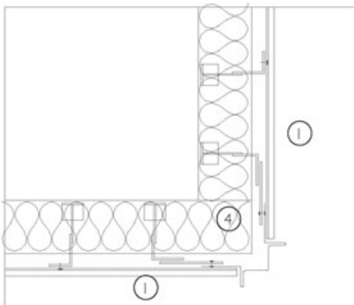
Polycarbonate is used for wall cladding as either profiled sheet or as twin wall / triple wall sheet. Where profiled sheet is used, it is typically used in long lengths to avoid horizontal joints formed by lapping sheets over one another. The sheet is orientated typically with the profile lines running vertically to allow rainwater to run off with a minimum of visible staining to this translucent material, but horizontally orientated sheet is increasingly being used. When set vertically, sheets are



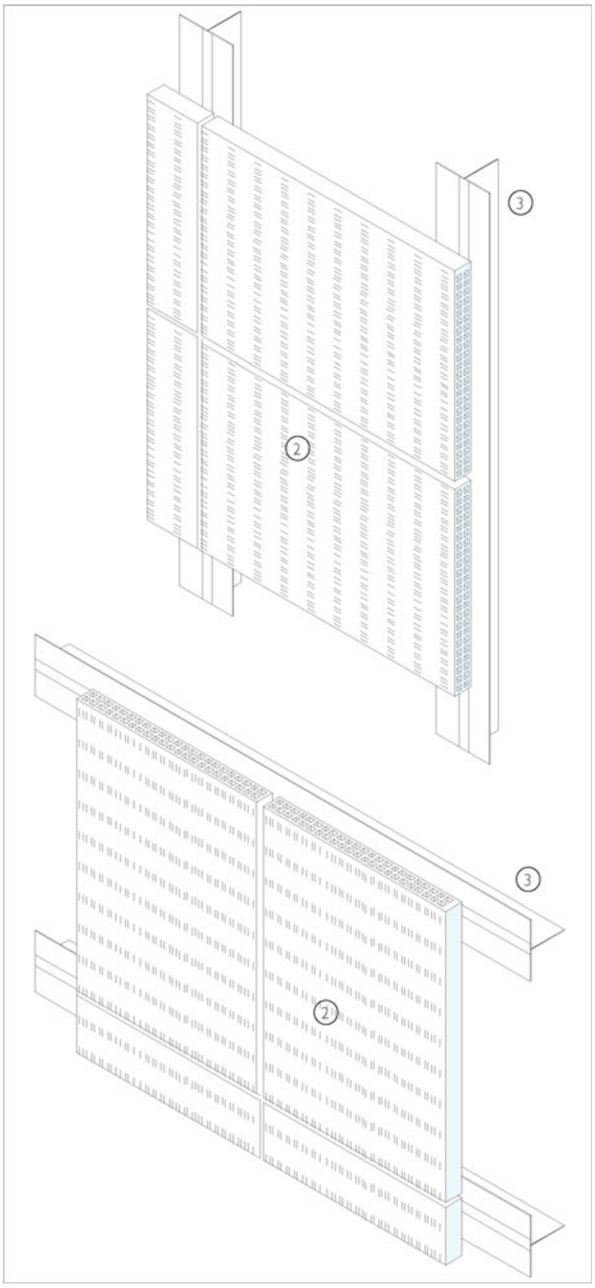
Vertical section 1:25. Two skins of polycarbonate fixed to aluminium support frame



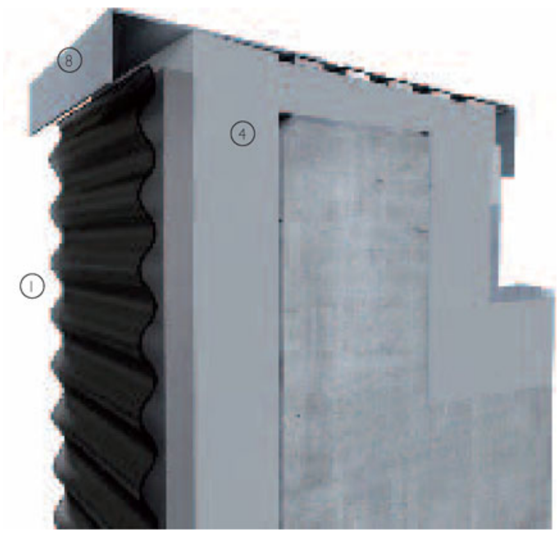
Sections 1:10. Junctions at parapet and cill



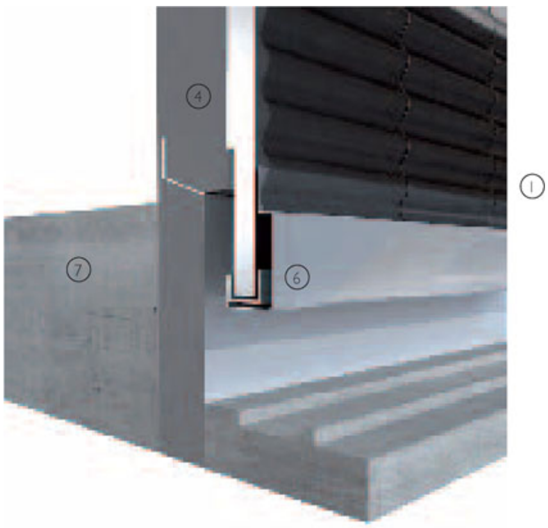
Horizontal section 1:10. Corner condition



Isometric views of wall assembly:
1. Vertically set, 2. Horizontally set



3-D view of parapet detail

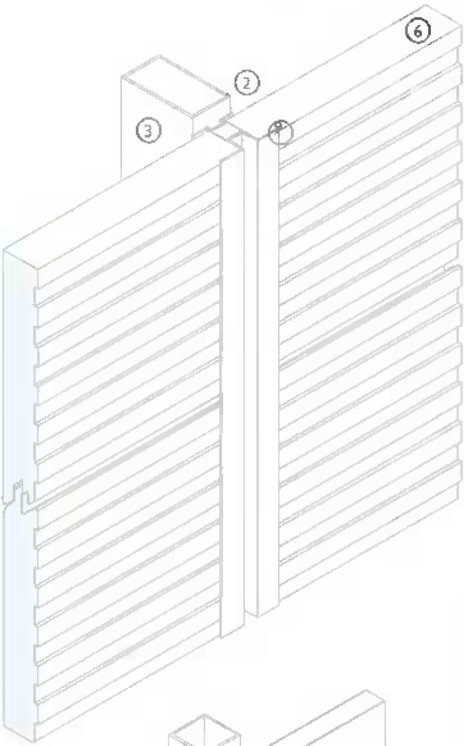


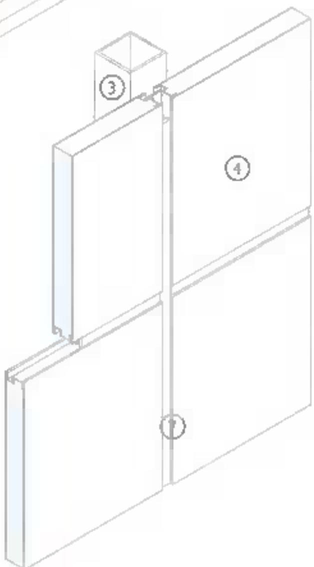
3-D view of ground junction

Details
1. Twin wall polycarbonate sheet
2. Thermal break
3. Supporting structure
4. GRP cladding panel, insulated
5. Stick curtain wall-type support system
6. Extruded aluminium edge framing
7. Rubber-based or silicone-based seal
8. Adjacent wall
9. Metal cover strip

3-D detail of corner junction

Isometric views of wall assembly
1. Vertically set.
2. Horizontally set with interlocking joints.
3. Horizontally set with stepped joints

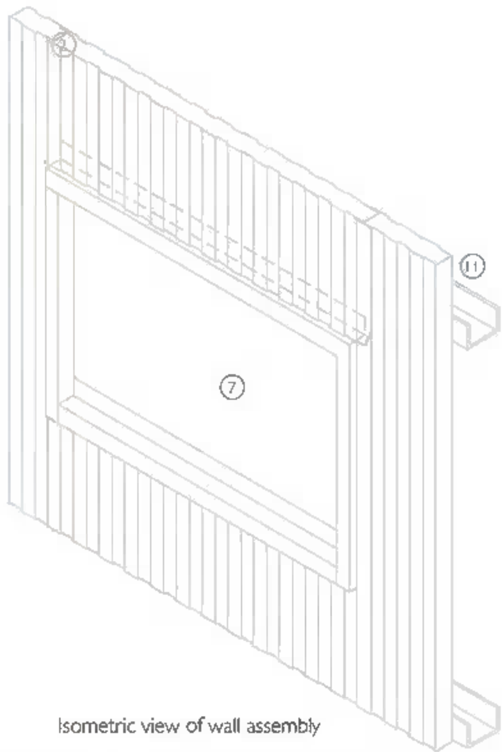




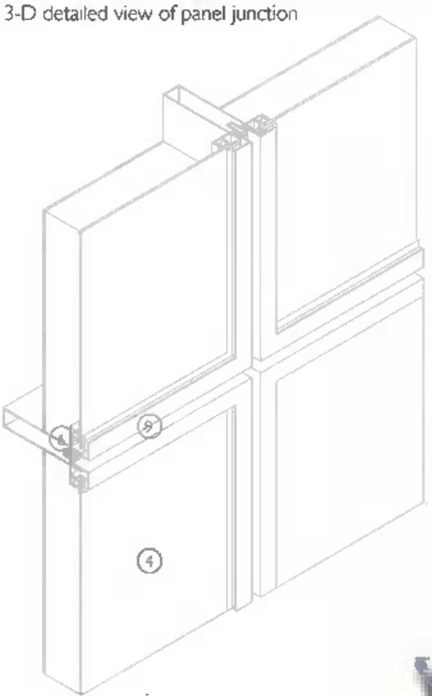
joined by either a straightforward lap of the material, which results in visible staining through the translucent material, unless an opaque sealant is used. Alternatively, an aluminium top hat section is used, set between two adjacent sheets used as described in the section on profiled metal sheet. The manufacture of polycarbonate cladding is restricted only to the sheet material, and accessories such as cill profiles, coping profiles and window trims are not usually available. Aluminium trims are used instead, and are fixed so as to reduce their visibility to a minimum. Trims are fixed in the same way as for profiled wall cladding described earlier.

Twin wall polycarbonate is fixed with either conventional aluminium framing for windows, or framing for stick glazing curtain walling. Some manufacturers provide extruded I-sections, similar to those used in GRP cladding, to clip the twin wall sheets to provide a completely lightweight system. This is a very economic form of cladding which can be screen printed to create visually dramatic translucent facades. Its lack of fire resistance makes it a less attractive material for warehouses and factory buildings, where its translucency and thermal insulation, combined with economy, would make it a much more popular material. As with profiled polycarbonate sheet, other standard components are not usually manufactured, and folded aluminium sections are used for drips and parapet copings instead of polycarbonate sections, which are expensive to produce as new profiles.

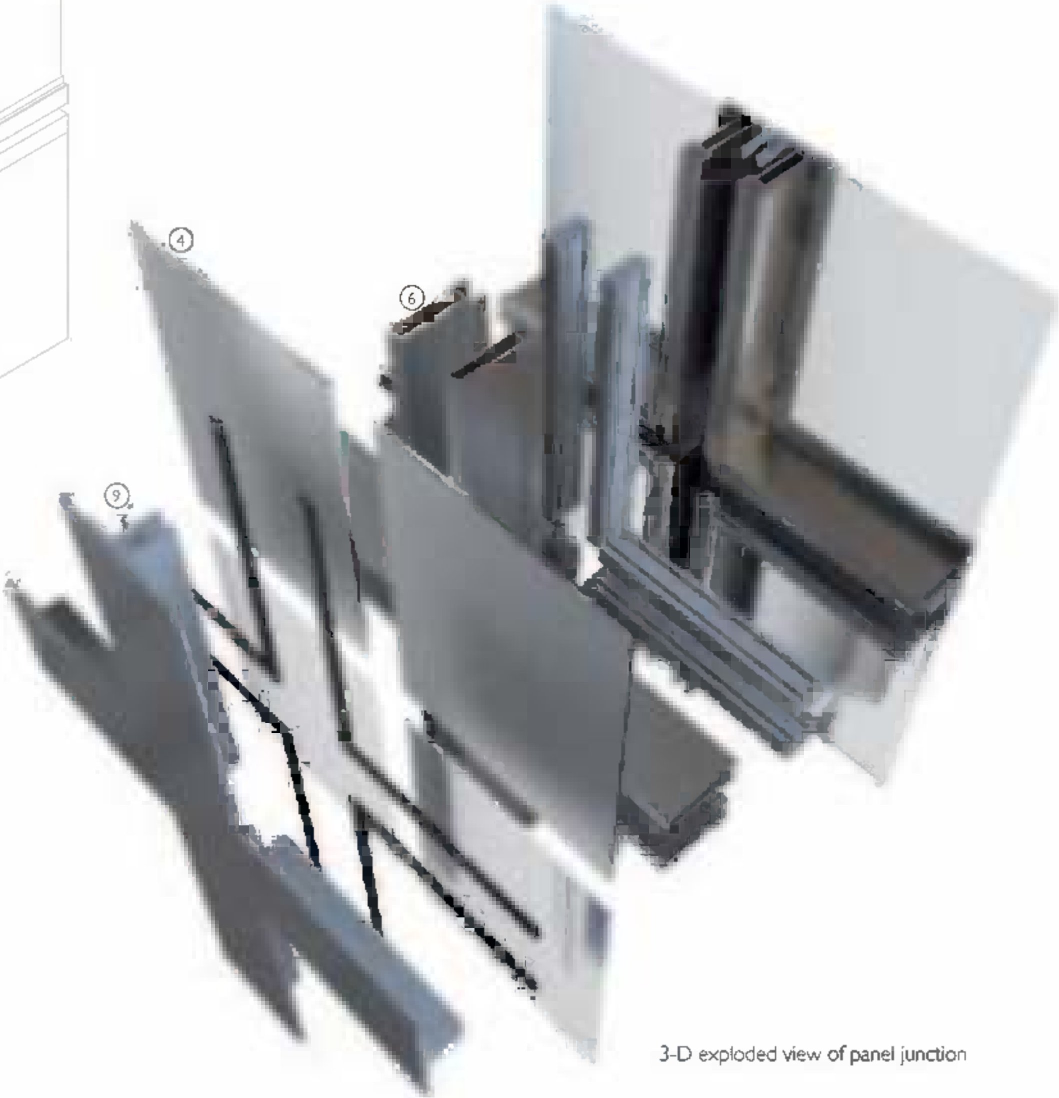
3-D detailed view of panel junction



Isometric view of wall assembly



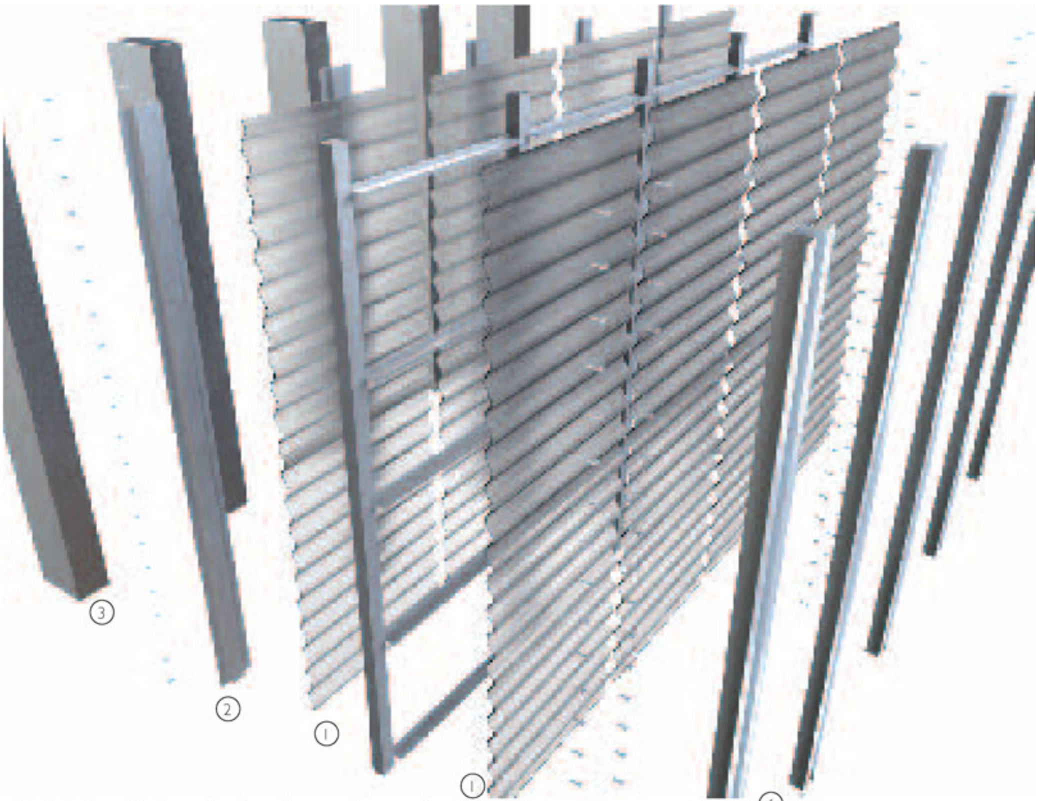
Isometric view of wall assembly



3-D exploded view of panel junction

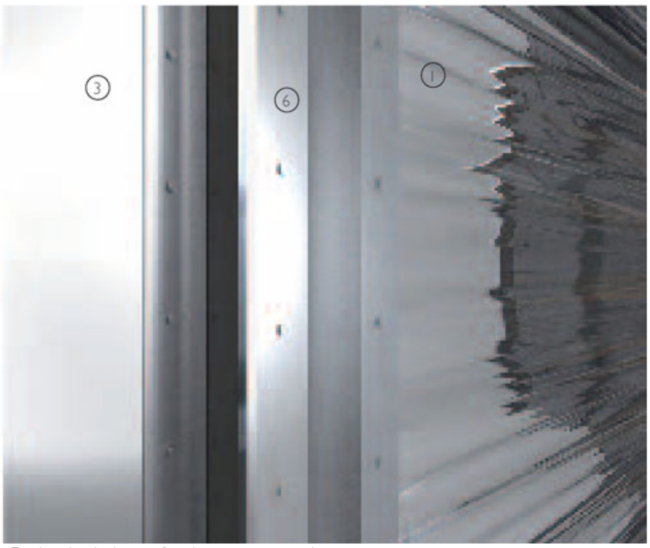
3-D view of twin wall polycarbonate sheet wall

3-D view of twin wall polycarbonate sheet wall

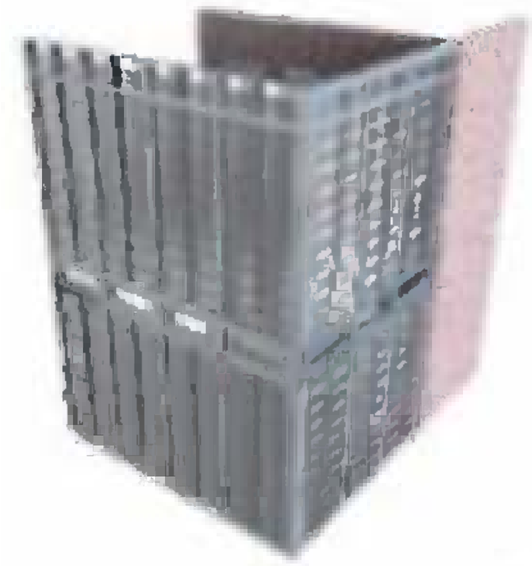


3-D exploded view of twin wall polycarbonate sheet wall

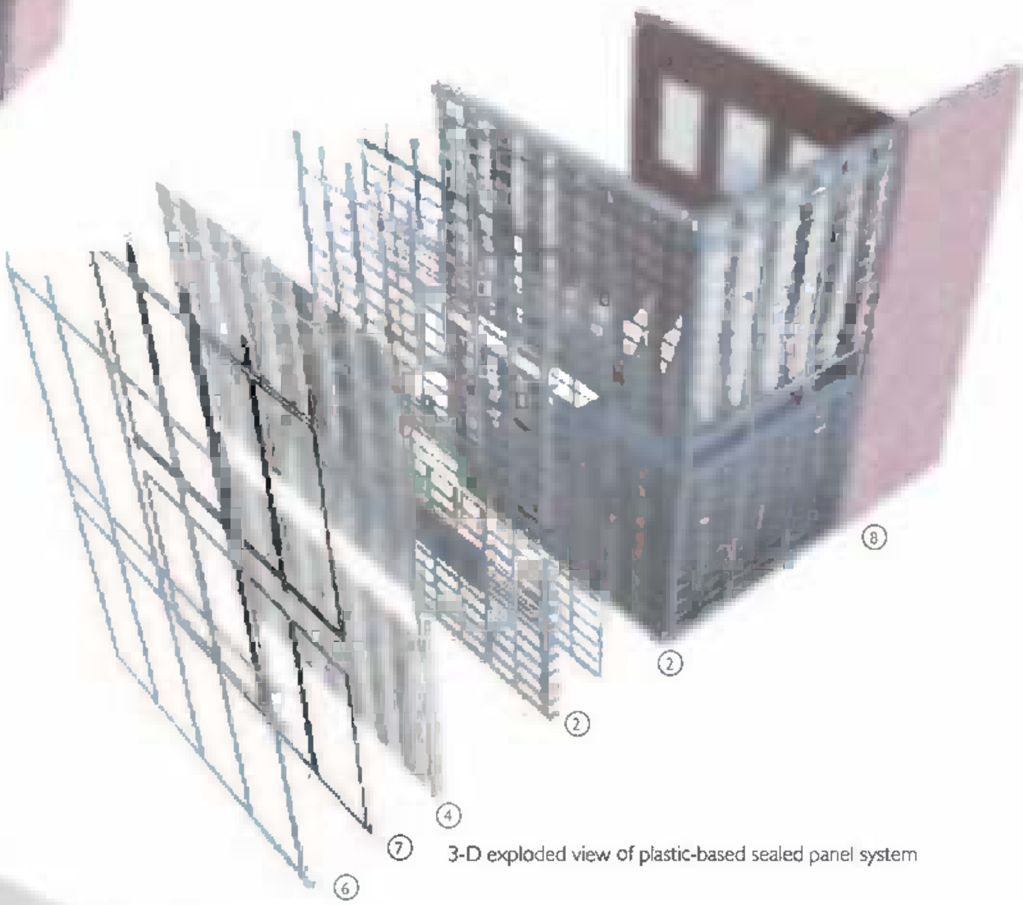
3-D detailed view of twin wall polycarbonate sheet wall



3-D detailed view of twin wall polycarbonate sheet wall

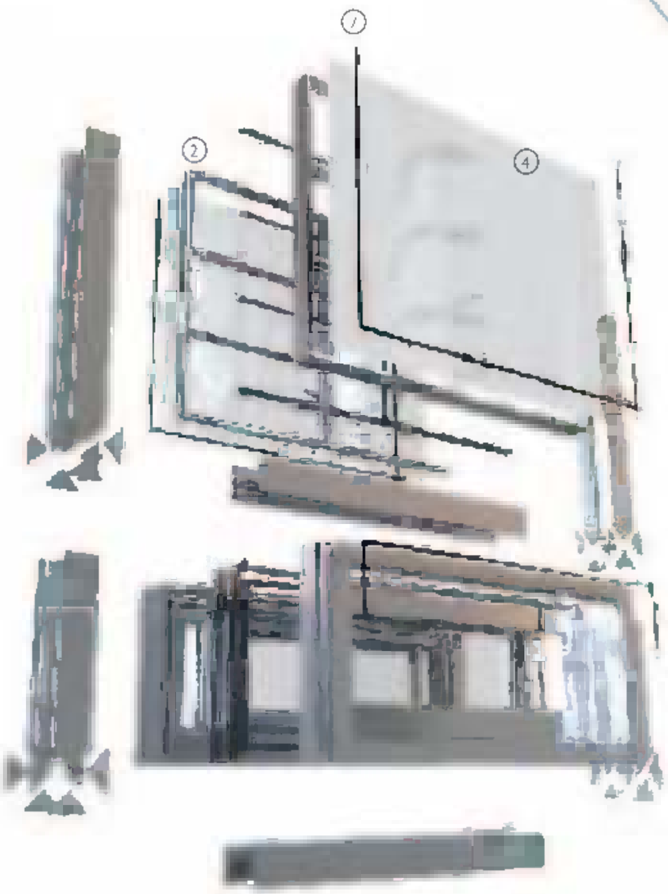


3-D view of plastic-based sealed panel system

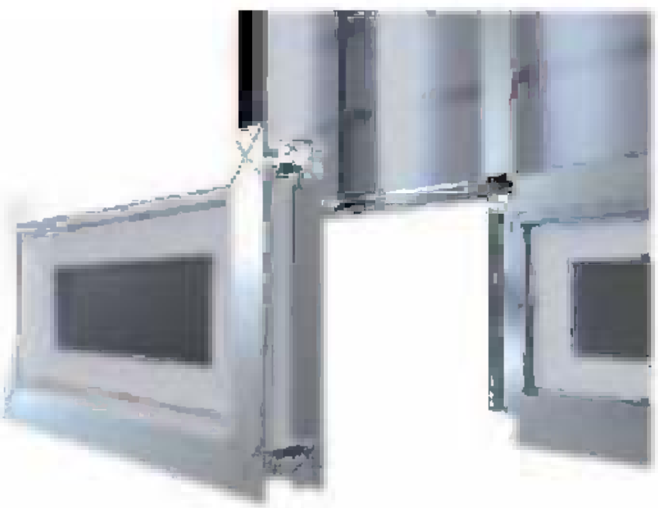


3-D exploded view of plastic-based sealed panel system

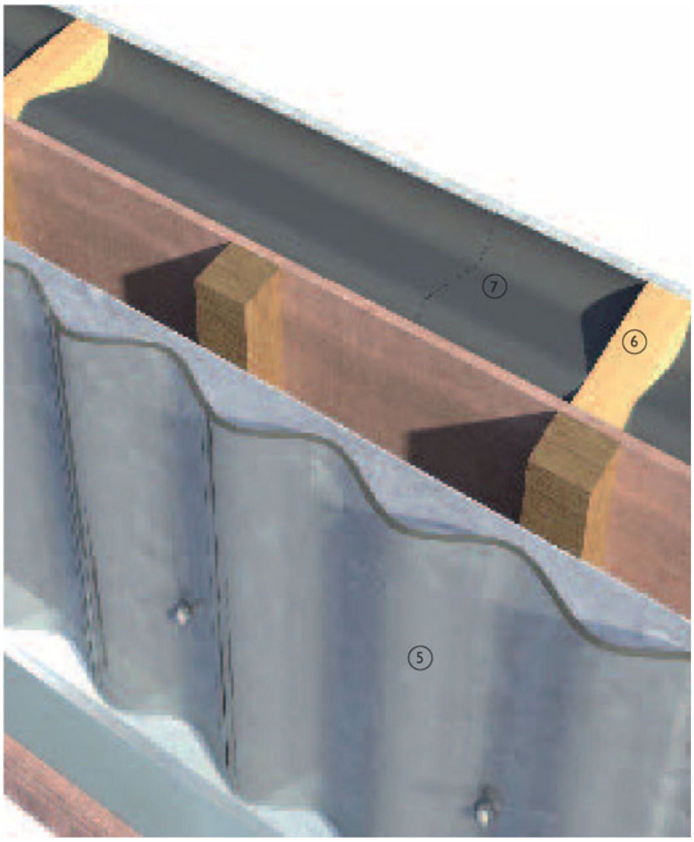
Details
1. Twin wall polycarbonate sheet
2. Thermal break
3. Supporting structure
4. GRP cladding panel, insulated
5. Stick curtain wall-type support system
6. Extruded aluminium edge framing
7 Rubber-based or silicone-based seal
8. Adjacent wall
9 Metal cover strip



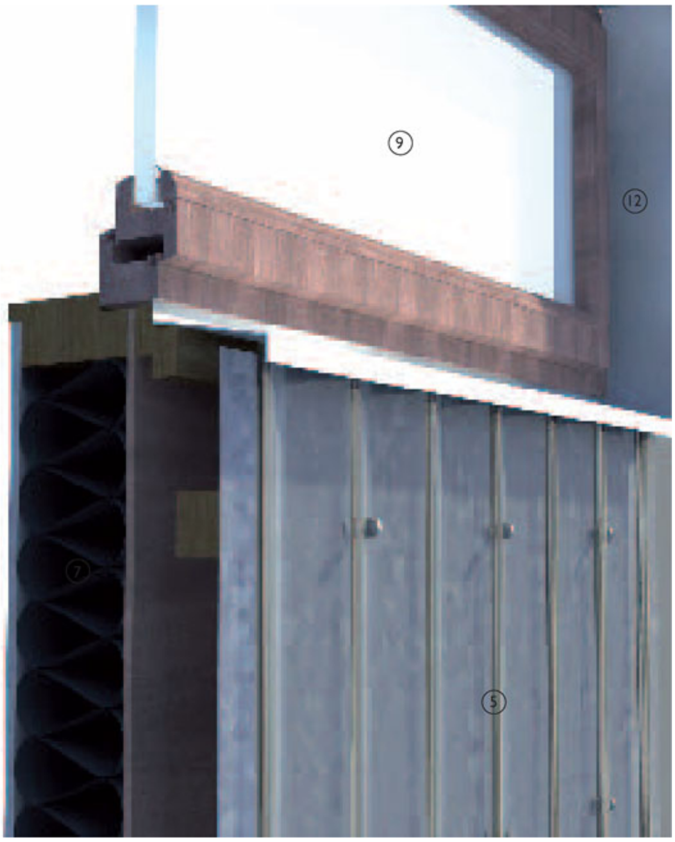
3-D exploded view of plastic-based sealed panel system with window



3-D exploded view of plastic-based sealed panel system window detail



3-D view of typical polycarbonate rainscreen cladding assembly



3-D view of typical window opening in polycarbonate rainscreen

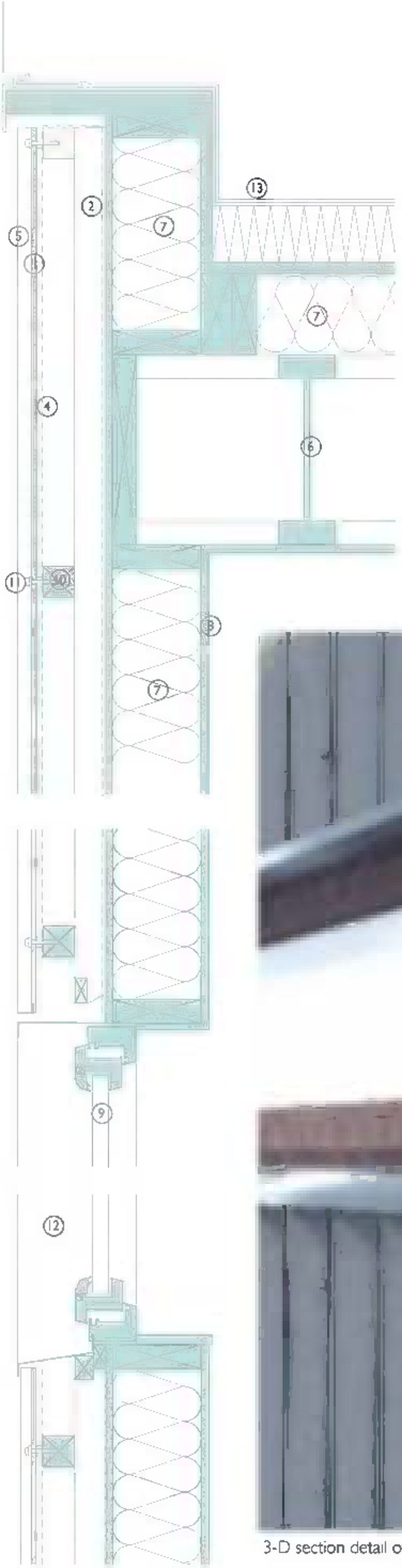
The two main types of plastic-based rainscreen are flat panels, cassette panels, profiled sheet and overlapping tiles. They are used as either outer screens to glazed walls, typically as solar shading, or as rainscreen panels to an opaque wall, typically in-situ concrete or concrete blockwork. The materials used are either polycarbonate or glass reinforced polyester (GRP). Acrylic and UPVC, while softer than both these materials, are used for window frames and special moulded elements. In addition, composites other than GRP (described in the previous section on plastic-based cladding) are used for rainscreens. Thermosetting polymer resins can be mixed with cellulose fibres to provide sheet materials with high durability which fade little in sunlight. In common with rainscreens in other materials, panels or sheets are fixed with either visible point fixings, vertical/horizontal rails with partially concealed framing members, or partially interlocking panels where there is no view through the joints.

Flat polycarbonate sheet

Opaque flat sheet is fixed as rainscreen cladding panels using similar techniques to bolt fixed glazing and clamped glazing, with open joints between panels. Flat sheet is made in a wide range of colours. Sheets are held captive at their corners with an aluminium clamp on both sides, with a set of bolts squeezing the clamps together without the need to drill through the polycarbonate. Since the cost of drilling polycarbonate sheet is much lower than glass (glass has to be heat strengthened after drilling), point fixings are more common when this technique is used. Bolts are much simpler than those used for glass, since the material is much lighter, though polycarbonate has higher thermal expansion than glass. Polycarbonate sheets usually have UV protection on both sides to avoid yellowing with age. The problem of yellowing has now been largely overcome with the higher quality sheet materials. Sheet sizes are around 2000mm x 3000mm (6ft6in x 10ft) and 2000mm x 6000mm (6ft6in x 20ft), varying between manufacturers, in thicknesses from 3mm to 8mm (0.118-0.3mm). When opaque colours are used, rather than the translucent or clear types, hook-on fixings can be bonded to the rear face of the panel with structural silicones. The panel can then be attached to vertically- or horizontally-set rails without the fixings being visible. An alternative fixing method is to fix the panels through the front face as visible fixings. Panels are set onto continuous rails, running vertically or horizontally, which are positioned behind the panels. A layer of EPDM or silicone is set between the panels and framing to provide a smooth consistent surface for the panels. The panels are fixed with screws from the front through holes pre-drilled in the panel. These screws then have a decorative capping applied, such as a dome head screw that is secured into the head of the fixing screw that is already in place.

Multi-wall polycarbonate sheet

Like flat sheet, multi-wall sheet can be used for rainscreens, where its main advantage is the ability to provide large, flat panels rather than its high level of thermal insulation. Thicknesses are from 4mm to 32mm (0.15-1.2in) in sheet sizes from 1000mm x 6000mm (3ft3in x 20ft) to 2000mm x 7000mm (6ft6in x 23ft). The material can be screen printed or coated to provide a wide variety of colours

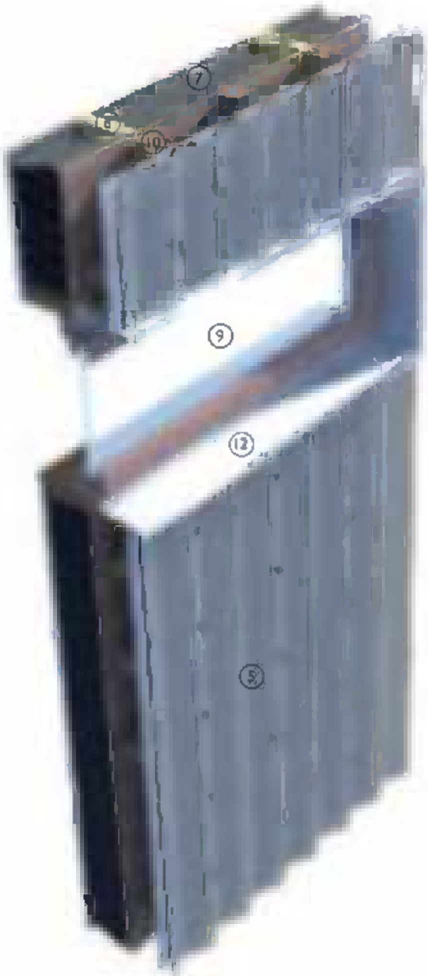


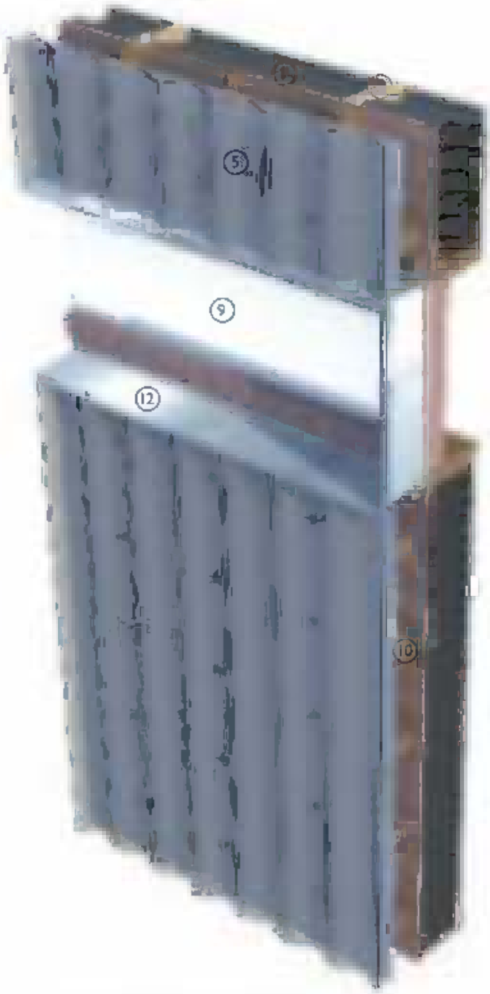
Vertical section 1:10 . Detail of polycarbonate rainscreen

Details

1. 10mm plywood sheathing
2. Breather membrance
3. Vertical timber battens
4. Reflective foil breather membrane
5. Profiled polycarbonate cladding (orientated vertically)
6. Composite timber joist
7. Thermal insualtion
8. Internal dry lining
9. Timber framed window
10. Horizontal timber battens
11. Screw fixing with plastic spacer
12. Aluminium window surround
13. Roof construction
14. Metal coping

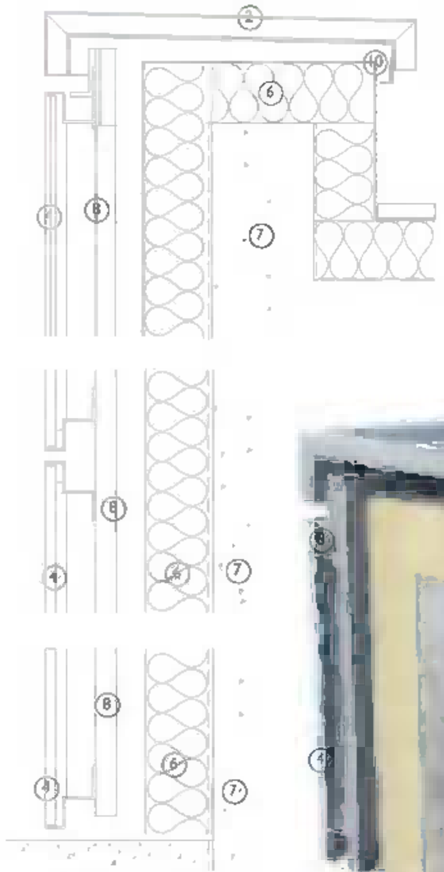
3-D section detail of polycarbonate rainscreen





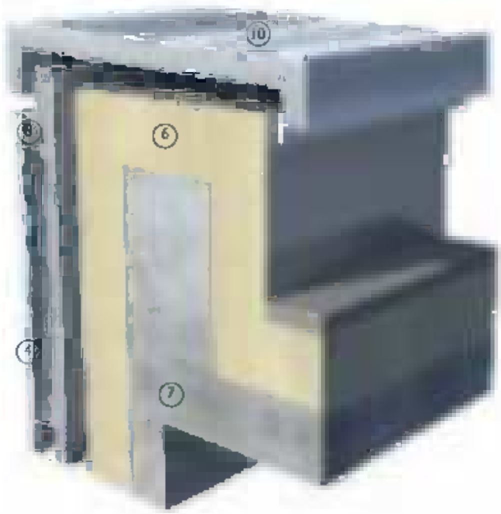
3-D section detail of polycarbonate rainscreen

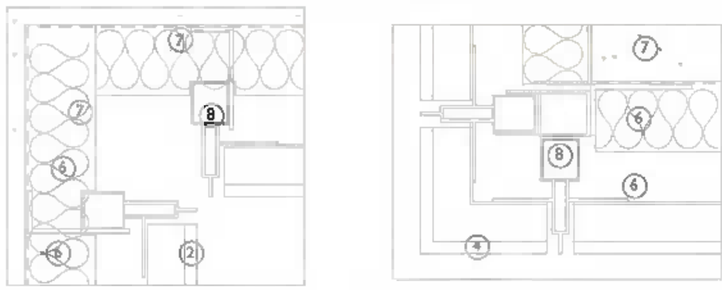
3-D view of parapet detail



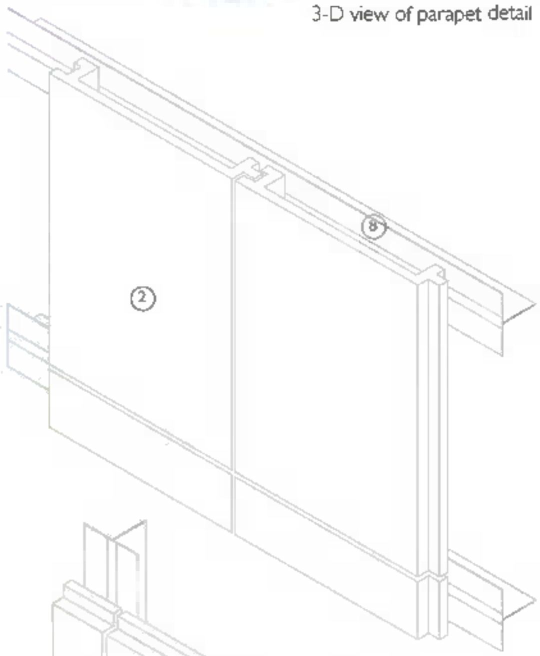
Section 1:10. Parapet detail, wall assembly and ground junction

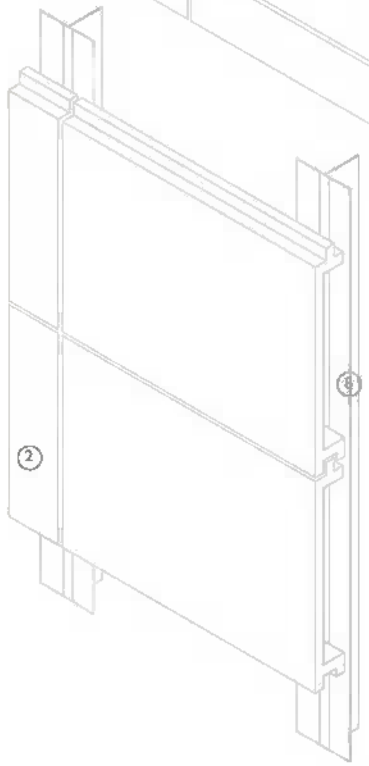
Details
1. UPVC section
2. Plastic-composite flat panels
3. UPVC board cladding
4. GRP cladding panel
5. Glazed unit
6. Thermal insulation
7. Backing wall
8. Support rails
9. UPVC window
10. Plastic-composite coping





Horizontal sections 1:10. Internal corner and external corner



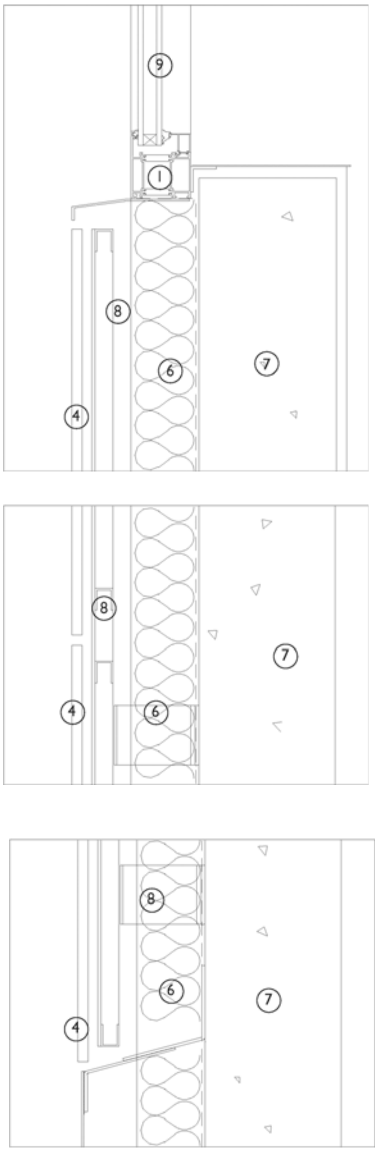


Isometric views of wall assembly:
1 Horizontally set supports, 2 Vertically set supports

on a large format sheet. As with flat sheet, the material can be coated to give UV protection on one side or both sides to avoid yellowing. The sheet material is used in increasing numbers of walls, from twin wall to five or six walls thick. Panels are fixed using the same methods as flat sheet, with thicker sheets being supported up to around 1800mm centres (6ft). Panels can be curved by setting them into a pre-formed aluminium edge frame, when the material can be curved to a minimum radius of 1500mm (5ft) for twin wall sheets and around 4000mm (13ft) for the thickest sheets.

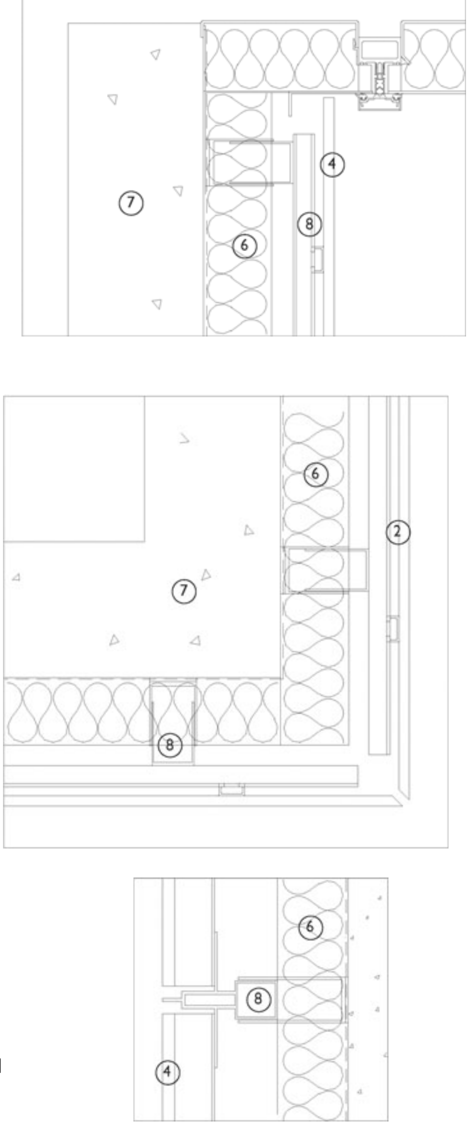
Profiled polycarbonate sheet

Profiled sheets are made from extruded polycarbonate resin, manufactured to provide transparent panels with around 90% light transmission, made to match steel and aluminium sheeting from other companies. They are used mainly to provide daylight in roofs and in wall cladding in industrial buildings without the need for special rooflight panels. Sheets are made in profiles to suit sheets by a particular manufacturer with whom they have an agreement. They are produced in both sinusoidal (curved) profiles and trapezoidal (zigzag) profiles in lengths up to around 10 metres (32ft) with thicknesses around 1mm. The width of most sheets is around 1200mm (4ft). They can also be used for rainscreen wall cladding, as a material in its own right. Vertically set sheeting is being used in city centre buildings, far from its use as an economic roofing material. Its high

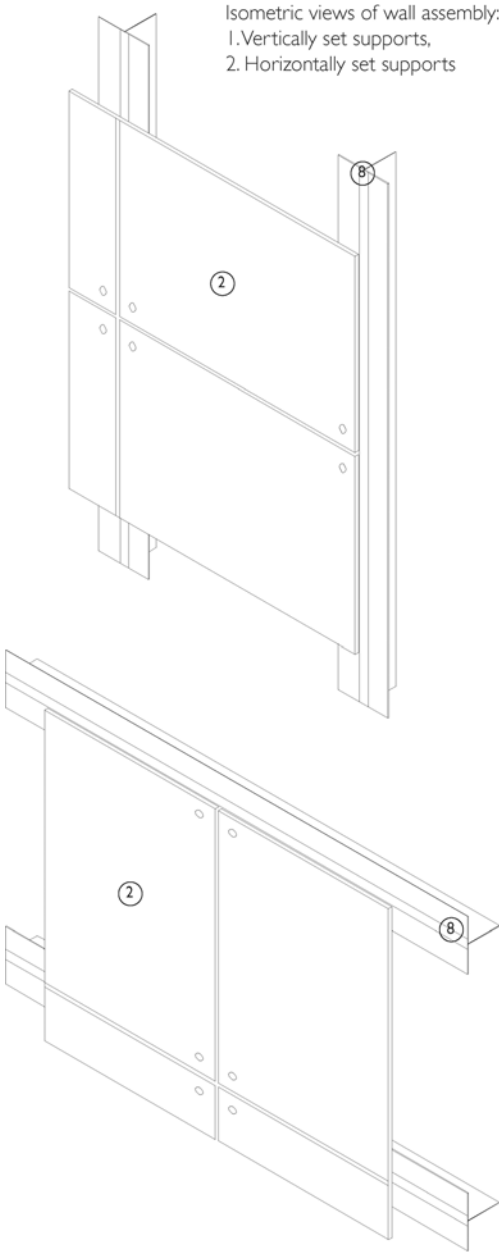


Vertical section 1:10. Window opening, ground level

Horizontal sections 1:10. Internal corner (top), external corner (middle), panel to panel junction (bottom)



Isometric views of wall assembly:
1. Vertically set supports,
2. Horizontally set supports

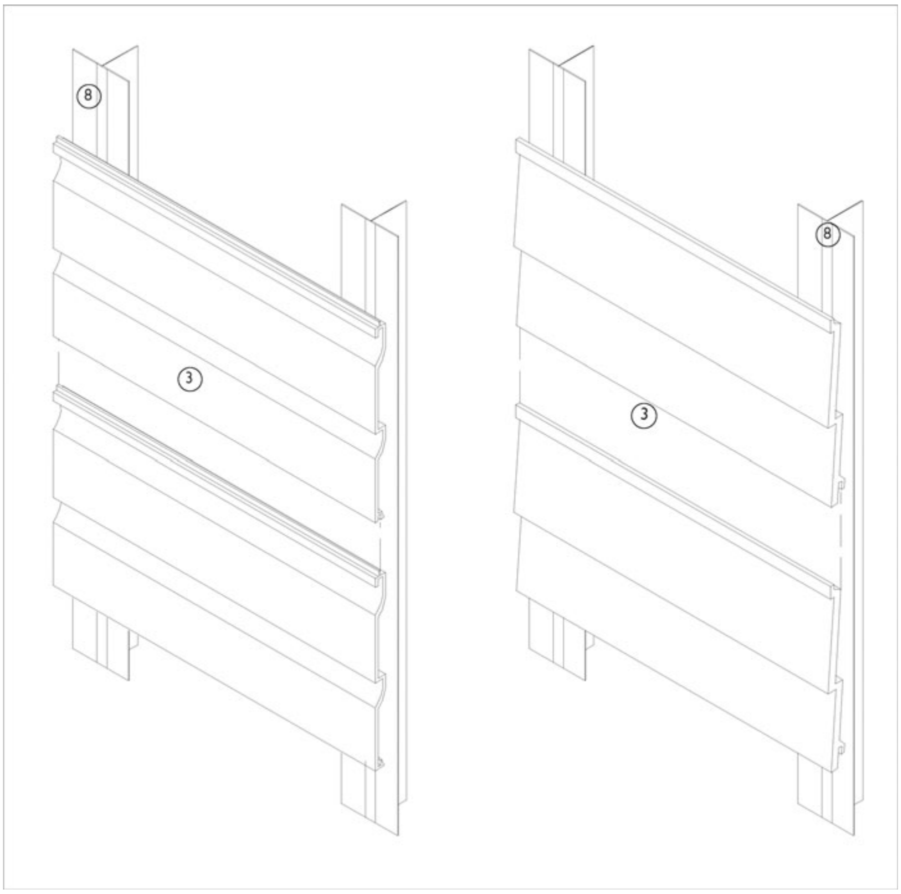


impact resistance, lightness in weight and long term high weather resistance make polycarbonate very suitable for dramatic cladding structures where weight is a critical issue. Profiled sheets are fixed with self-tapping sealed screws, with a watertight washer on the outside. More elaborate point fixings are difficult to use due to the profiled nature of the sheet, where a screw or bolt is attached through the peak or trough of the profile. Sheets are lapped on all sides, creating a shadow where they lap, which can be concealed by the support structure behind. Alternatively, sheets can be lapped in the horizontal direction, regardless of the sheet orientation, and can be joined by aluminium top hat profiles in the vertical direction in the manner of profiled metal sheeting. Cill, drip and coping profiles are made from either extruded UPVC, GRP or extruded aluminium. The material can be curved to a minimum radius of around 4000mm (13ft) for a sheet of 50mm (2in) thickness. Profiled polycarbonate sheet is also made in a translucent white colour to provide a light transmission of around 45% and in grey colours with light transmission of around 35%.

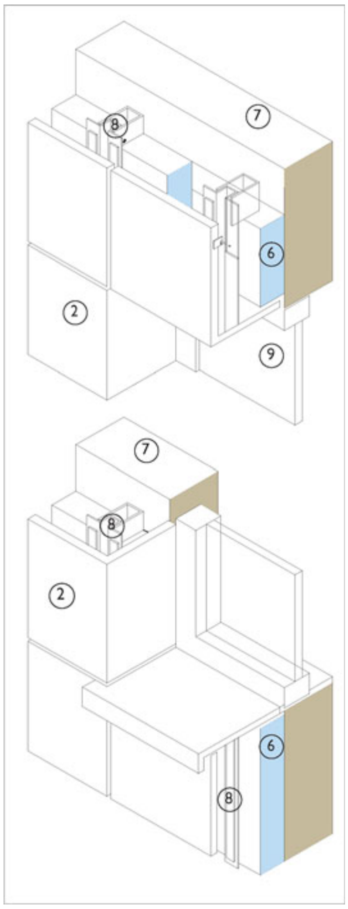
Plastic-composite flat panels

Flat panels can also be made from thermosetting resins mixed with cellulose fibres. This is usually a mixture of 70% softwood fibre and 30% resin, manufactured at high temperature and pressure. Panels can be coloured on one side, both sides or have different colours on each side. Panels are smooth with an

3-D view. External corner detail



Isometric views of wall assembly: 2 different UPVC board-type profiles



Isometric view of wall assembly: head and cill of window opening

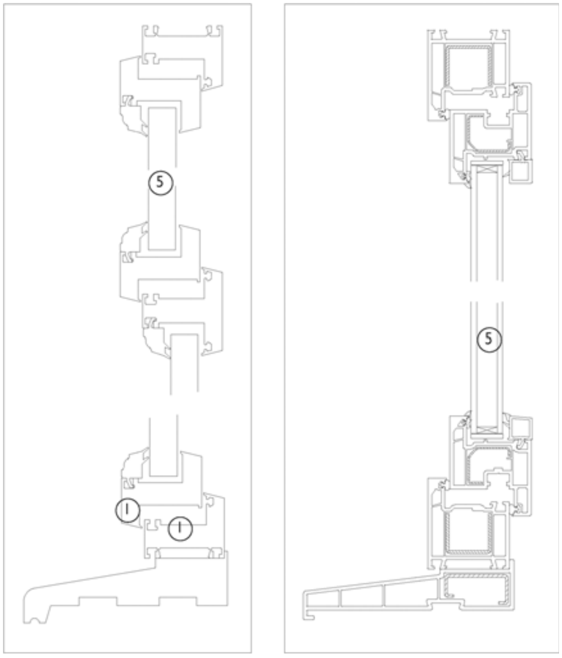
almost impervious sealed surface. Although the finish colour is formed by using pigmented resins as a top coat in the mould, sawn edges do not require repainting or protective cover since the colour extends all the way through the material. Rainscreen panels formed in this material are very resistant to the long term effects of weather, with high UV resistance and colour stability and high fire resistance. Plastic-composite flat panels can be cut drilled and routed on site, making it more like timber in terms of its flexibility during construction. Components do not all have to be cut off-site in a workshop. Because the sawn edges are smooth, they can be laid as overlapping tiles in the manner of timber shingles, a technique used in sheet metal cladding. Their high impact resistance and impervious surface make them well suited to demanding conditions where damage can occur easily. The material is made in sheet sizes from 3600mm x 1800mm (12ft x 6ft), 3000mm x 1500mm (10ft x 5ft) and 2500mm x 1800mm (8ft x 6ft)in thicknesses from around 5mm to 12mm (0.25-0.5in). Corner panels and parapets are also manufactured in the same material. Plastic-composite flat panels can be fixed with visible fixings or concealed fixings used for flat sheet and multi-wall polycarbonate sheet.

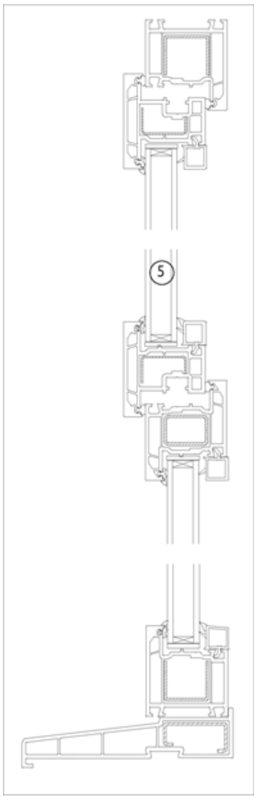
UPVC Board cladding

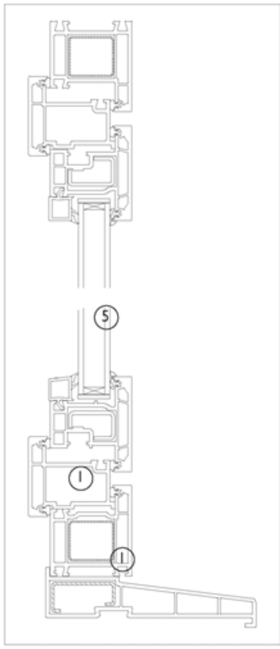
Extruded UPVC boards are used as a substitute for timber cladding, and are often fixed back to a timber frame in the same way as timber boarding. Although the main advantage of this material is its low maintenance when compared to painted timber boards, the material is beginning to be used in its own right, without the imitation of the language of timber wall cladding. Boards are made as extrusions in lengths up to around 5000mm (16ft), in widths from 250mm to 300mm (10-12in). Thicknesses match those of timber boarding at 18-20mm (around 0.7in). Boards are nailed back to timber frames or screwed back to aluminium frames and are fixed at around 600mm (2ft) along the length of the panels. Manufacturers have specially formed corner pieces in a range of angles to suit typical situations of 45° angles both internally and externally. Corners can also be glued with solvent adhesives or sealed with silicone sealants. Other components specially made for UPVC cladding include end covers for the exposed ends of extrusions, flashings for cills, copings and window surrounds. Boards are fixed back to battens that provide a ventilated void behind to allow the boards to function as a rainscreen. Where the supporting wall is timber framed, as is typically the case, this wall is faced in a waterproof membrane with plywood sheathing behind that forms part of a timber stud wall. UPVC board cladding provides a high level of thermal insulation, with U-values at around 0.15 W/m2 °C. UPVC boards are subject to relatively high levels of thermal expansion when compared to GRP, at 7x10-5 per °C for UPVC (like polycarbonate) and 2.5x10-5per °C for GRP. A length of UPVC at 3000mm (10ft) long will expand about 6mm (0.25in) with a 25°C increase in its temperature.

UPVC windows

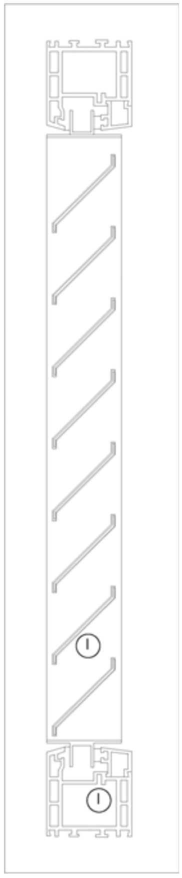
Extruded UPVC windows are used for windows, typically in rainscreen panels in plastic-

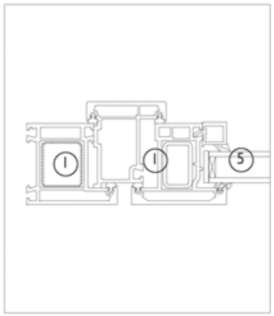






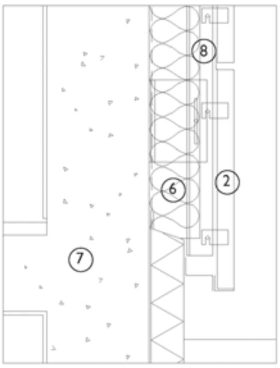
Vertical sections 1:10. Window at head and cill, louvre

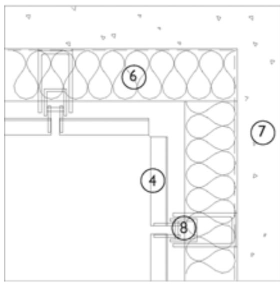




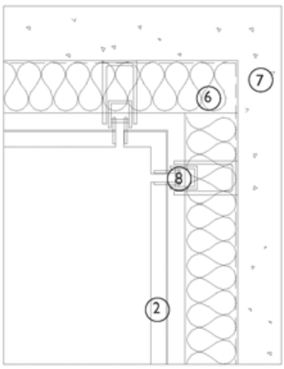
Horizontal section 1:10. Window, louvre

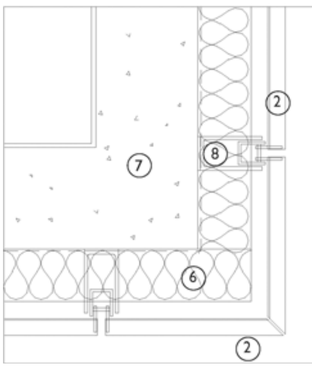
Vertical section 1:10. Junction with ground



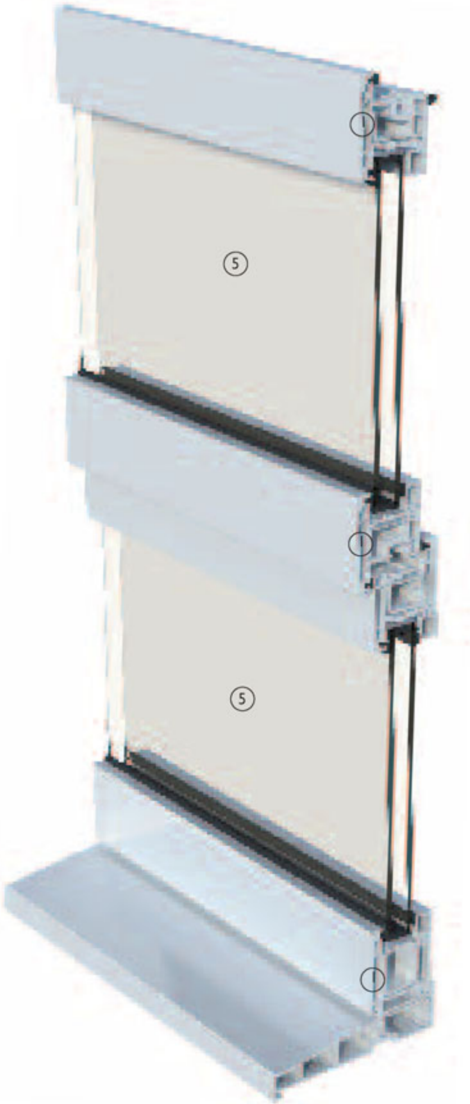


Horizontal section 1:10. Window jamb, internal corner





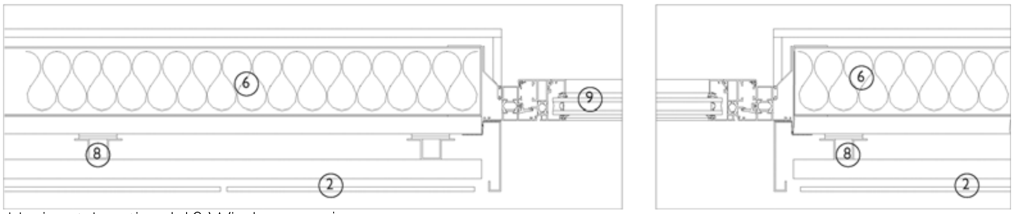
Horizontal sections 1:10. Internal corner, external corner



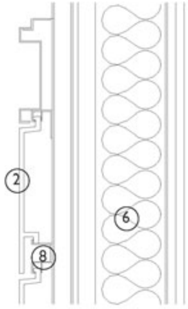
3-D view of UPVC window

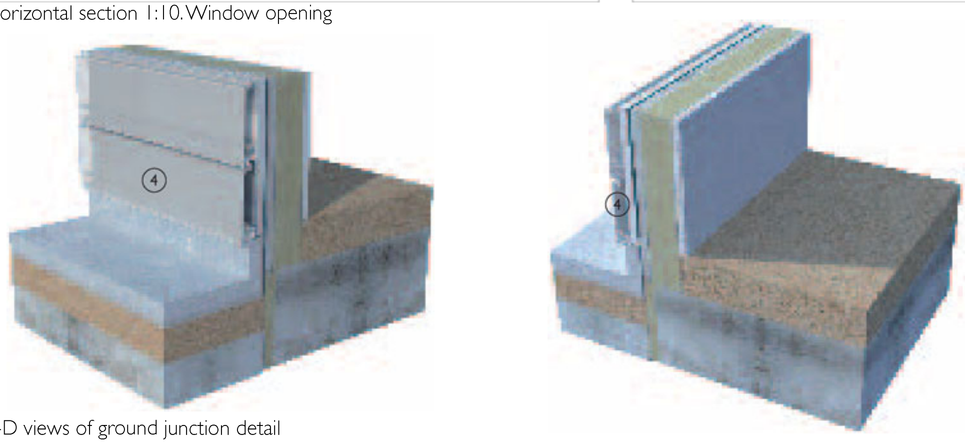
Details

1. UPVC section
2. Plastic-composite flat panels
3. UPVC board cladding
4. GRP cladding panel
5. Glazed unit
6. Thermal insulation
7. Backing wall
8. Support rails
9. UPVC window
10. Plastic-composite coping



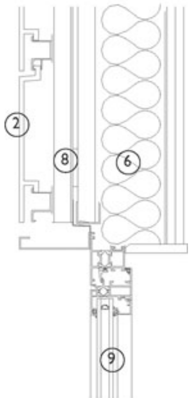
Horizontal section 1:10. Window opening

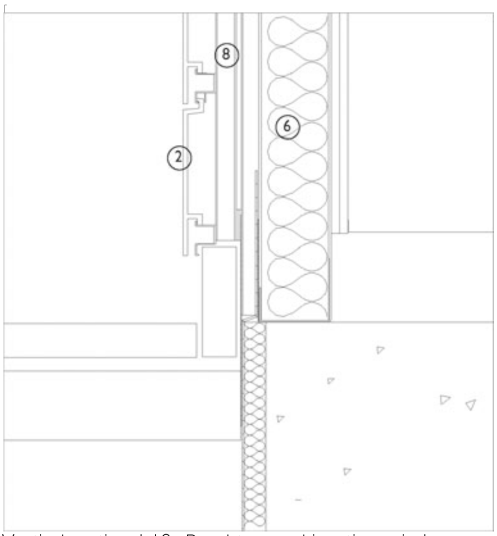


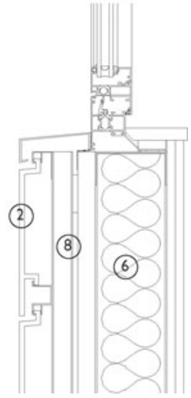


3-D views of ground junction detail

Details
1. UPVC section
2. Plastic-composite flat panels
3. UPVC board cladding
4. GRP cladding panel
5. Glazed unit
6. Thermal insulation
7. Backing wall
8. Support rails
9. UPVC window
10. Plastic-composite coping







Vertical section 1:10. Panel-to-panel junction, window opening, ground level

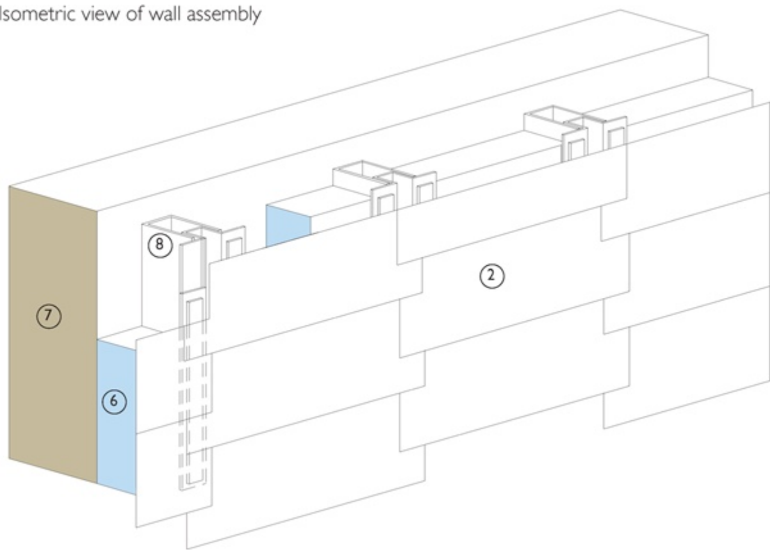
3-D views of window opening in plastic rainscreen

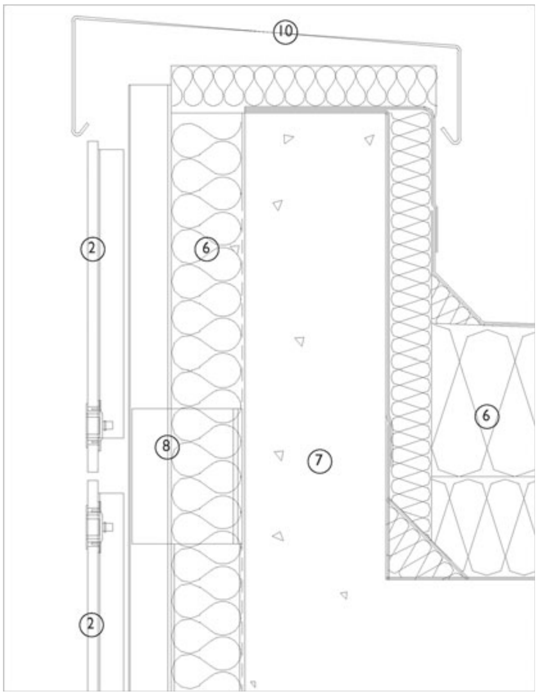
based materials. UPVC can be extruded to provide complex and accurate sections that can be appreciably more economic than those in aluminium. The material has a much lower thermal conductivity than aluminium, and so requires no additional thermal break. Windows have an inner chamber which is drained and ventilated in the manner of aluminium windows, with rubber-based seals providing the necessary air seals. Windows are typically sealed with silicone around their edges. U-values for window frames can reach as low as 1.4 W/m2 °C, which is comparable with highly insulated double glazed units. Some UPVC window sections have a galvanised steel internal core reinforcement to stiffen the frames, usually as folded sections that are held by the walls of the extrusion. Corners of frames are bonded together to avoid corrosion of the steel sections. UPVC windows have developed considerably in recent years with higher impact resistance and higher crack resistance, particularly in the low winter temperatures where the material is more vulnerable.

GRP panels

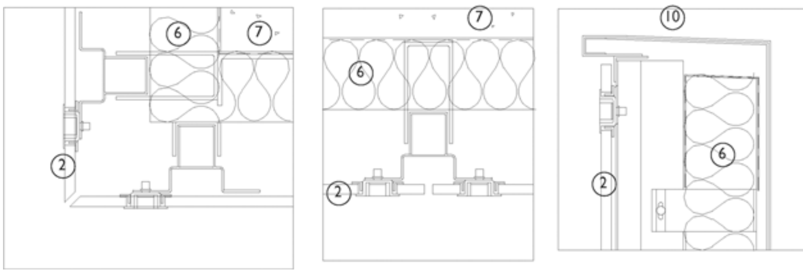
Polycarbonate is generally a more expensive material than GRP, making GRP more suitable for lower cost applications. However, GRP has one advantage over all the other plastic-based materials, which is its ability to be moulded easily and economically. When used as rainscreen panels the material needs a top gel coat to avoid its fibres being seen. The ability to see the fibres through the material make it very unsuitable for transparent or translucent panels, but for moulded rain-

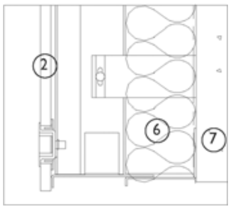
Isometric view of wall assembly



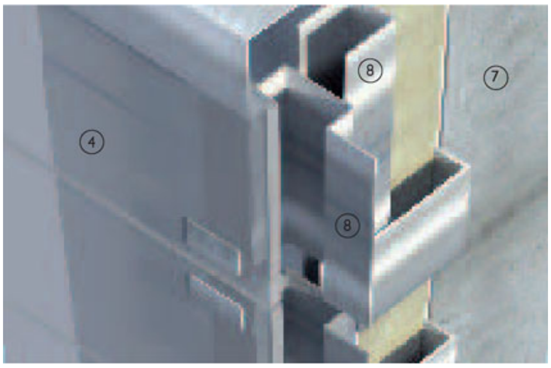


Vertical section 1:10. Parapet condition





Horizontal sections 1:10.
External corner,
panel-to-panel junction



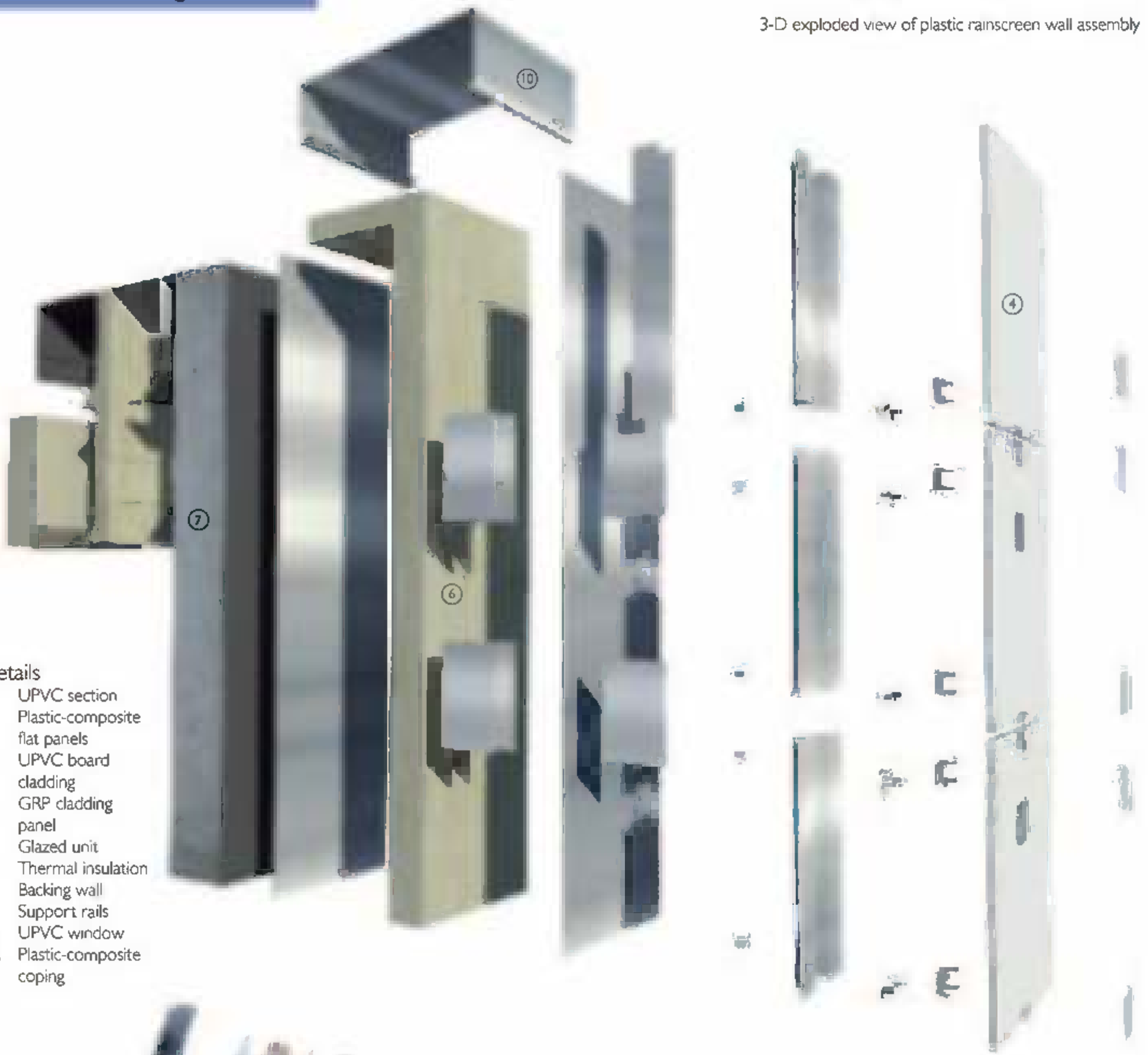
screen panels it is possible to introduce some 3D modelling into the facade panels. GRP can be bonded to honeycomb panels formed in the same material to produce large panels with high fire resistance. The face of the panel can be screen printed to any design, with the use of photographic images being increasingly popular.

3-D view of possible fixing method detail

3-D cut-away view of parapet condition and possible panel fixing method

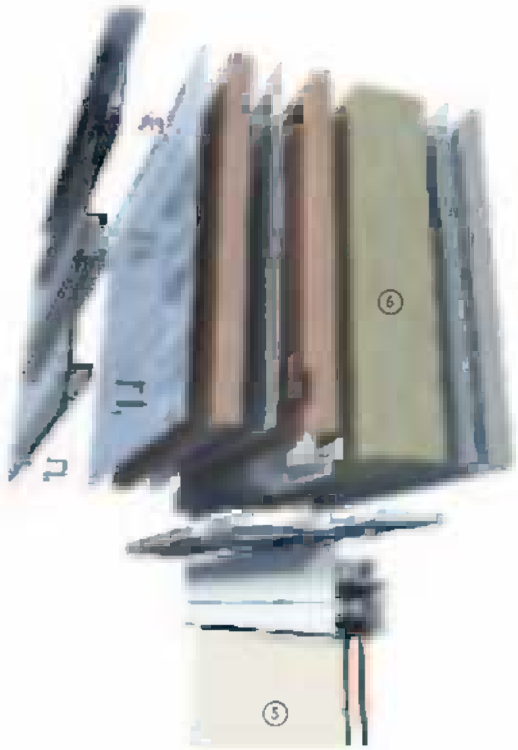
Details
1. UPVC section
2. Plastic-composite flat panels
3. UPVC board cladding
4. GRP cladding panel
5. Glazed unit
6. Thermal insulation
7. Backing wall
8. Support rails
9. UPVC window
10. Plastic-composite coping

3-D exploded view of plastic rainscreen wall assembly

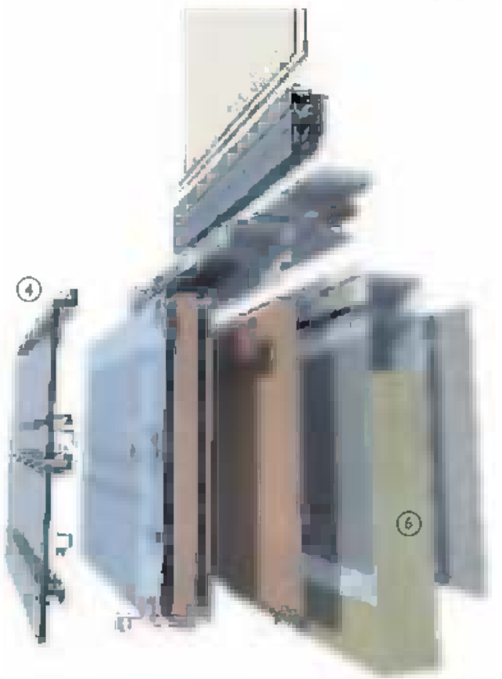


Details

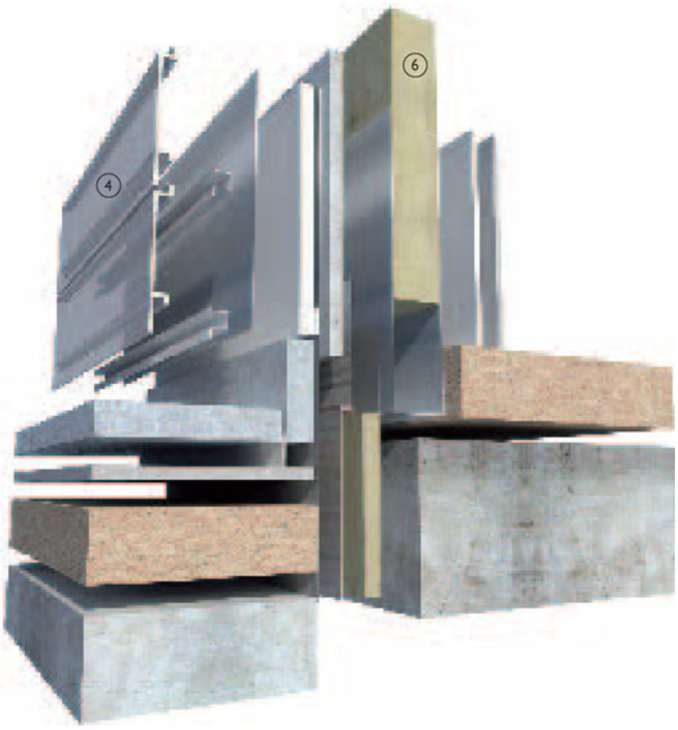
1. UPVC section
2. Plastic-composite flat panels
3. UPVC board cladding
4. GRP cladding panel
5. Glazed unit
6. Thermal insulation
7. Backing wall
8. Support rails
9. UPVC window
10. Plastic-composite coping



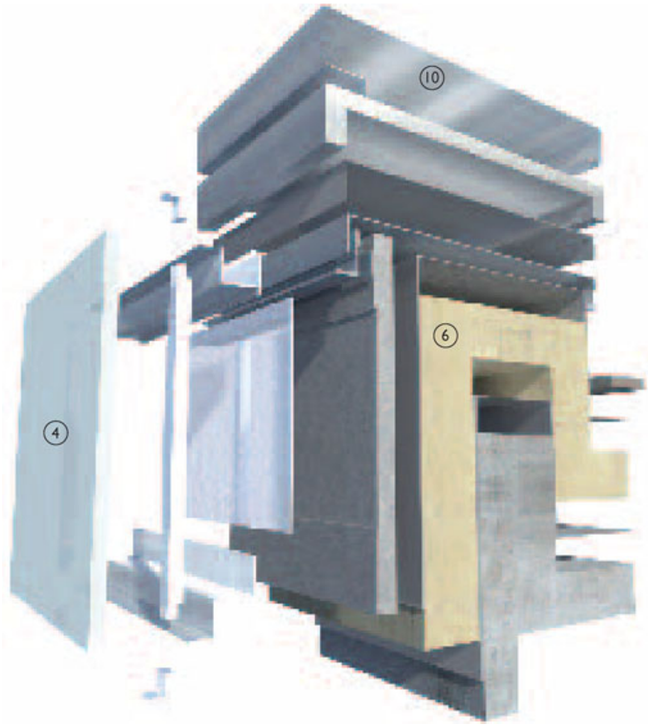
3-D exploded view of top of window opening in plastic rainscreen wall assembly



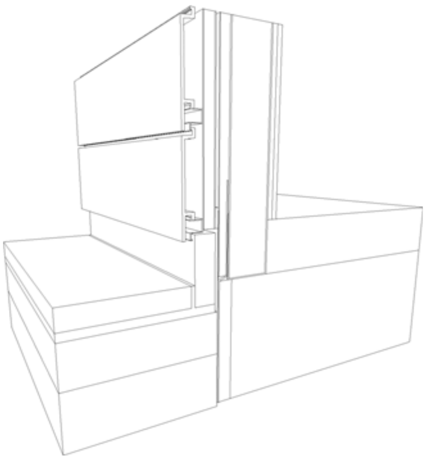
3-D exploded view of bottom of window opening in plastic rainscreen wall assembly

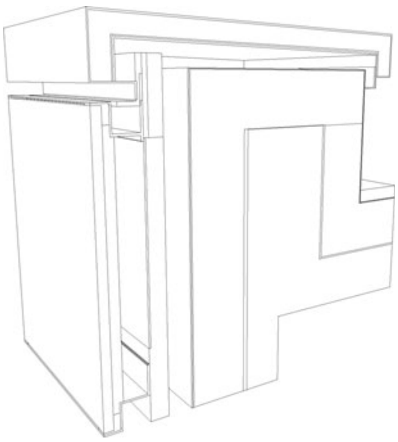


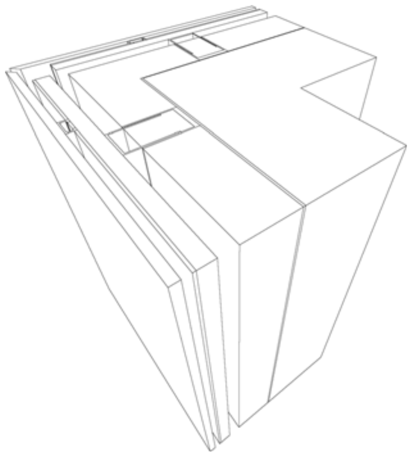
3-D exploded view of ground junction in plastic rainscreen assembly

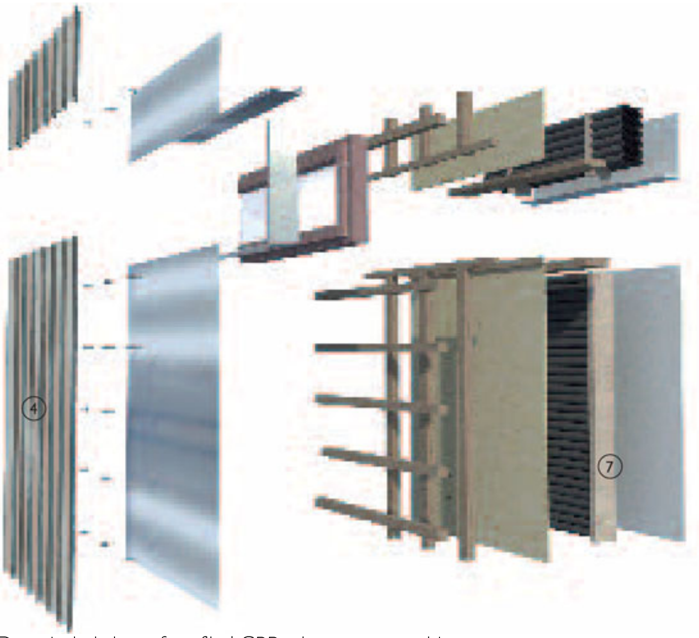


3-D exploded view of parapet condition in plastic rainscreen assembly

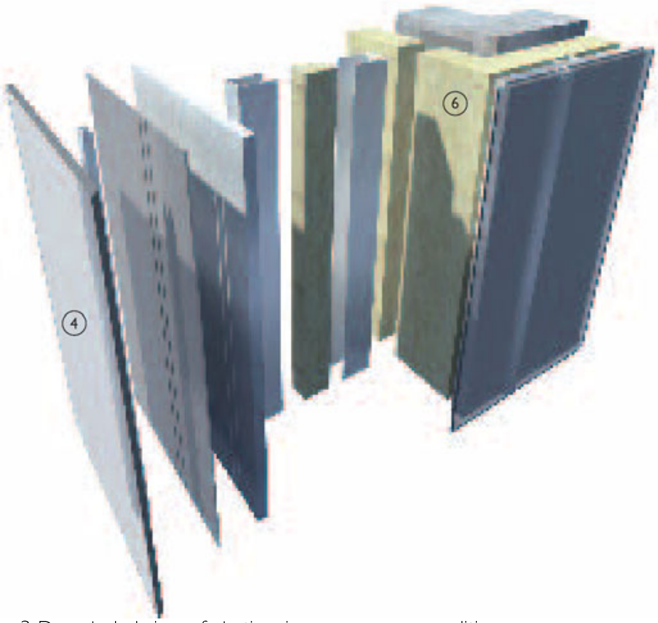

3-D view of ground junction in plastic rainscreen assembly


3-D view of parapet condition in plastic rainscreen assembly


3-D view of corner detail in plastic rainscreen assembly



3-D exploded view of profiled GRP rainscreen assembly

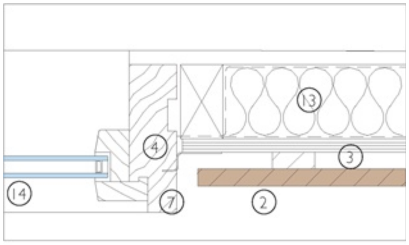


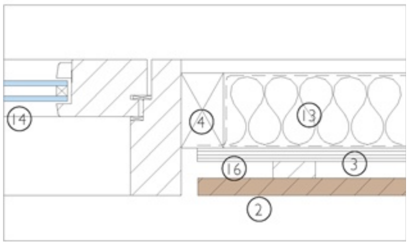
3-D exploded view of plastic rainscreen corner condition

6

TIMBER WALLS

Horizontal section 1:25. Window openings





Horizontal section 1:10. Window jambs

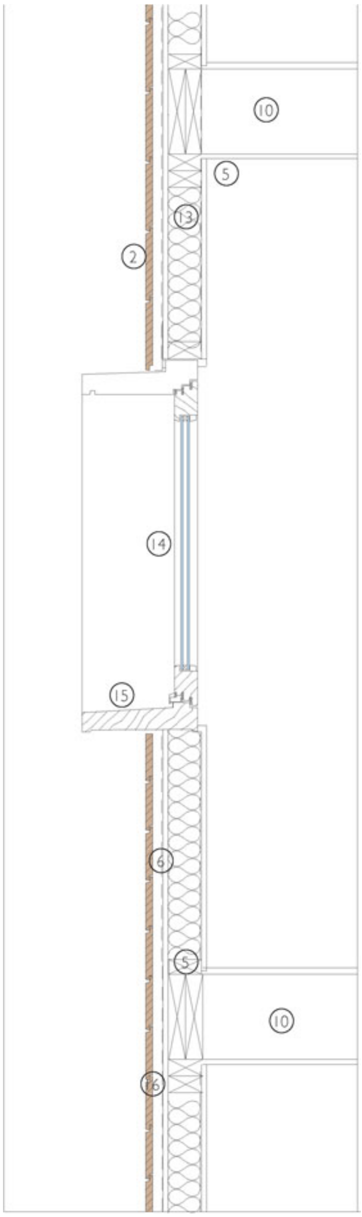
3-D view of window jamb

Timber cladding has traditionally been used on loadbearing timber framed walls, as discussed in this section. Its more recent application as cladding panels and as rainscreens is discussed in the second section of this chapter. There are two traditional generic forms of timber frame that use small section timbers to form framed loadbearing walls: the platform frame and the balloon frame. More historical types that use large timber sections with an infill in timber or another material are not discussed here, as their application is currently very limited. Both the platform frame and the balloon frame are based on softwood sawn timber sections around 100mmx50mm (4inx2in). These are economic, and set at close centres of around 400mm (16in) in order to be a multiple dimension of plywood sheets and related board materials used to form the sheathing for the walls and floor decking. Since the floor joists are set at the same centres as the vertical studs, board materials are used for the floor decking in the same size. The platform frame comprises studs spanning from floor to floor, with the timber floor structure being supported at each storey height set of timber frames. The balloon frame, which is now used less, is enjoying a revival in light gauge steel sections. This method has vertical framing members which are continuous, with the intermediary floors being supported by the wall running continuously past it.

Timber frames

Timber frames comprise vertical sections called 'studs' fixed to horizontal members called 'rails'. The studs run vertically continuously, with discontinuous horizontal members which are called 'noggins'. The outer face of the timber frame is clad with plywood sheathing to provide lateral bracing, typically 12mm-18mm thick (0.5in-0.75in), depending on the structural requirement of stiffening the frame. Timber boards can also be used as sheathing, this is an expensive solution. Framing members are typically formed from 100x50mm (4inx2in) softwood sections at 400mm (16in) vertical centres which are nailed together. Mild steel corner brackets and cleats are commonly used to make the connections more reliable and easy to form, either on-site or in a workshop. Voids between the framing members are filled with thermal insulation. A breather membrane is then fixed to the face of the sheathing layer. This provides a waterproof barrier which also allows the vapour to escape to allow the timber wall to release and absorb moisture with changes in the weather. Outer timber cladding boards are then fixed on the outside of the breather membrane.

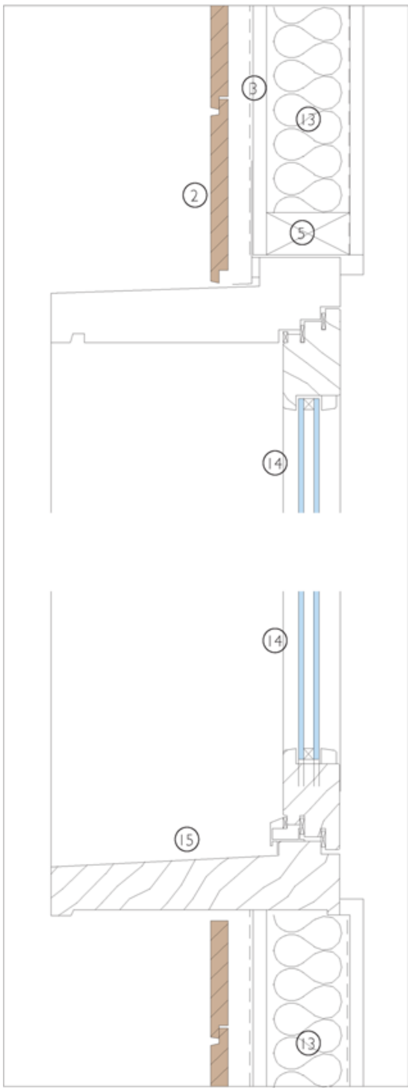
When timber cladding is used on timber frames, the softwood stud walls that form the wall structure can use the timber cladding to stiffen the wall. Traditionally, this has been done by fixing the boarding directly to the timber frame, with a breather membrane set between the frame and the timber boards to allow the outer cladding to 'breathe', or dry out and absorb moisture, in response to the changes in weather conditions. Alternatively, the timber boards are fixed to battens which are set forward of the breather membrane, or waterproofing layer, to ensure that the timber is ventilated on all sides. When battens are used, the timber boards are less able to stiffen the frame if the battens are not set



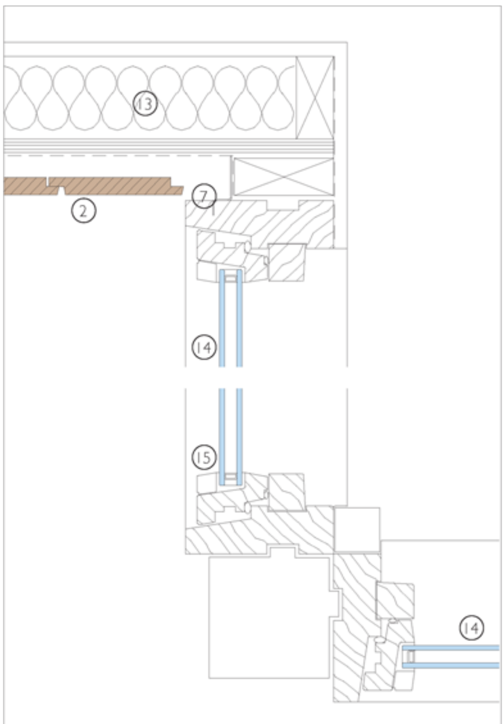
Vertical section 1:25. Window opening

Details

1. Metal parapet flashing
2. Timber boards
3. Plywood sheathing
4. Timber studs
5. Timber rail
6. Breather membrane
7. Window flashing
8. Damp proof course
9. Vapour barrier
10. Timber floor
11. Concrete ground slab
12. Internal plaster finish or dry lining/dry wall
13. Thermal insulation quilt set within timber frame
14. Timber framed window/door
15. Timber cill
16. Air gap

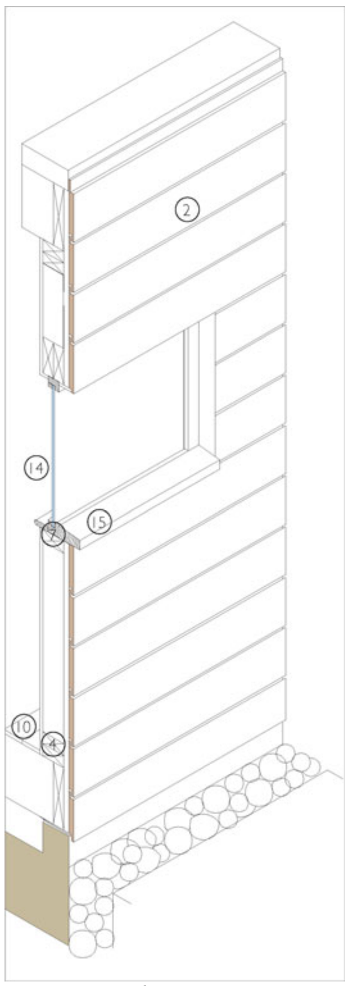


Vertical section 1:10.
Floor junction, window opening

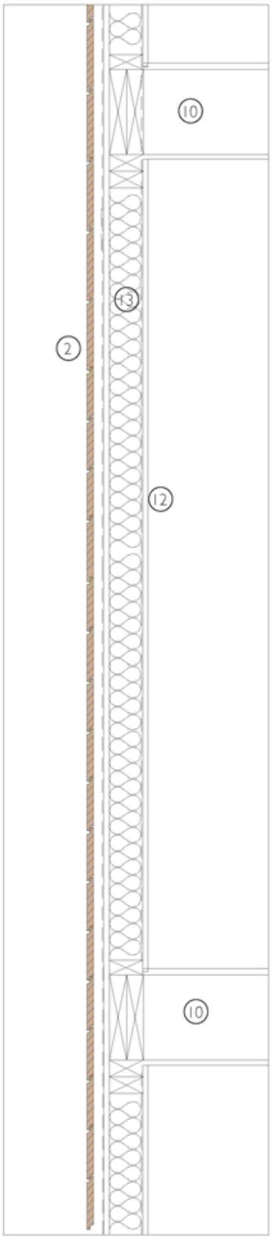


Horizontal section 1:10. Window jamb

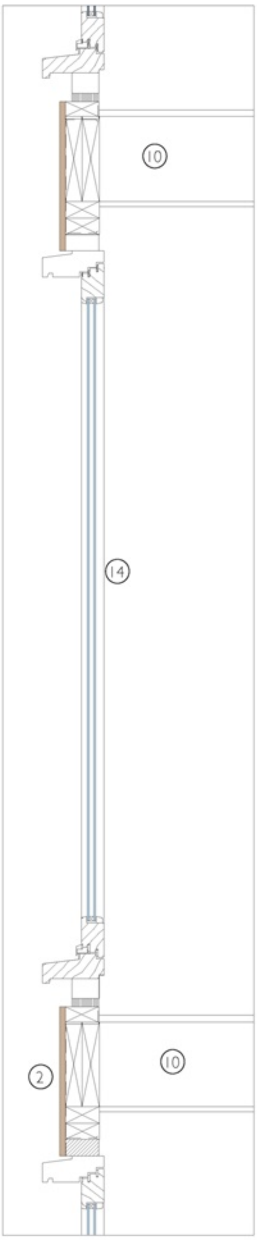
3-D view of window opening



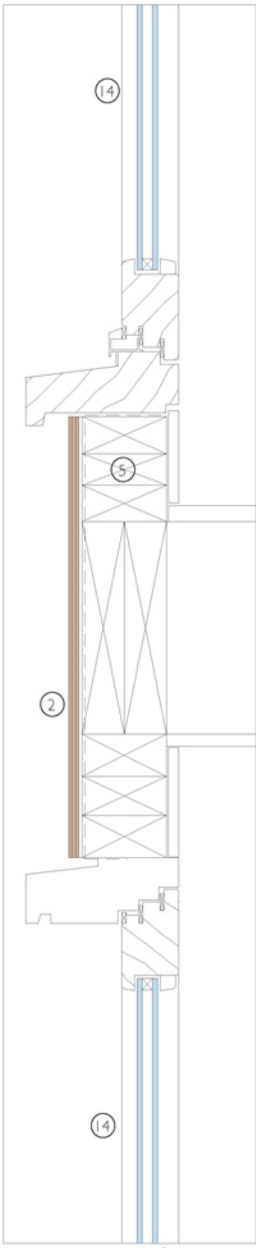
Isometric view of wall assembly



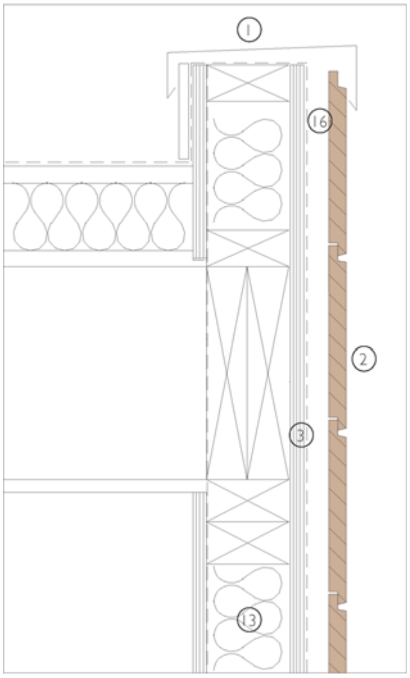
Vertical section 1:25
Wall assembly



Vertical section 1:25
Door opening



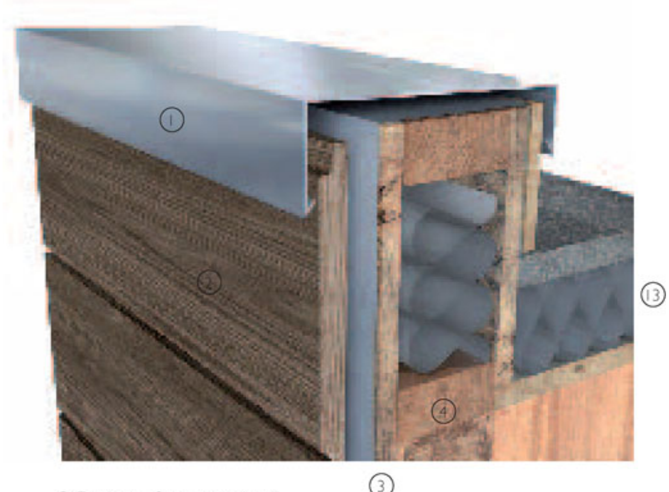
Vertical section 1:10.
Door opening



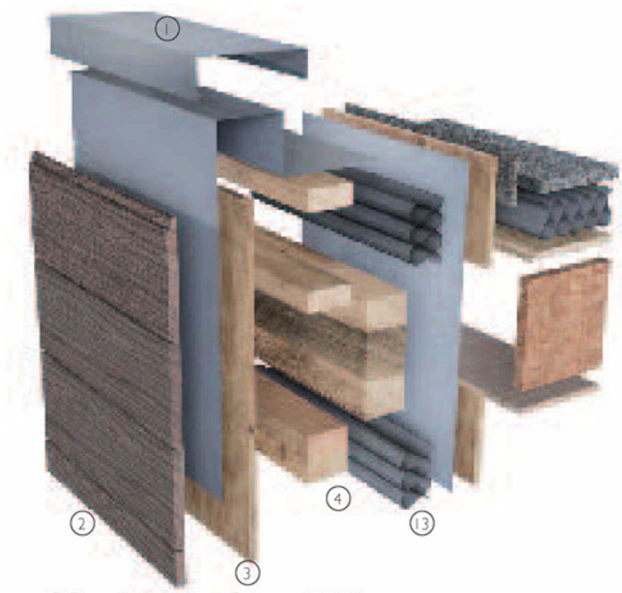
Vertical section 1:10.
Parapet

Details

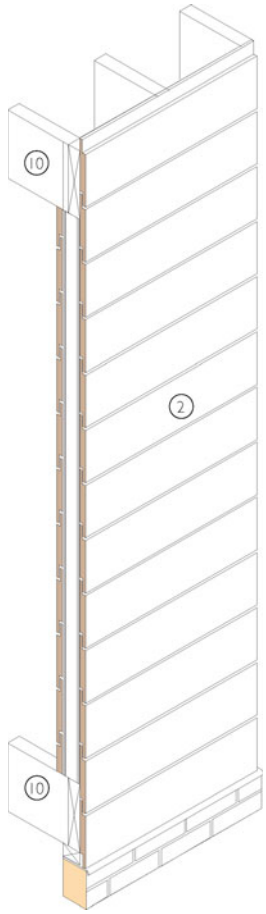
1. Metal parapet flashing
2. Timber boards
3. Plywood sheathing
4. Timber studs
5. Timber rail
6. Breather membrane
7. Window flashing
8. Damp proof course
9. Vapour barrier
10. Timber floor
11. Concrete ground slab
12. Internal plaster finish or dry lining/dry wall
13. Thermal insulation quilt set within timber frame
14. Timber framed window/door
15. Timber cill
16. Air gap



3-D view of parapet detail

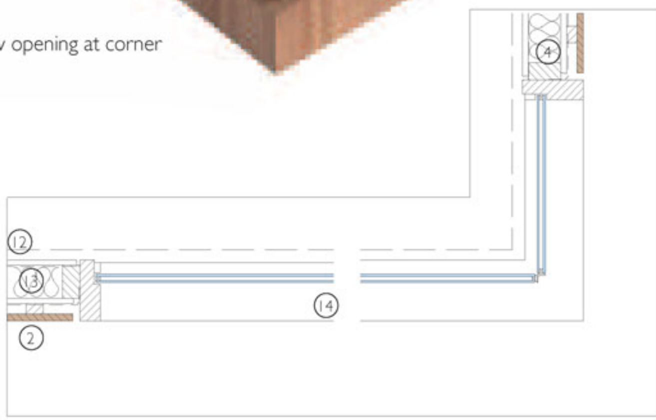


3-D exploded view of parapet detail



Isometric view of wall assembly

3-D view of window opening at corner



Horizontal section 1:25. Window opening at corner

in alignment with every stud forming the frame of the wall behind.

The inside face of the timber framed wall has a continuous vapour barrier, typically thick polythene sheet, set onto it, in temperate climates, on the 'warm in winter' side of the wall. The inner face of the wall is then finished with plasterboard (drywall) to provide an internal finish.

Ground level

This text focuses on different conditions at ground level, upper floor levels and at roof level. The lightweight nature of timber cladding has led to its use with a raised timber ground floor, often with no concrete ground slab. This makes the junction with the ground quite different from those of the other materials described in this book. Details around windows and doors are as those described in the section on timber window walls in the Glass chapter.

Timber cladding at ground level stops a minimum of 150mm (6in) above external ground level to avoid rainwater splashing up the timber, which would cause staining and deterioration of the material. Cladding is usually supported at ground level on a concrete slab or edge beam that forms part of the concrete wall. Alternatively, the wall can span between concrete pads at 3000mm-5000mm centres (10ft-16ft), with timber beams at the base of the wall to provide support between pads. Where a concrete slab is used, the edge of the slab has traditionally been exposed as a base to the wall. With increasing concerns of increased thermal insulation at the ground level of a building, thermal insulation has been introduced on the visible edge of the slab between ground level and the base of timber cladding. The insulation requires an outer protection to the insulation, typically thin concrete slab or brickwork.

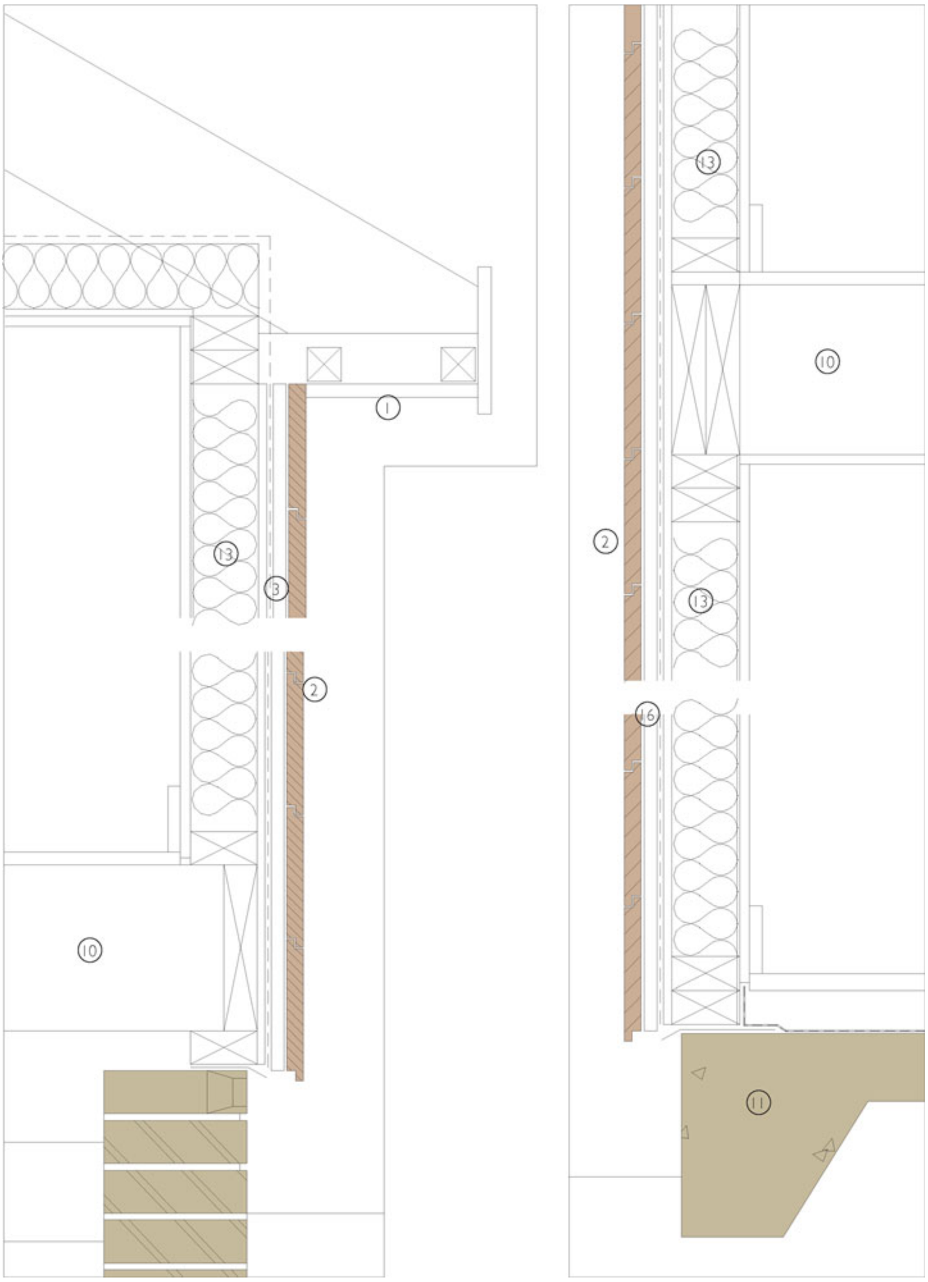
The timber wall frame is not fixed directly to the floor slab but instead is usually set on a continuous timber section, which is first fixed to the concrete slab to provide both a level surface to set the timber in place and to be an easier fixing to use than simply nailing. A damp proof course (DPC) is set beneath the continuous timber base plate to protect the timber, the DPC usually extending down the vertical face of the concrete slab where it connects with the damp proof membrane (DPM) beneath the concrete slab or the vertical face of the basement wall. The DPC will also be continuous with a DPM set on top of the concrete slab. Floor finishes are then applied in the same depth as the continuous baseplate, allowing internal skirting boards to be fixed to the bottom rail of the timber frame, which sits at the finished floor level. Where concrete pads are used, the timber beam is set into stainless steel shoes which are fixed to the concrete pads. The pads may extend below ground level to form foundations where the ground is allowed to continue underneath the building. Alternatively, the panels may sit on a concrete floor slab set below the timber ground floor to prevent the growth of any vegetation beneath the raised ground floor. Gravel is often set at ground level in the void below a raised timber floor. Door thresholds at ground level

Details

1. Metal parapet flashing
2. Timber boards
3. Plywood sheathing
4. Timber studs
5. Timber rail
6. Breather membrane
7. Window flashing
8. Damp proof course
9. Vapour barrier
10. Timber floor
11. Concrete ground slab
12. Internal plaster finish or dry lining/dry wall
13. Thermal insulation quilt set within timber frame
14. Timber framed window/door
15. Timber cill
16. Air gap

3-D view of ground condition

3-D view of ground condition



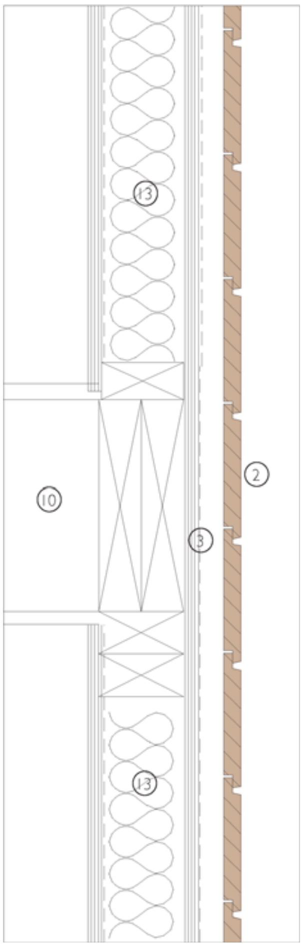
Vertical sections 1:10. Floor junction, eaves to pitched roof, two ground conditions

usually have a raised profile to prevent water from penetrating through the opening, and these are also fixed directly onto the continuous baseplate. An additional DPC is set on top of the baseplate to avoid moisture penetration through the door threshold.

Timber can also be supported on brick walls set at a minimum of 150mm (6in) above external ground level and be supported on a concrete strip foundation or ground beam. As bricks go below ground they usually change to either a dense concrete block or a dense engineering quality brick. A raised floor is then set into this brick wall. The void beneath the timber floor is ventilated with air bricks that encourage cross ventilation. This avoids stagnant air in the void from damaging and eventually rotting the timber floor. Instead of supporting the floor on the brick wall, floors can be supported separately as pads, typically in mild galvanised or stainless steel posts. This allows the ground floor slabs to be built before the timber wall is started, and avoids any risk of long term damage to the floor joists from contact with a damp wall below DPC level. An alternative method of supporting the low level brickwork is on stainless steel lintels spanning between the concrete pads that support the timber floor. The brick base can be avoided completely by the use of beams spanning between concrete panels as described previously.

Upper floors

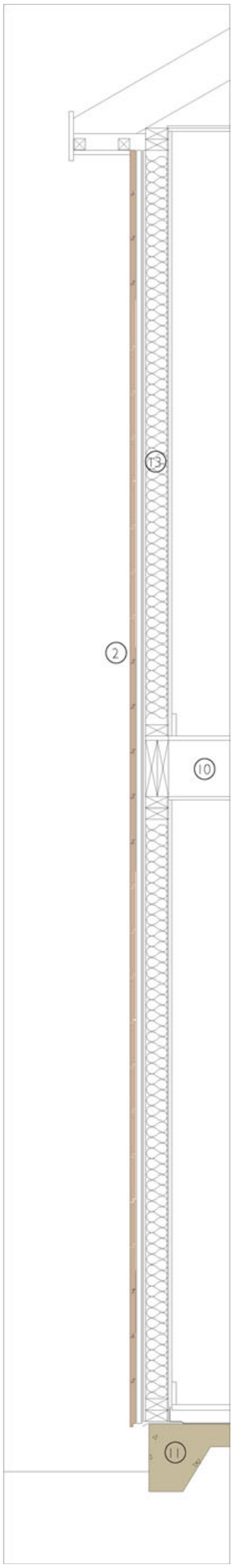
Timber framed wall panels are used to support upper floors also in timber. Floor joists are set directly into the timber frame, where they are supported, either on the top of the



Vertical section 1:10. Floor junction

3-D view of floor to wall junction

3-D view of floor to wall junction

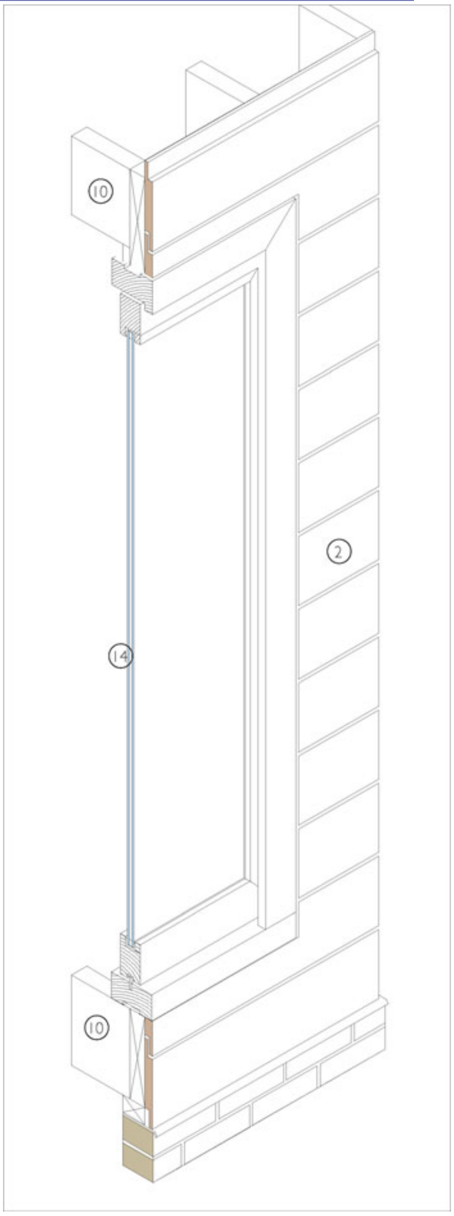


Vertical section 1:25. Wall assembly

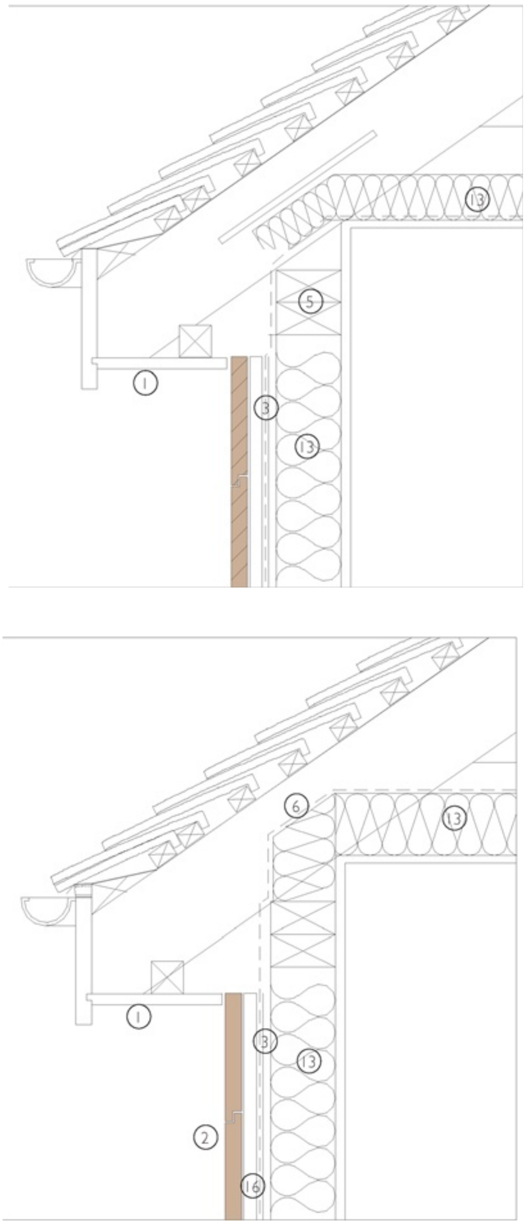
floor-height panel below, or to the sides of the timber studs if the floor extends over two or more floors in the balloon frame. Where timber wall frames span only from floor to floor, as is more commonly the case, floor joists are fixed to the face of timber beams that form part of the wall frame instead of penetrating the frame itself. This allows the gap between wall and floor to be filled with timber, which drastically reduces sound transmission between floors. Because the timber floor and wall form a continuous structure, there is no need to form a horizontal movement in the timber cladding outside. This gives the continuous surface of timber cladding across two or three floors that is characteristic of platform frame construction.

Corners

The most common corner formed in timber cladding is a single timber bead set so that the timber boards on both sides butt into the corner bead. If a breather membrane is used behind the cladding, then an additional waterproof flashing is added to the corner. This is formed in a durable polymer-based sheet or metal sheet. Alternatively, the boards can be allowed to make a corner with a butt joint, and an additional L-shaped timber trim, formed from two separate timber sections, is added on the face of the corner to protect the exposed end grain of one of the sides forming the corner. These trims also provide a visual tidiness to the corners. Boards can be joined with a mitred joint (45°) without any cover strip but the timber used must be of the highest quality to avoid the joint opening



Isometric view of wall assembly



Vertical sections 1:10. Two eaves conditions to pitched roofs

Details
1. Metal parapet flashing
2. Timber boards
3. Plywood sheathing
4. Timber studs
5. Timber rail
6. Breather membrane
7. Window flashing
8. Damp proof course
9. Vapour barrier
10. Timber floor
11. Concrete ground slab
12. Internal plaster finish or dry lining/dry wall
13. Thermal insulation quilt set within timber frame
14. Timber framed window/door
15. Timber cill
16. Air gap

up with moisture movement, and very high levels of workmanship are required. A waterproof layer or flashing behind the mitred joint is essential to the waterproofing performance of this detail. Internal corners are formed using the same sets of timber beads or mitred joints.

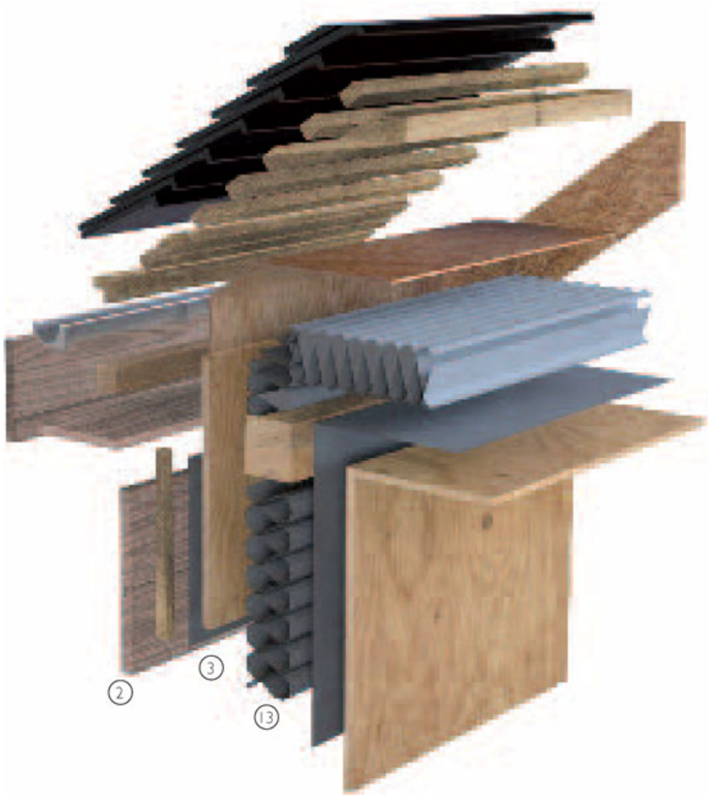
Roof eaves and parapets

Overhanging eaves from pitched roofs or flat roofs are very common with timber cladding as they provide protection to the wall beneath from the worst effects of weathering from water running directly down the facade. A continuous timber section, or wallplate, is set on top of the timber frame, creating a double thickness of timber at the top of the wall. This serves as a base for sloping rafters or for flat joists. For large scale roof structures, deeper timber sections are used, set on end, as used for connections to upper floor structures. The waterproof layer on the outside of the timber framing, or breather membrane, is made continuous with that of the roof structure. In the case of overhanging eaves, the roof may be ventilated or be sealed, but in both cases the membranes must be continuous to avoid water penetrating the joint. On the inside face of the wall, the vapour barrier must be continuous from wall to roof, or wall to ceiling level, beneath the roof.

3-D view of eaves condition

3-D exploded view of eaves condition

3-D view of eaves condition



3-D exploded view of eaves condition

3-D view of timber framed wall with two openings

3-D view of timber wall construction

-D exploded view of timber framed wall with two openings

Details

1. Metal parapet flashing
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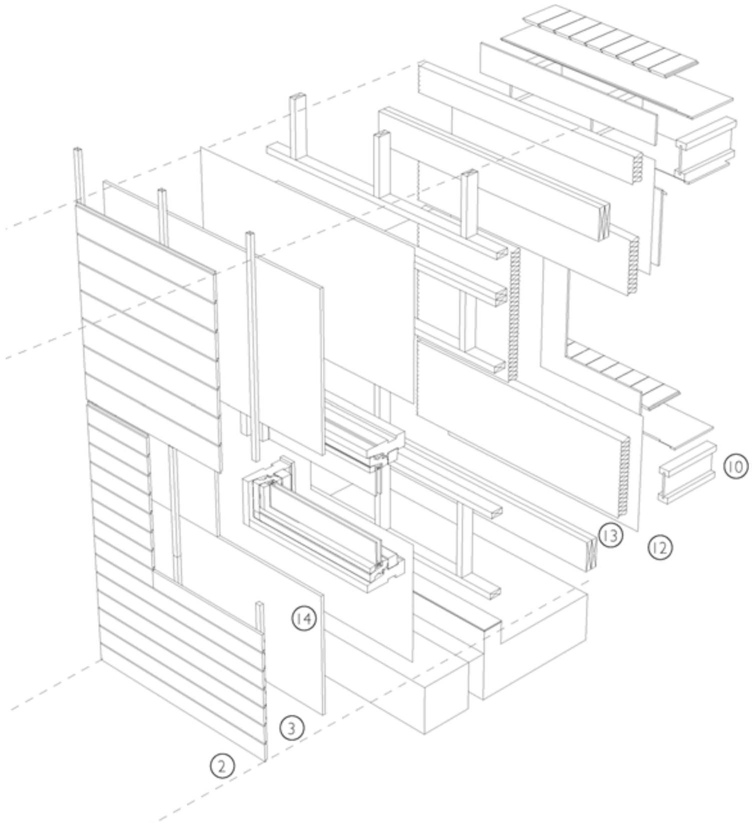
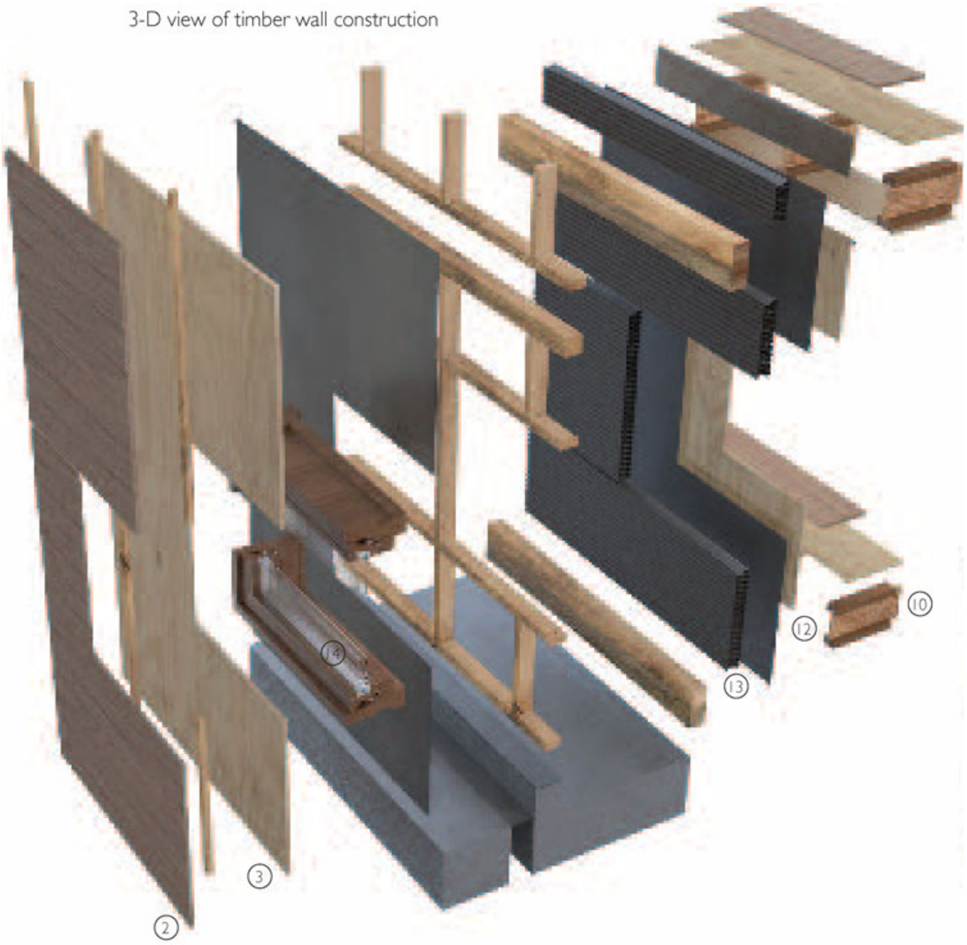
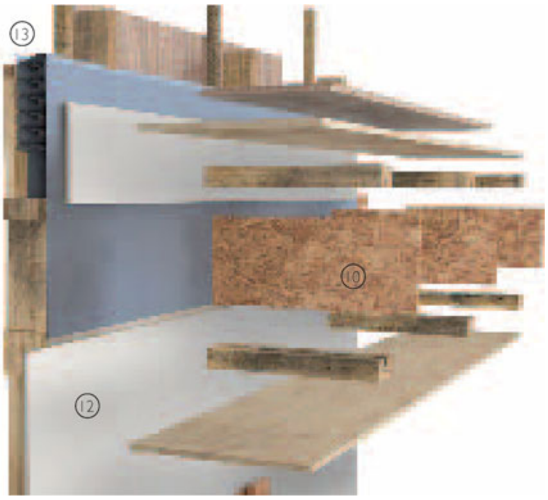
3-D view of timber wall construction



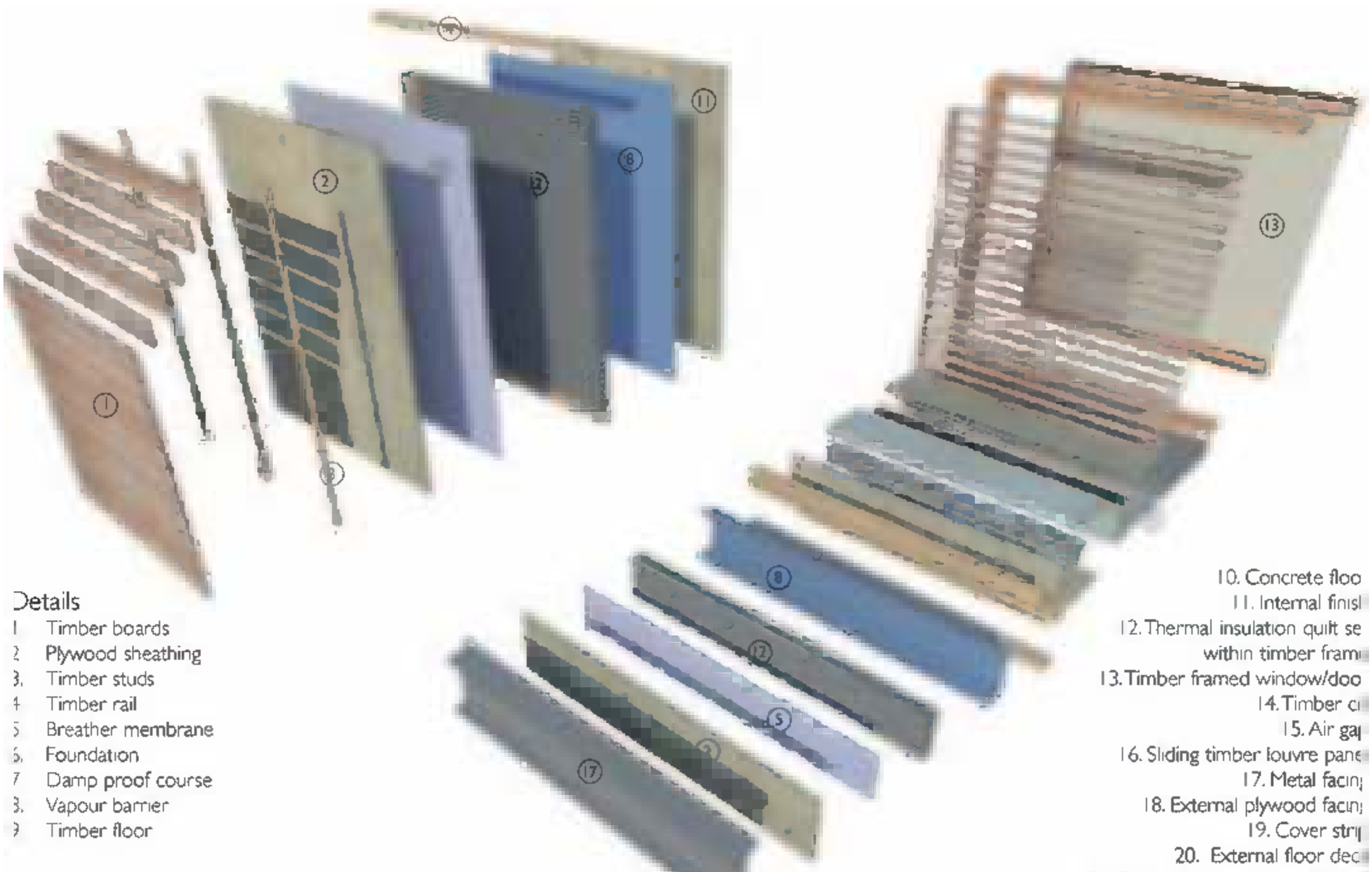
Exploded axonometric drawing of timber wall construction



3-D exploded view of timber wall construction



3-D exploded view of floor to wall junction



Exploded diagram showing assembly of timber cladding panels

Timber boards

Timber boards for cladding panels and rainscreens are sawn and are available in many timber species, though environmental concerns have led to an increasing preference for locally-grown timber for large-scale applications. This is because timber has a negative effect on CO_2 levels, reducing the levels in the atmosphere. The CO_2 emissions created as a result of cutting and working timber before it reaches a local building site are still less than the amount of CO_2 consumed by the timber during its growth. The highest timber grades are used for wall cladding boards, since exposure to the weather will involve considerable temperature and humidity variations, as well as fading in sunlight. Softwoods are generally used for the cladding of timber frames, with hardwoods being more commonly used for cladding panel and rainscreen applications. Where hardwoods are used, those species that are naturally durable are used. Where less expensive, less durable timbers are used, these require higher levels of finishing and maintenance. For softwoods, preservative treatment is used, but with an increasing scrutiny of the methods, since some preservatives can damage ground around the site as a result of water run-off from the timber into the ground around the timber wall. Softwood boards are made usually in 250mm (10in) widths, with trimmed boards with profiles routed into them usually trimmed down to 150mm - 200mm widths (6in-8in). Wider boards cannot generally be used due to the risk of the material curving in section.

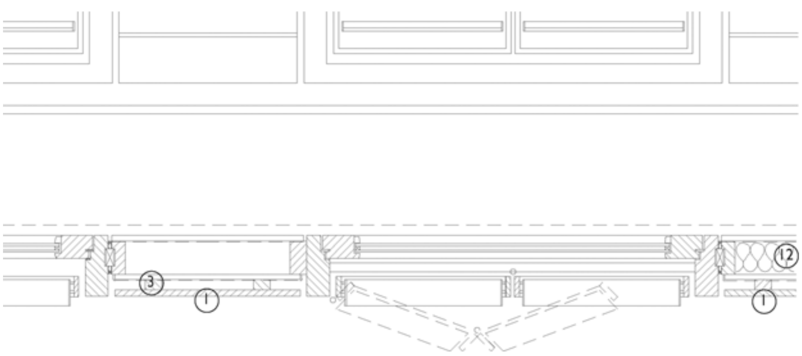
The increased use of hardwoods in rainscreens, for their durability, has led to different thicknesses and sections of timber being used. This has led to the increased use of louvred timber screens and panels in front of glazed windows and doors to provide solar protection while contributing to the texture of the timber facade.

All timbers vary in moisture content with changes in temperature and air humidity, this being one of the essential aspects to be considered in timber detailing. Most timbers used in cladding will have a moisture content from around 5% to 20% when in use. Similar levels are found in timbers from timber suppliers, and are classified as 'dry', 'kiln dried' or 'seasoned'. However, some softwoods are supplied unseasoned, depending on the supplier, so the amount of timber drying and seasoning is critical to the way that timber is cut on site to fit a junction. Unseasoned timber will shrink as it dries, and consequently an allowance is made for later shrinkage by increasing the overlap between timbers where applicable, or making tighter butt joints where these are used. Unseasoned timbers are fixed in place soon after delivery to site to avoid any twisting or warping of the timber. As a result, lapped boards are not nailed together where they overlap, and nails and screws are secured so that the timber can move without the timber splitting or being damaged.

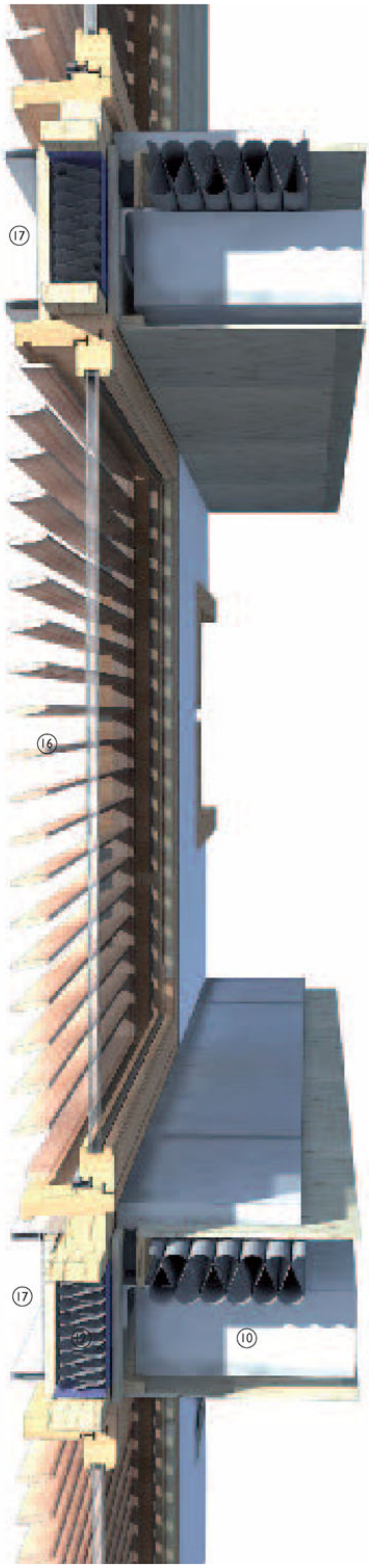
Finishes

Timber cladding is finished with the timber being left either as supplied, with preservative applied or injected by the supplier, or alternatively is given coats of preservative in clear,

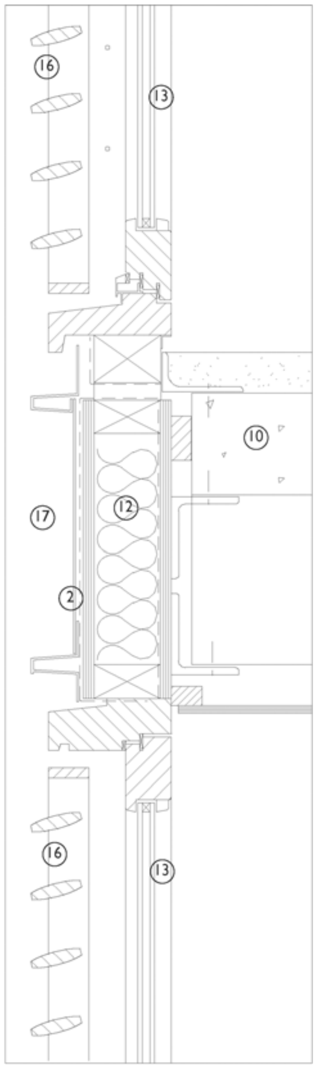
3-D Elevation. Timber cladding panels and relationship with structural frame



Horizontal sections 1:25. Cladding panel in twin wall configuration for taller buildings

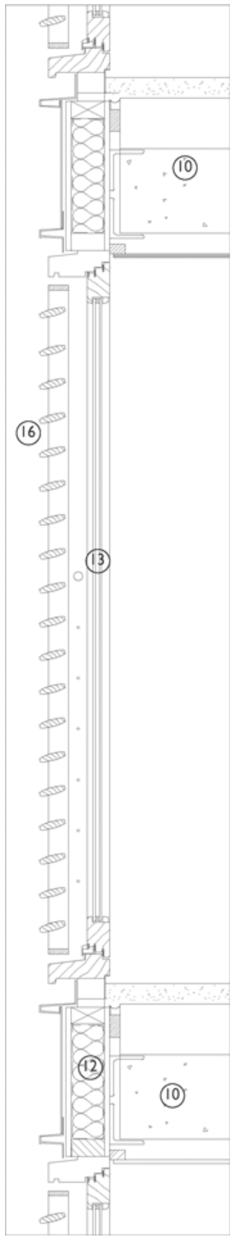


3-D sectional view of timber louvre cladding panel and junction with upper floors

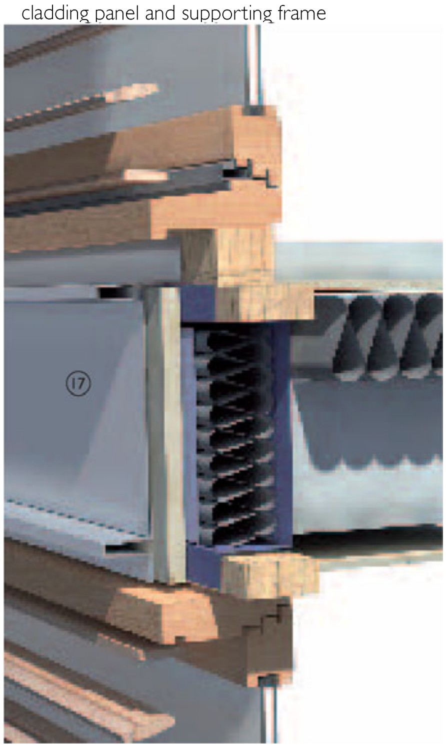


Vertical section 1:10. Junction with floor slabs

Right: - Vertical section 1:10. Timber louvre cladding panels and typical assembly

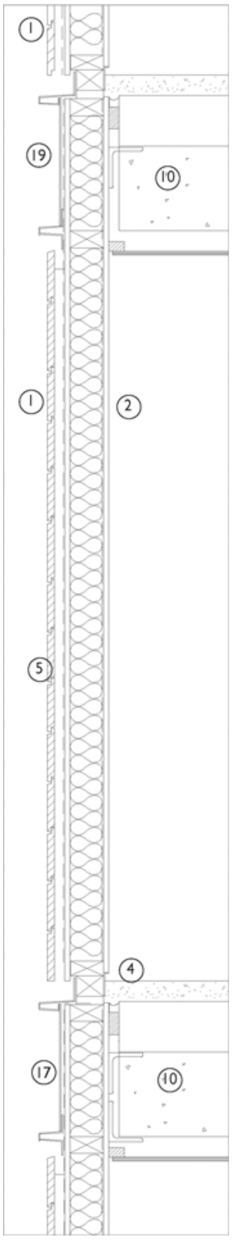


3-D views showing connection between timber cladding panel and supporting frame

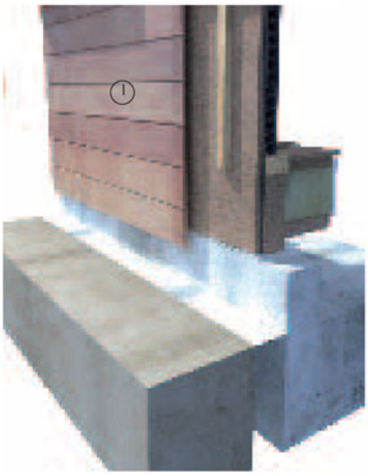


stained, or opaque finish on site with preservatives that repel rainwater, or wood stains and paint. Paints can be oil-based or acrylic, while preservatives are clear and can be used as a finish that penetrates the depth of the wood without appreciably changing its appearance. It can also be used before staining or painting the timber. Preservatives help to prevent moisture absorption as well as reduce fungal growth. This is because they enhance the life of the timber but do not prevent the material changing colour and fading to a silver grey appearance. Site-applied finishes and regular maintenance help overcome the effects of the weathering of timber.

In addition to the use of preservatives and coatings, the orientation of timber boards is critical to the long term performance of timber cladding. The most common types of jointing of boards is 'shiplapping' where timber boards are set horizontally and lapped over one another with the upper board lapped over the top of the board below to protect it from rainwater ingress. Shiplapping can be assisted by the use of 'feathered' or wedge-shaped boards to give the lapping a more elegant appearance. Tongue-and-groove boards are used to give a continuous flat appearance, while having the advantage of locking boards together into a continuous plate-like structure. Boards are typically around 20mm (0.75in) thick, made as long as possible at around 3000mm - 3500mm (10ft-11ft6in), to avoid vertical joints which are a potential source of rainwater penetration except in rainscreen configuration. Where tongue-and-groove boards are used, the groove is set on the underside to



Details
1. Timber boards
2. Plywood sheathing
3. Timber studs
4. Timber rail
5. Breather membrane
6. Foundation
7. Damp proof course
8. Vapour barrier
9. Timber floor
10. Concrete floor
11. Internal finish
12. Thermal insulation quilt set within timber frame
13. Timber framed window/door
14. Timber cill
15. Air gap
16. Sliding timber louvre panel
17. Metal facing
18. External plywood facing
19. Cover strip
20. External floor deck
21. External glass wall in twin wall
22. Structural timber frame



3-D view showing ground floor junction

Left:- Vertical section 1:10. Timber board cladding panels and typical assembly

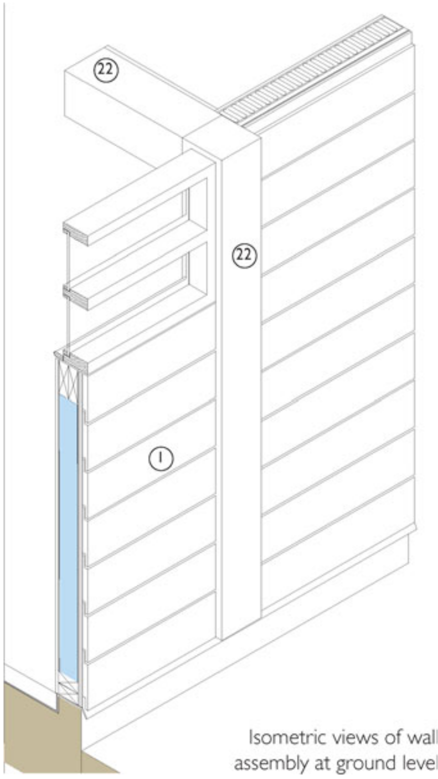
3-D view of cladding panel assembly with built-in opening window

avoid water accumulating when the boards are set horizontally or diagonally. Where tongue-and-groove boards are set vertically, the groove is set away from the prevailing wind direction to avoid windblown rain being blown into the joint. Joints between boards are never sealed along their long edges with silicone or mastic sealants as this prevents the timber from drying properly, which would cause the material to deteriorate and eventually rot. However, sealants are used on the ends of timber boards when the complete external surface is sealed with paint.

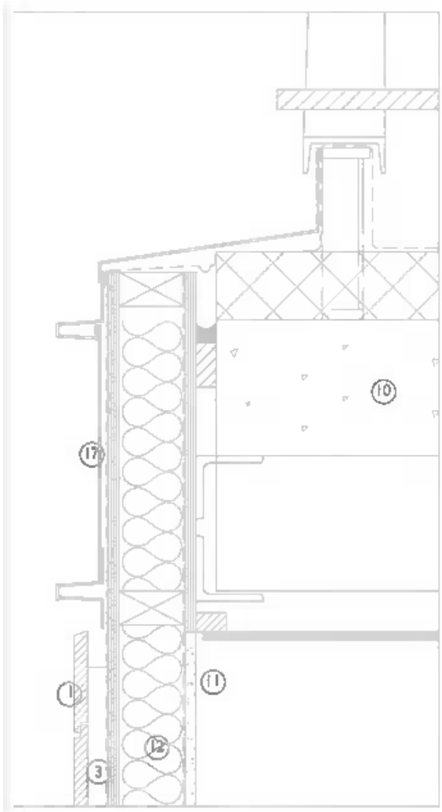
Cladding panels and rainscreens

Timber cladding to a platform frame or a balloon frame is continuous, forming an integral part of the wall structure. In contrast, timber cladding panels are fixed to building frames in reinforced concrete, steel and timber. In this application, cladding panels follow the principle of other forms of cladding, requiring pre-fabrication of panels and allowance for structural movement in the supporting frame associated with larger-scale structures. Cladding panels can also be faced with plywood rather than timber boards, in rainscreen applications. Because of the higher moisture movement associated with timber than with other materials, junctions between cladding panels require allowance for movement as a result of changing moisture levels in the material.

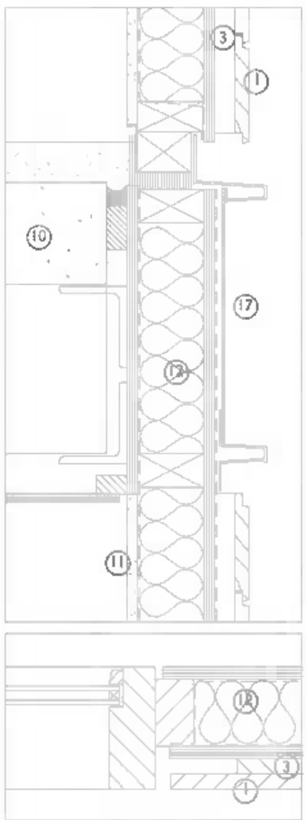
When reinforced concrete or steel frames are used, the timber cladding panels are set forward of the floor slabs in the manner of glazed curtain walling. Panels extend from floor to floor, being either hung from a



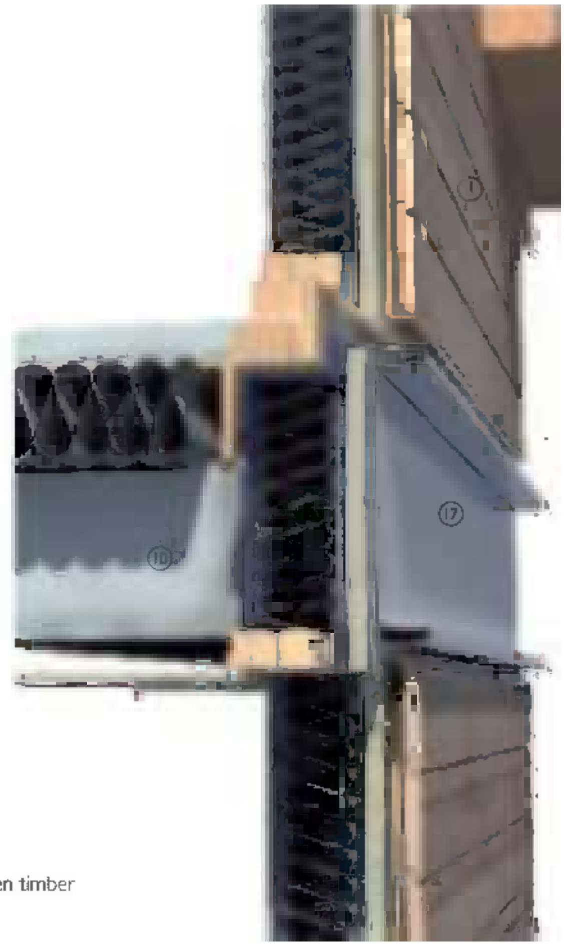
Isometric views of wall assembly at ground level



Vertical section 1:5. Timber board cladding panel wall assembly and junction with upper floor



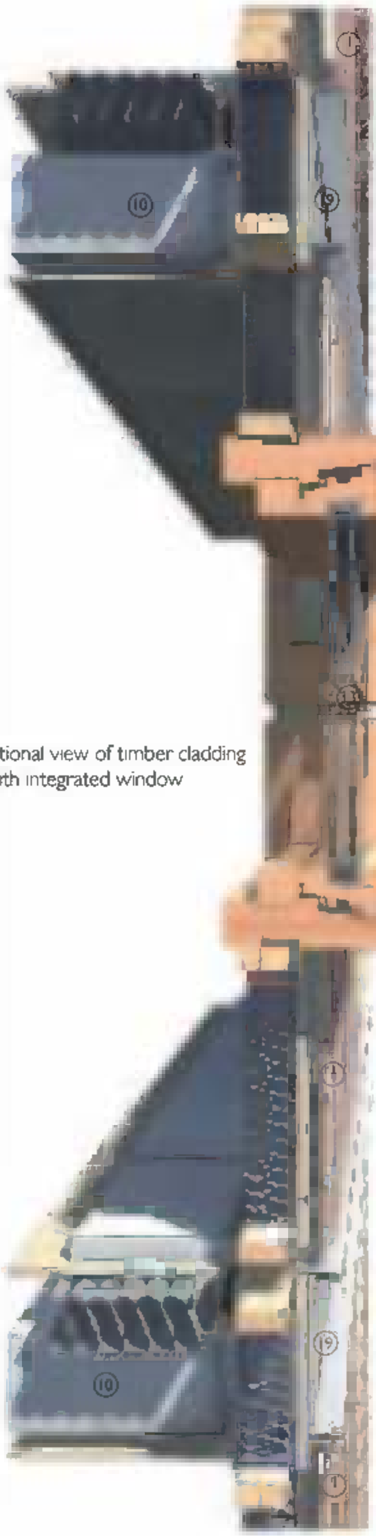
Vertical section 1:5. Connection between timber cladding panel and supporting frame



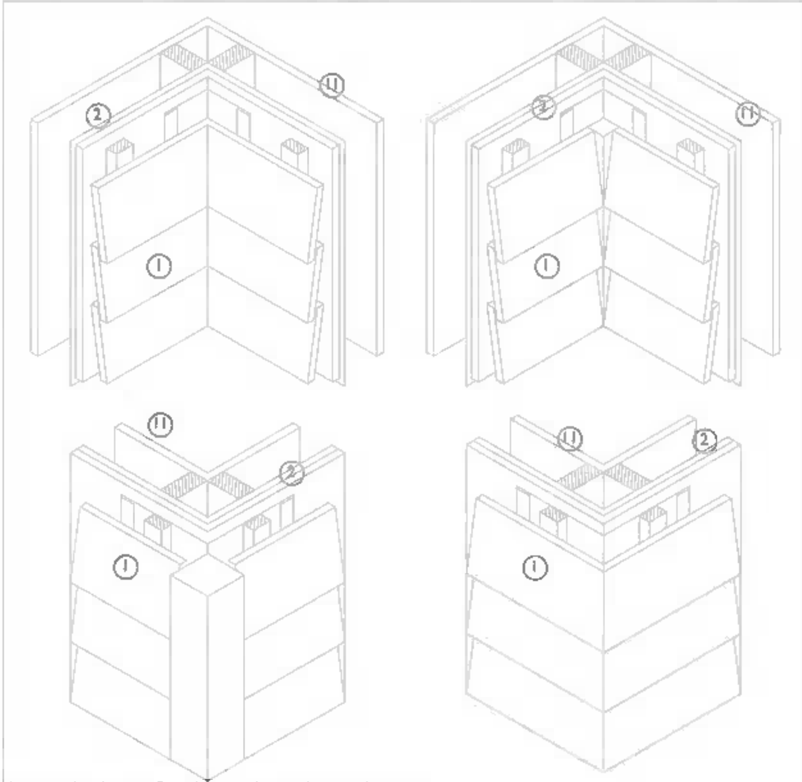
floor slab or else sitting on a bracket on the floor below. In taller buildings, timber cladding is used in conjunction with a twin wall construction with an inner timber wall and an outer open jointed glazed wall. The outer glazed wall provides protection against wind, dust and noise, allowing the windows to be opened for natural ventilation. The outer wall provides a 'thermal buffer' to reduce the effects of heat and cold at different times of the year. The two walls are set 700mm - 1000mm (2ft3in-3ft3in) apart to allow access from the inner timber wall to the zone between the two walls for maintenance and cleaning access. The outer glass screen also provides protection to the timber cladding from the effects of rain and wind, allowing the material to maintain its appearance without full exposure to outside conditions. Vertical joints between panels have a stepped joint to allow for deflections in floor slabs between panels, following principles of glazed curtain walling. This stepped joint is covered on the outside with timber boards, set forward of the face of panels on battens in rainscreen configuration. The construction of panels follows the same principle of timber cladding described in the previous section. Horizontal joints have an inner chamber formed between two adjacent panels. Any rainwater that penetrates the outer seal, which is also kept open in some designs, is drained down an inner chamber where the water is discharged through the horizontal joint at floor level. The outer timber cladding has continuous vertical joints to allow panels to be fixed sequentially, unless the outer timber boards are applied after the panels have been installed, but this is contrary to the panel-based form of construction.

Where timber frames are used to support timber cladding panels, cladding is set between floor structures rather than forward of them, since there is no significant thermal bridge from outside to inside, allowing the structural frame to be exposed on the outside. Where timber frames are exposed, laminated timber is often used, since it can be formed in beams of significant loadbearing capacity, and is able to form a frame rather than the continuous loadbearing wall of the platform frame. Cladding panels are set into openings in the laminated timber frame, with panels supported at their base on the tops of beams. Floor decks in timber are then fixed to the side of the laminated timber beams. Timber panels are fixed at their base to the beam beneath, but have a sliding restraint at the top to allow the slab and panel above to deflect without damaging the panel below. A metal flashing at the base of the panel drains water at its base and throws it clear of the beam beneath in order to avoid staining of the timber beam. The outer timber rainscreen cladding is set flush with the outer face of the laminated timber frame to avoid any views into the waterproofing layer behind.

The use of computer numerically controlled (CNC) machines ensures the accurate cutting of components to make timber wall panels with the close tolerances of high quality, large scale construction, particularly housing, where timber has undergone a huge revival, partly due to its lower levels of embodied energy in its construction. The use of composite aluminium / timber windows, with their high performance, low U-values



3-D sectional view of timber cladding panel with integrated window



Isometric views of wall assembly at internal corners

Details

1. Timber boards
2. Plywood sheathing
3. Timber studs
4. Timber rail
5. Breather membrane
6. Foundation
7. Damp proof course
8. Vapour barrier
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14. Timber cill
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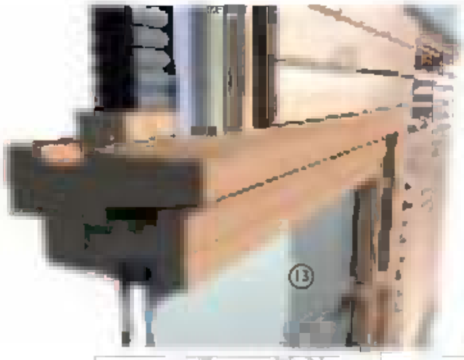
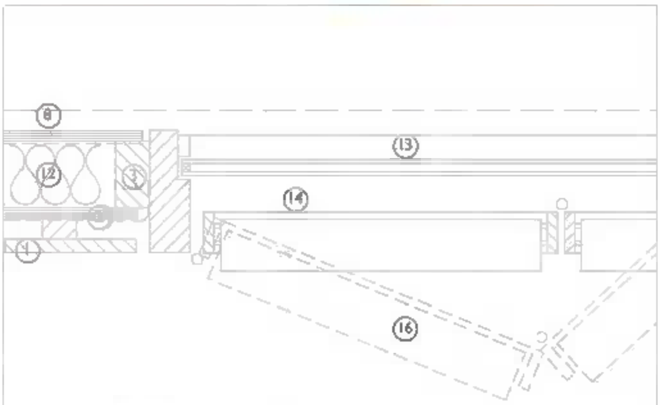
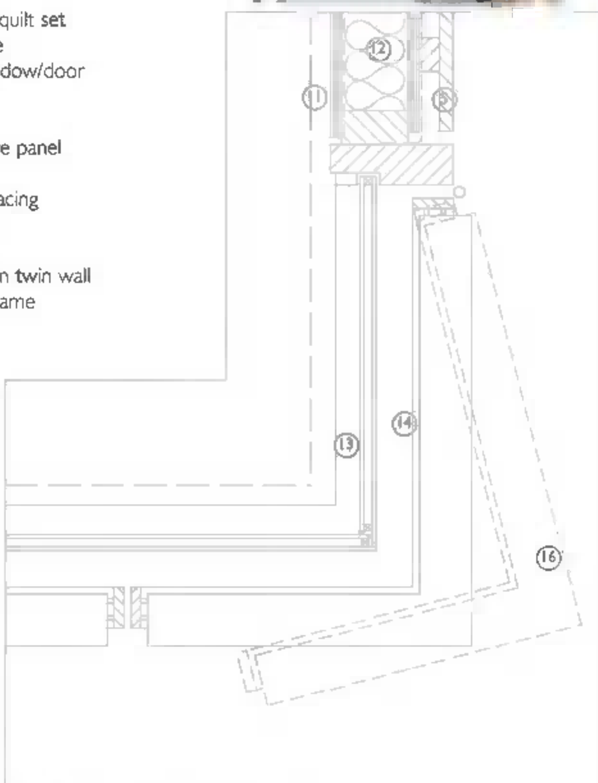
22. Structural timber frame

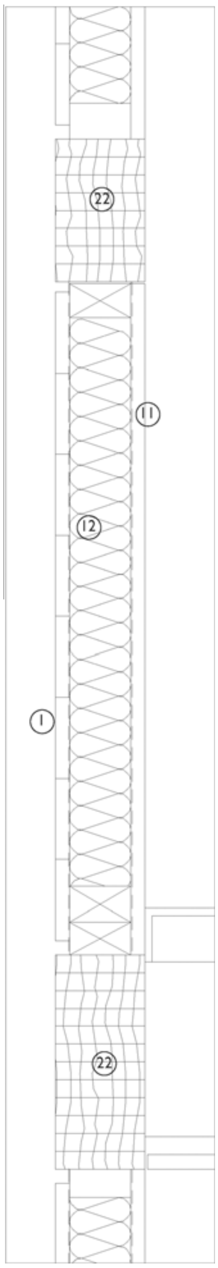




Horizontal section 1:10. Window jamb

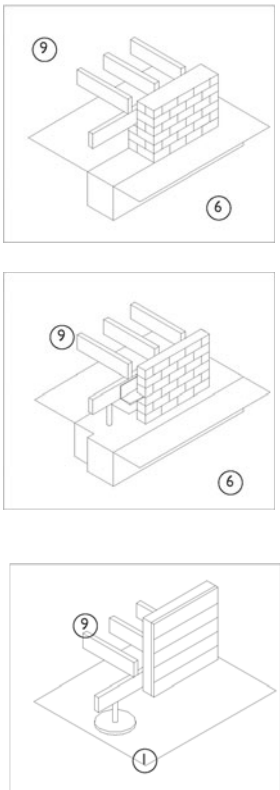


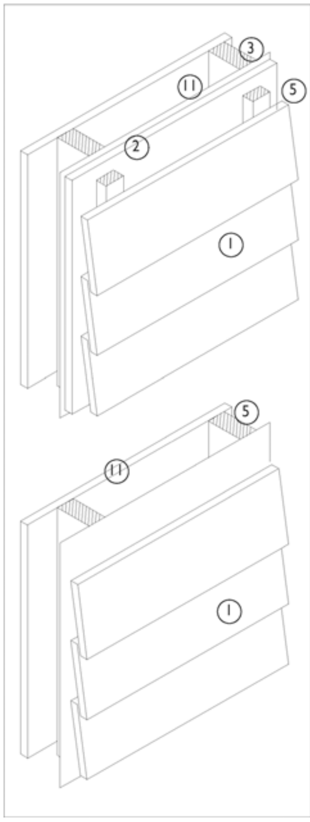
Horizontal section 1:10. Window jamb



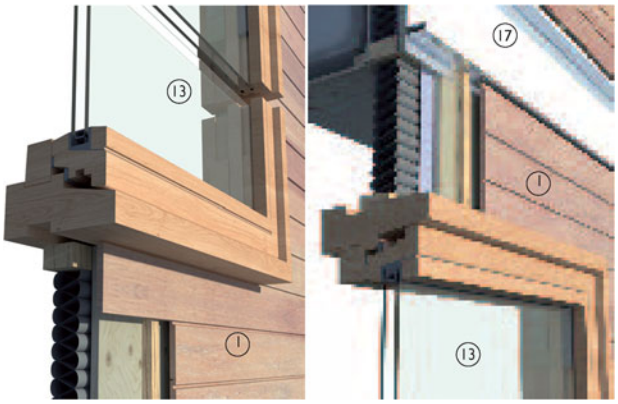
Vertical section 1:10. Timber cladding wall assembly

3-D view of basic timber cladding wall assembly





Isometric views of wall assembly



Details

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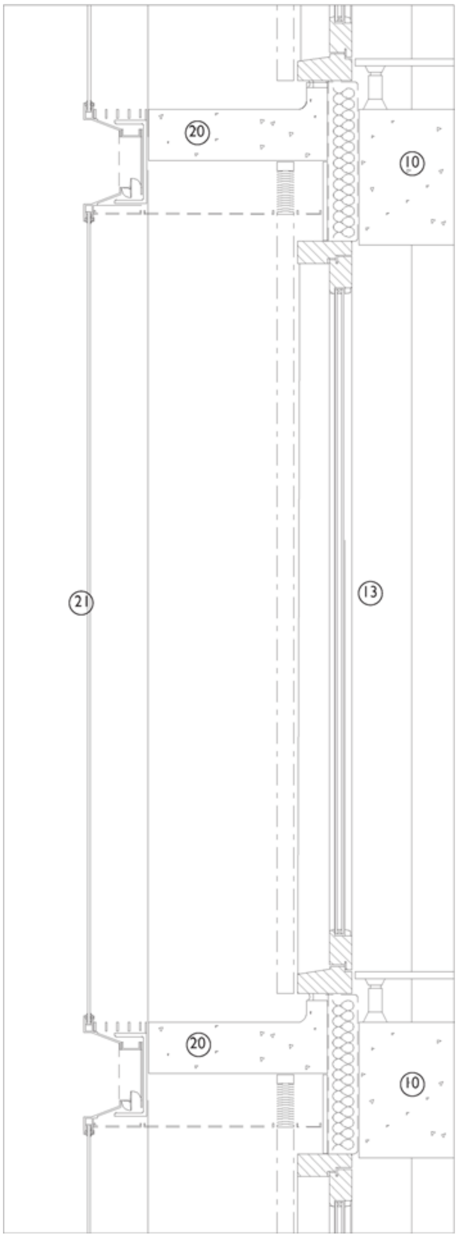
21. External glass wall in twin wall
22. Structural timber frame

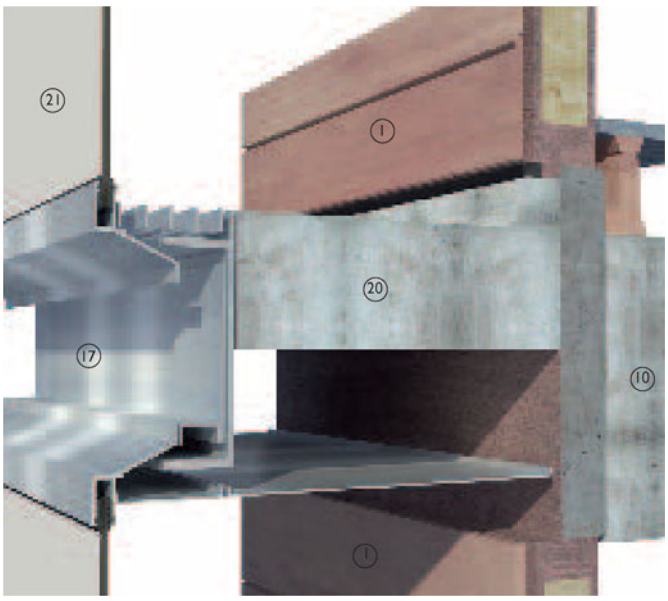
and acoustic attenuation, has given timber cladding panels greater impetus for large scale projects where traditionally the thermal and weather resisting performance of timber windows and frames has been much poorer than that of aluminium or UPVC windows and doors.

Plywood sheets

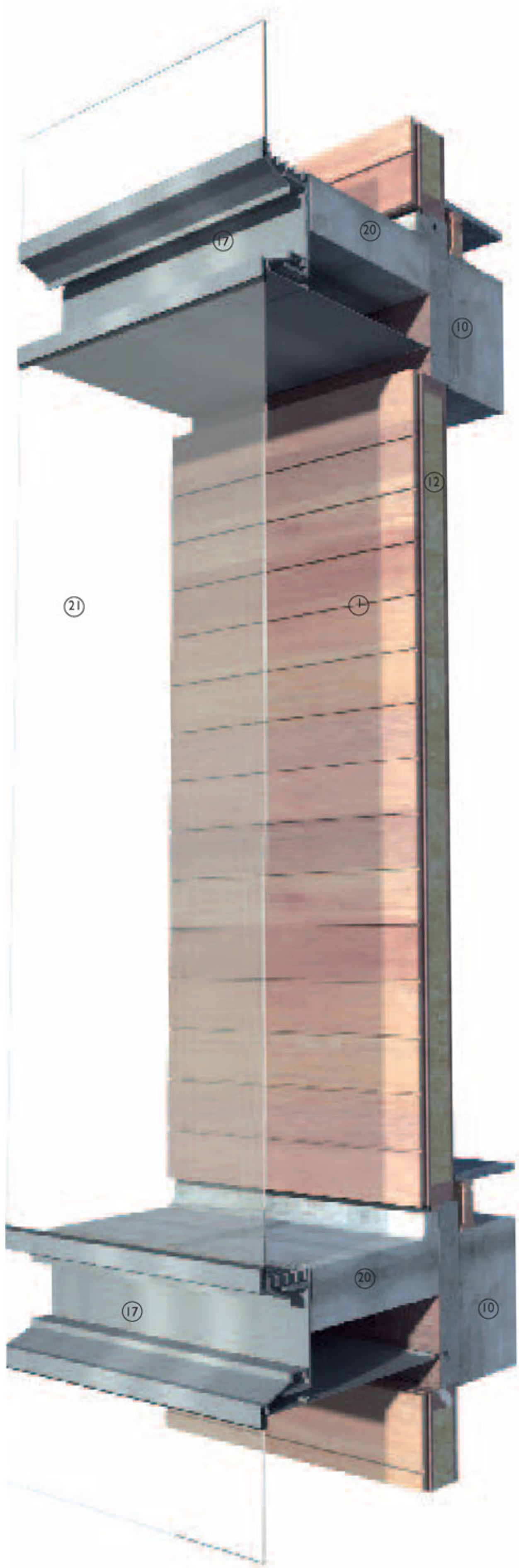
When plywood sheets are used with timber cladding panels, the edges of the sheets are protected, since the edges of plywood are susceptible to damage and rot if left exposed in an external environment. Edges can be protected with metal trims and flashings, where an aluminium Z-shaped profile is set on the back of one sheet, projecting out through a vertical or horizontal joint, and is set over the face of the adjacent panel. Timber strips can also be set over joints to protect the outside face of the plywood but also allow the rear face to be ventilated into a cavity to allow the material to be kept dry. Since plywood sheets can now be supplied in very large sizes, bays of plywood can be made from a single sheet, reducing the need for edge protection of the plywood. Plywood sheets are also lapped in the horizontal joints to create a visual effect like shiplapped timber boards, or are shingled in the manner of sheet metal cladding. The increased use of rainscreen timber cladding with a waterproof backing wall has increased the freedom for timber panel design.



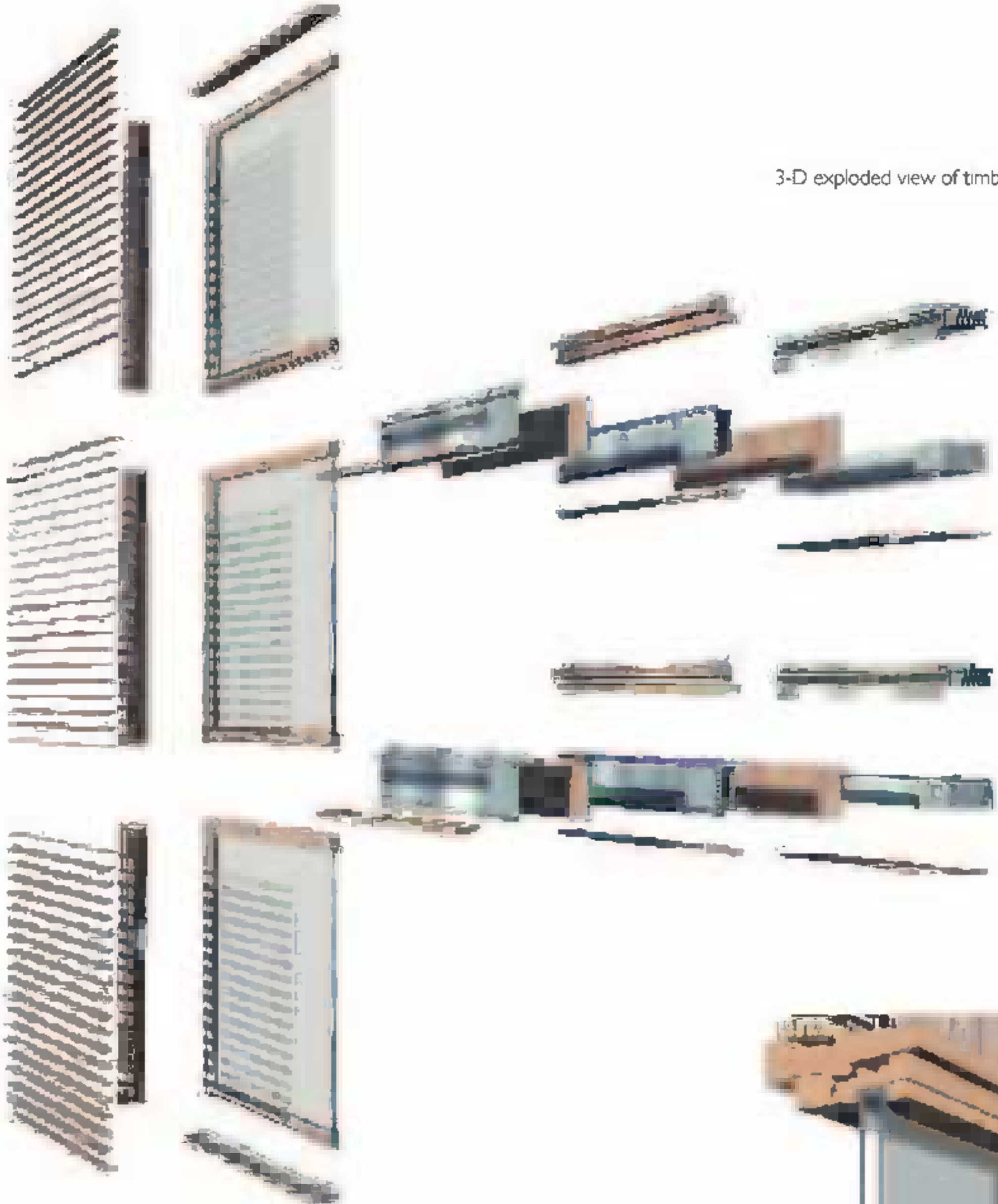
Vertical section 1:25. Cladding panel in twin wall configuration for taller buildings.



3-D detail view of floor junction in twin wall configuration for taller buildings



3-D view of cladding panel in twin wall configuration for taller buildings



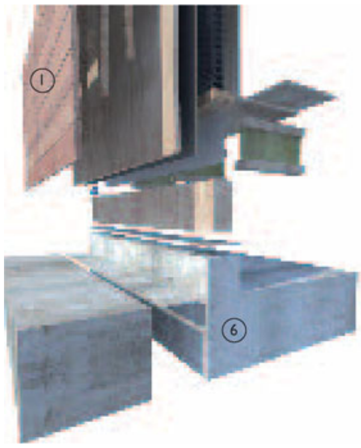
3-D exploded view of timber cladding system consisting of fixed glazing and louvre screens

Detail
1. Timber board
2. Plywood sheathin
3. Timber stud
4. Timber ra
5. Breather membran
6. Foundatior
7. Damp proof cours
8. Vapour barrie
9. Timber floo
10. Concrete floo
11. Internal finisl
12. Thermal insulation quilt se within timber fram
13. Timber framed window/doo
14. Timber
15. Air gap
16. Sliding timber louvre pane
17. Metal facin
18. External plywood facin
19. Cover strip
20. External floor deci
21. External glass wall in twin wa
22. Structural timber fram

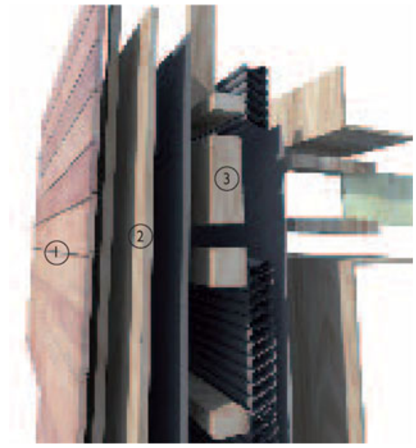
3-D exploded view of window opening and connection between cladding panel, supporting frame and upper floor in fixed glazing-louvre screen system

3-D view of timber clad facade incorporating both louvred and board panel types

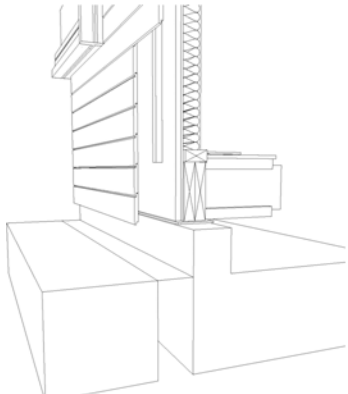
3-D exploded detail view of top of window opening in timber cladding system



3-D exploded detail view of ground floor junction



3-D exploded detail view of conncection between timber cladding panel and upper floor



3-D view of ground junction in timber cladding system

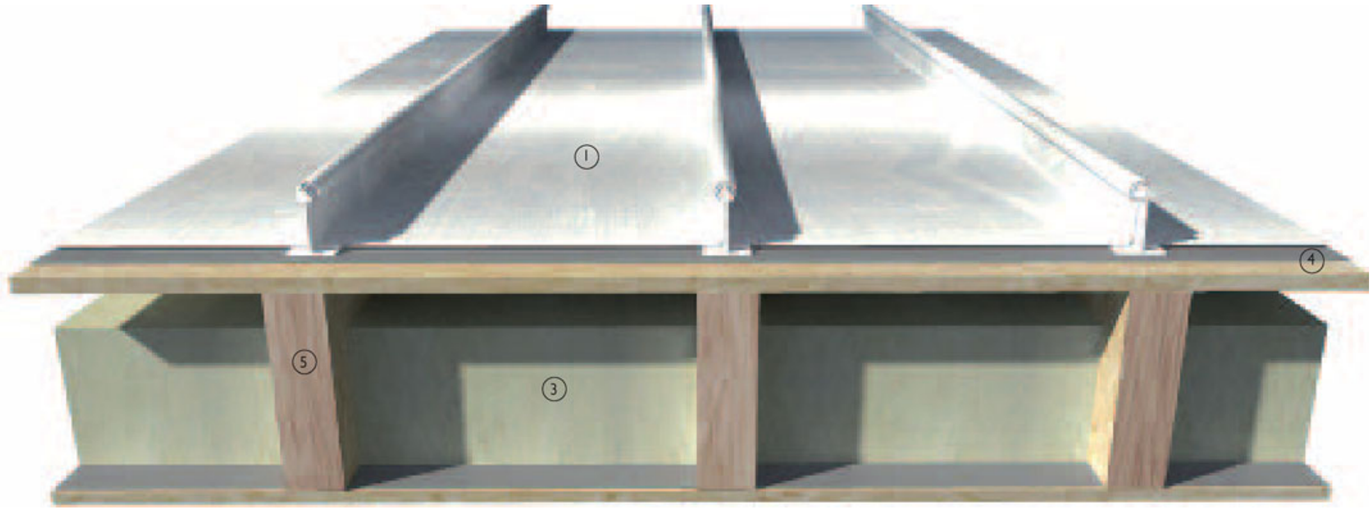
3-D view of window opening in timber cladding system

3-D exploded view of cladding panel in twin wall configuration for taller buildings

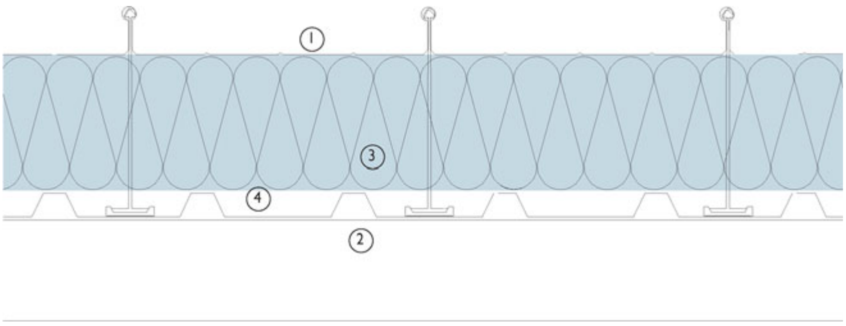
3-D exploded view of timber cladding panel wall assembly

7

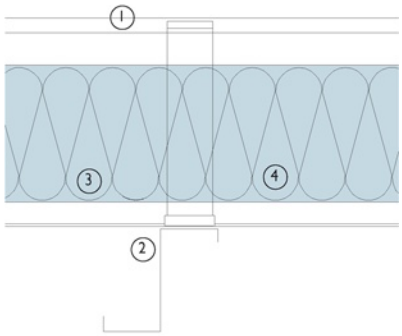
METAL ROOFS



3-D section through metal profile roof on timber structure



Vertical section 1:10. Typical roof assembly without acoustic layer



Vertical section 1:10. Typical roof assembly without 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.

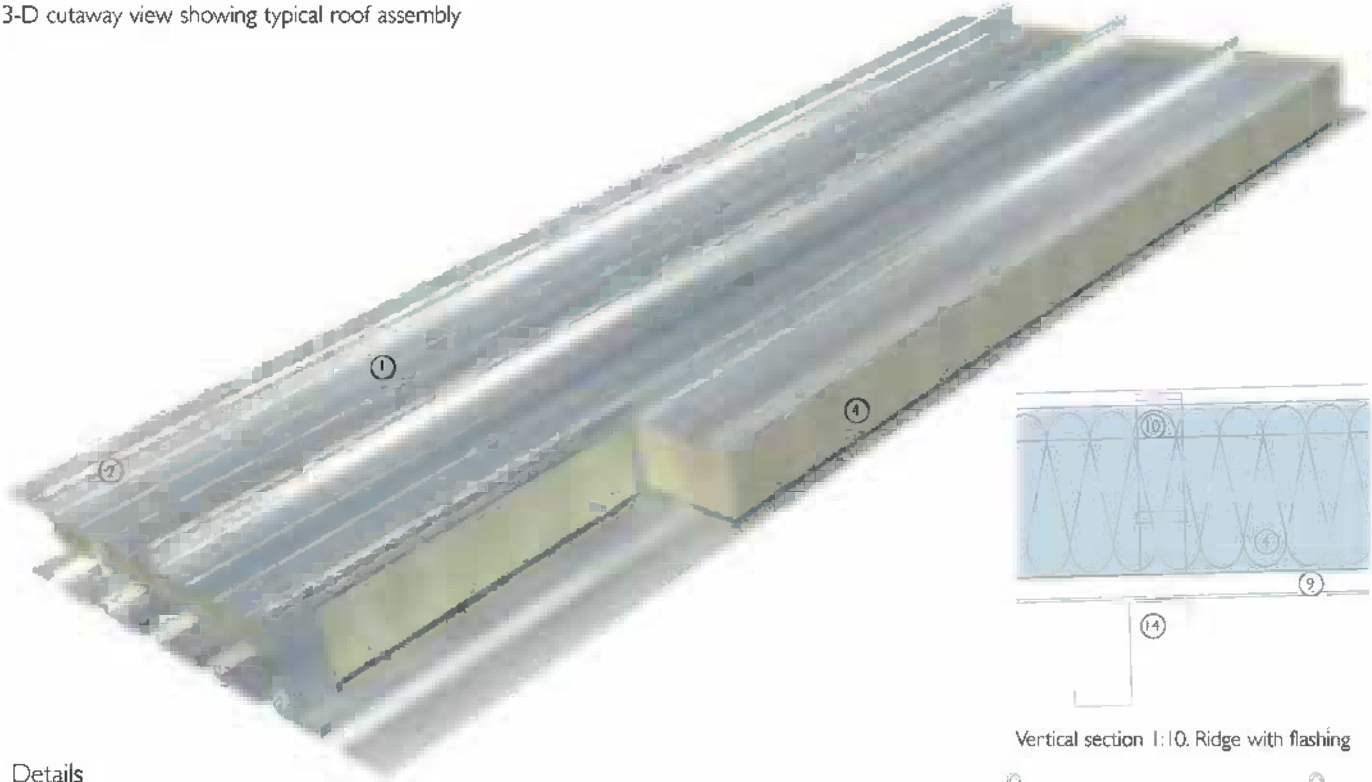
Site-based method

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 are used to form a continuous substrate, or supporting surface. Standing seams are formed by timber strips of rectilinear 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 ventilated 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

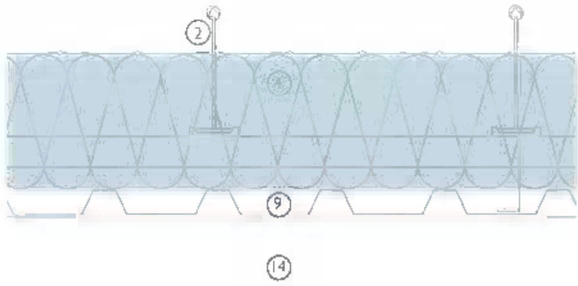
3-D cutaway view showing typical roof assembly



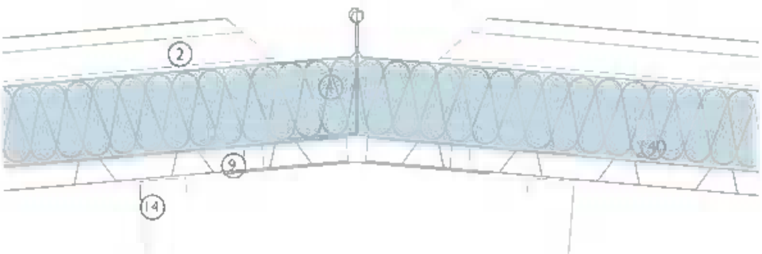
Vertical section 1:10. Ridge with flashing

Details

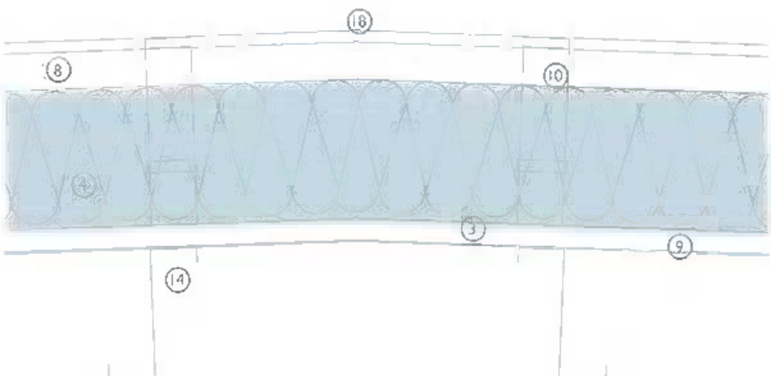
1. Metal sheet
2. Standing seam joint
3. Breather membrane
4. Thermal insulation
5. Substrate, typically timber/metal rafters with plywood facing
6. Vapour barrier
7. Drywall/dry lining if required
8. Outer standing seam sheet
9. Inner lining sheet
10. Clips at centres
11. Folded metal gutter
12. Curved eaves sheet
13. External wall
14. Structural frame
15. Outer sheet fixing bracket
16. Rooflight
17. Metal flashing
18. Ridge piece



Vertical section 1:10. Ridge with recessed flashing

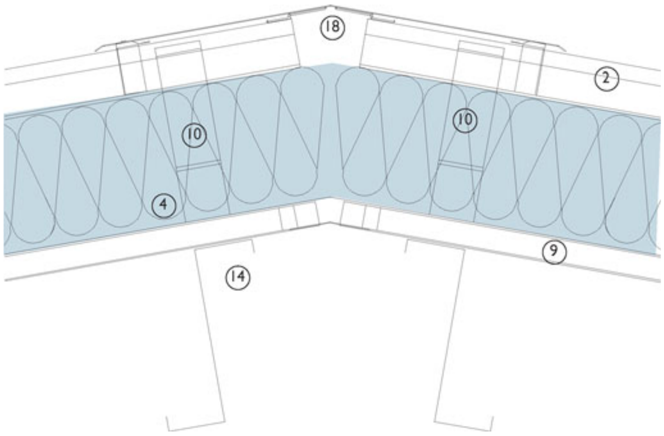


Vertical section 1:10. Ridge with recessed flashing

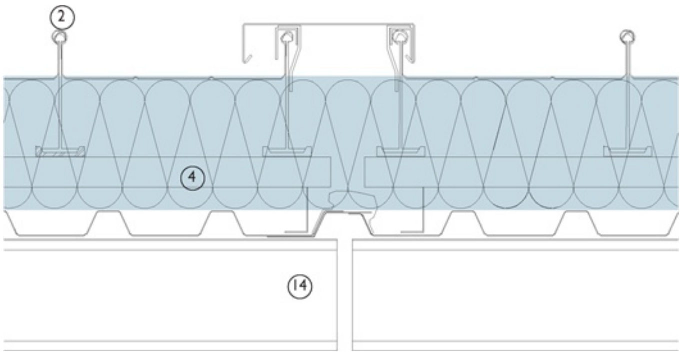


Vertical section 1:10. Ridge with flashing

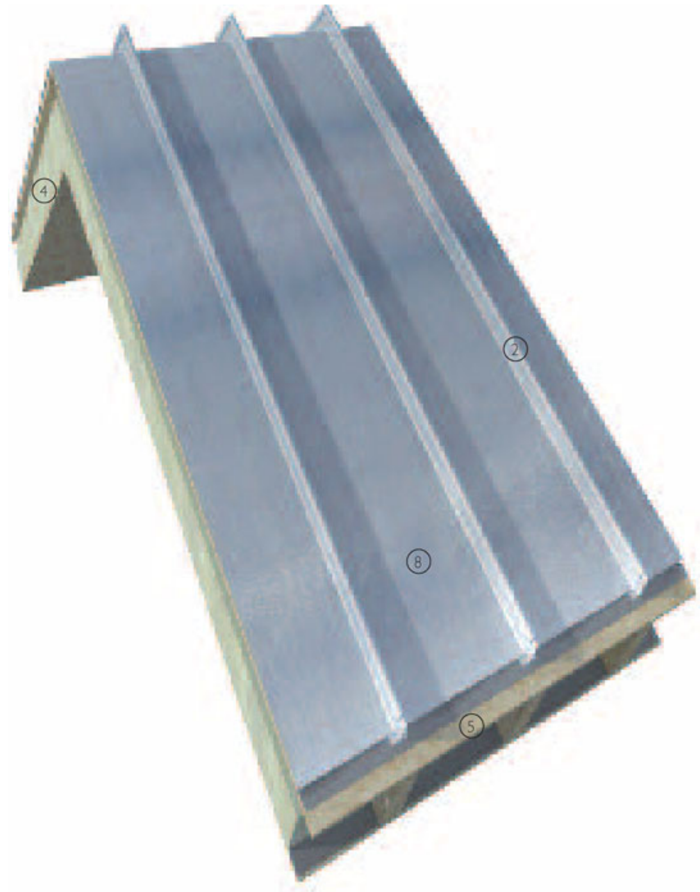
3-D cutaway view of typical roof assembly



Vertical section 1:10. Ridge detail on pitched metal standing seam roof



Vertical section 1:10. Flat metal standing seam roof



3-D view showing pitched metal standing seam roof assembly

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 purlins. A metal liner sheet is set below the purlins to support the 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.

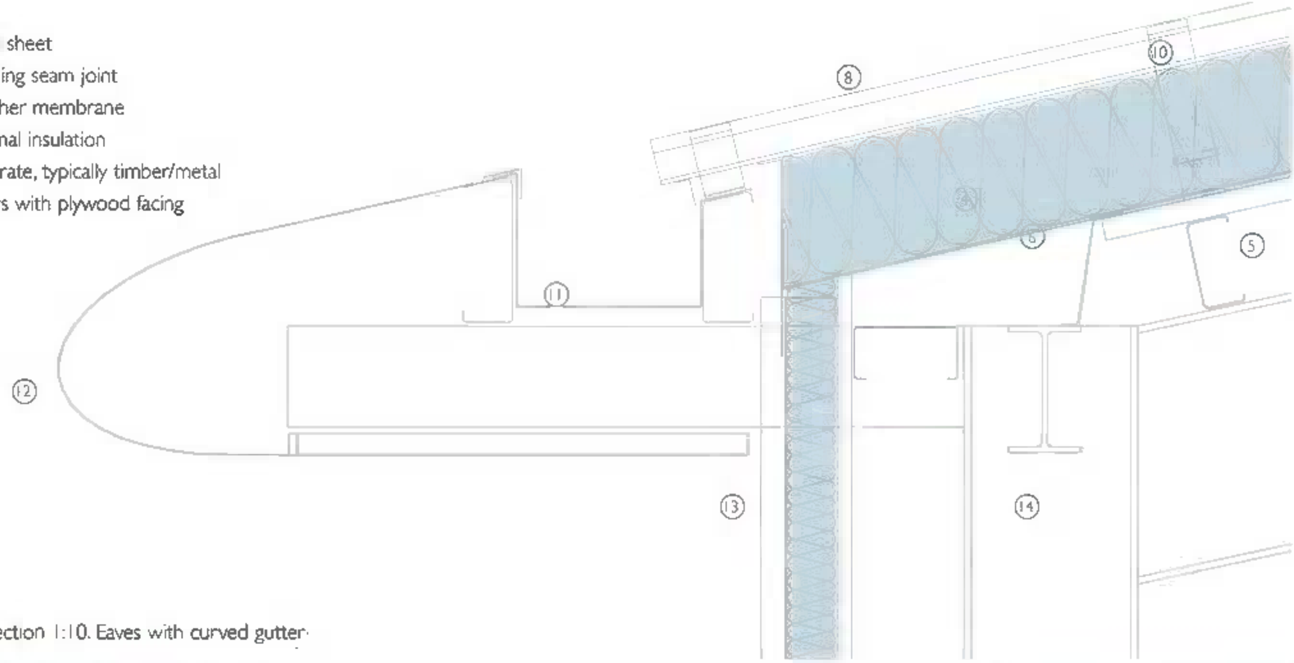
For both construction configurations the roof pitch can go down to 1°, after taking into account any structural deflections that would further reduce this angle. Metal sheets can be made up to 40 metres in length, but road transport is difficult, with long sheets (longer than a trailer length) requiring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

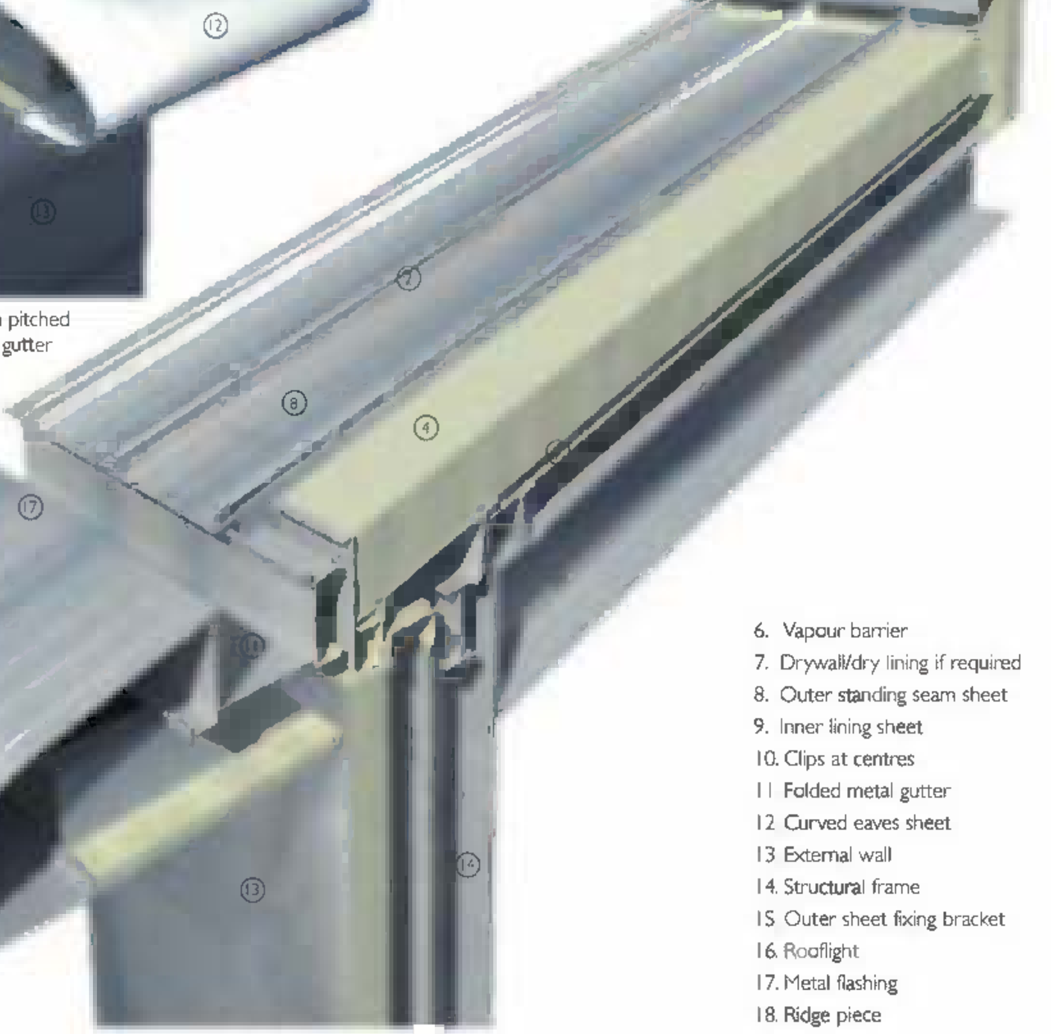
Details

1. Metal sheet
2. Standing seam joint
3. Breather membrane
4. Thermal insulation
5. Substrate, typically timber/metal rafters with plywood facing

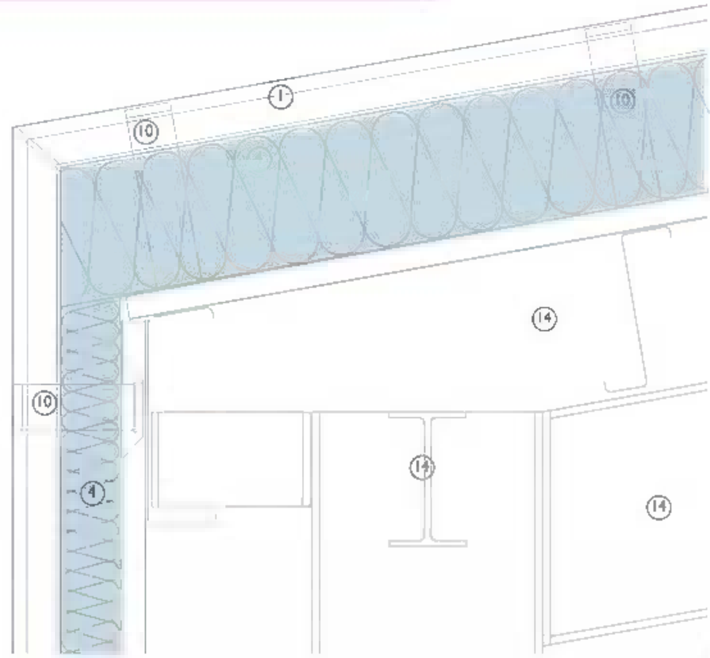


Vertical section 1:10. Eaves with curved gutter

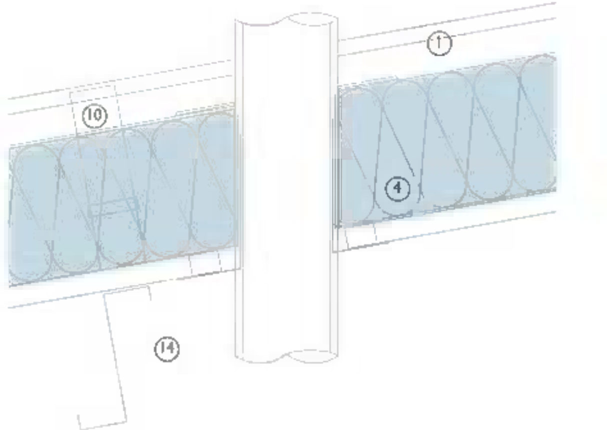
3-D views showing eaves condition on pitched metal standing seam roof with curved gutter



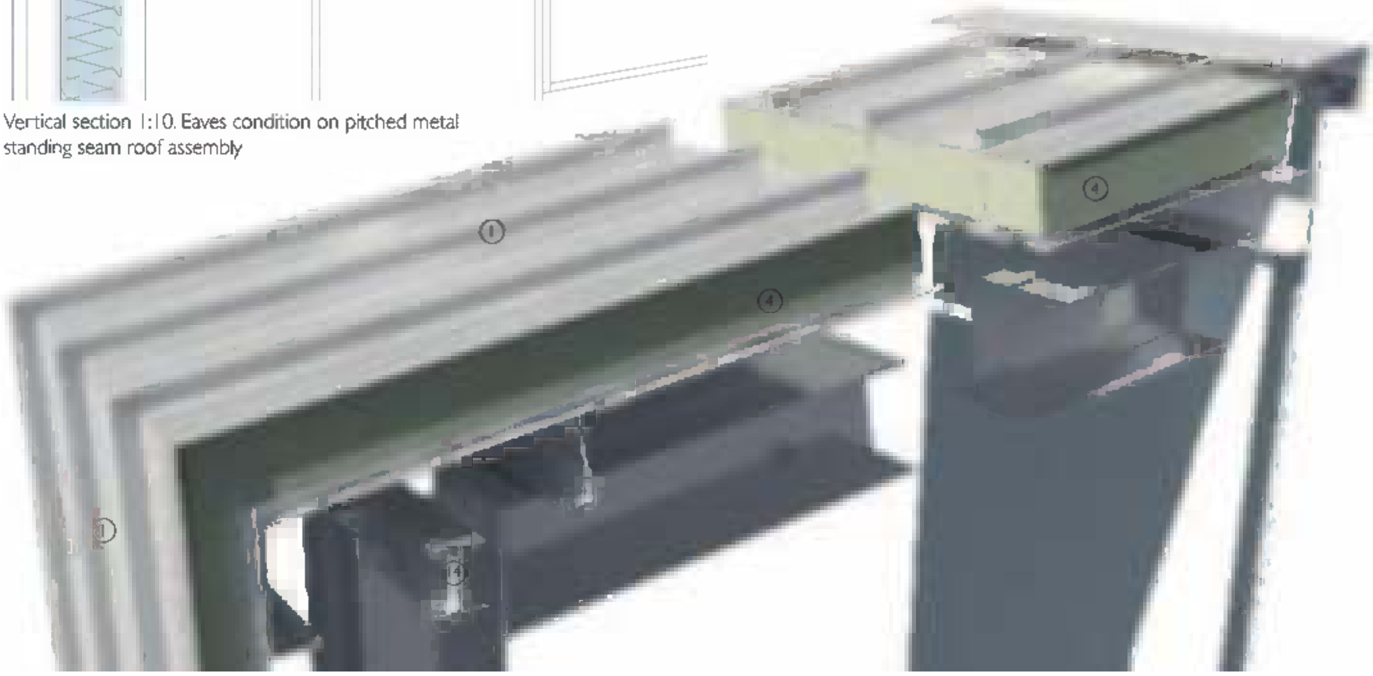
6. Vapour barrier
7. Drywall/dry lining if required
8. Outer standing seam sheet
9. Inner lining sheet
10. Clips at centres
11. Folded metal gutter
12. Curved eaves sheet
13. External wall
14. Structural frame
15. Outer sheet fixing bracket
16. Rooflight
17. Metal flashing
18. Ridge piece



Vertical section 1:10. Eaves condition on pitched metal standing seam roof assembly



Vertical section 1:10. Pipe opening in pitched metal standing seam roof assembly



3-D view showing mono-pitch metal standing seam roof assembly

Details

1. Metal sheet
2. Standing seam joint
3. Breather membrane
4. Thermal insulation
5. Substrate, typically timber/metal rafters with plywood facing
6. Vapour barrier
7. Drywall/dry lining if required
8. Outer standing seam sheet
9. Inner lining sheet
10. Clips at centres
11. Folded metal gutter
12. Curved eaves sheet
13. External wall
14. Structural frame
15. Outer sheet fixing bracket
16. Rooflight
17. Metal flashing
18. Ridge piece

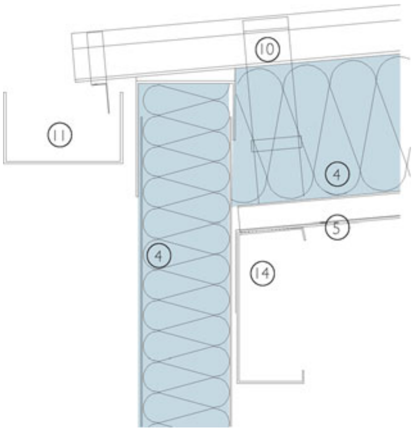
Sealed and ventilated roofs

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.

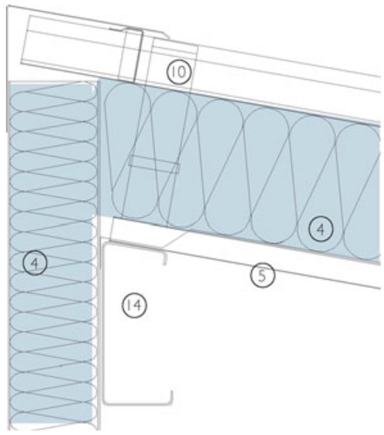
Unlike other metals, zinc sheet requires ventilation on the underside to avoid corrosion from water vapour trapped inside the construction. Ventilation for zinc roofs has traditionally been provided with open jointed timber boards, but this method is being replaced on larger applications by a plastic-based 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

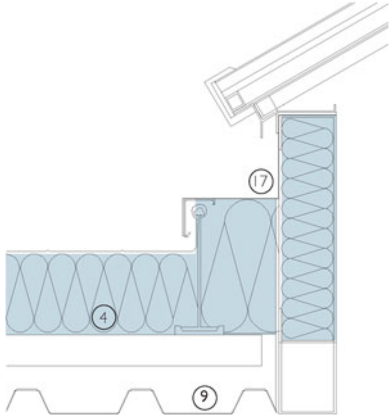
Rooflights are set into standing seam roofs in one of two ways: either by forming a pressed



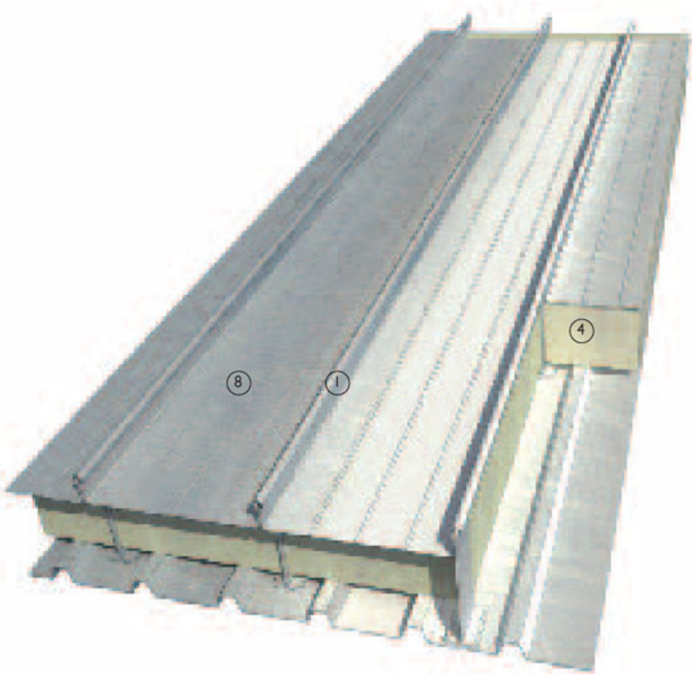
Vertical section 1:10. Eaves and gutter on pitched metal standing seam roof assembly



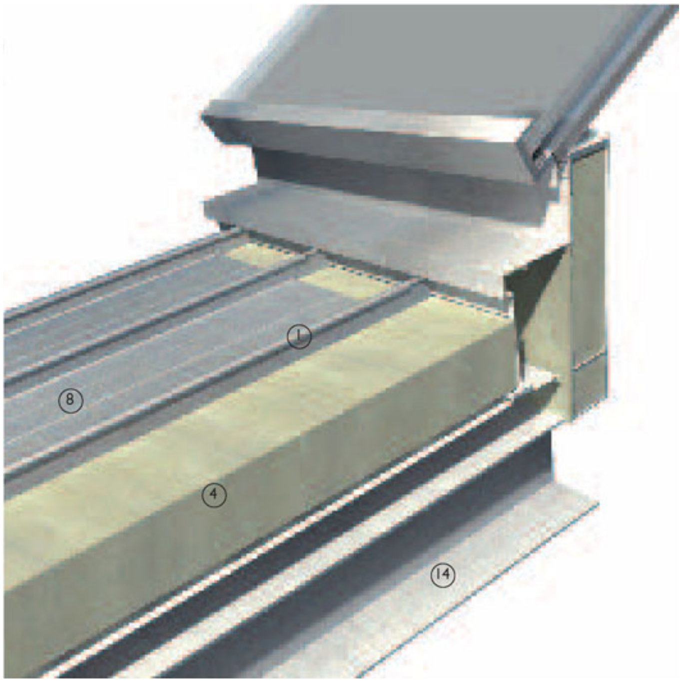
Vertical section 1:10. Eaves and gutter on pitched metal standing seam roof assembly



Vertical section 1:10. Abutment



3-D cutaway view showing typical roof assembly

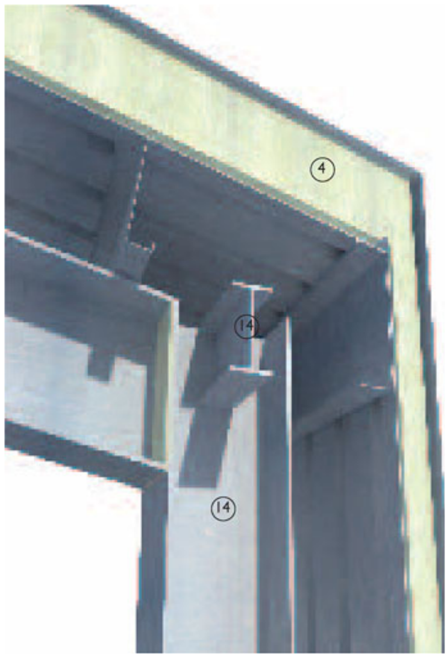


3-D view showing metal roof at abutment

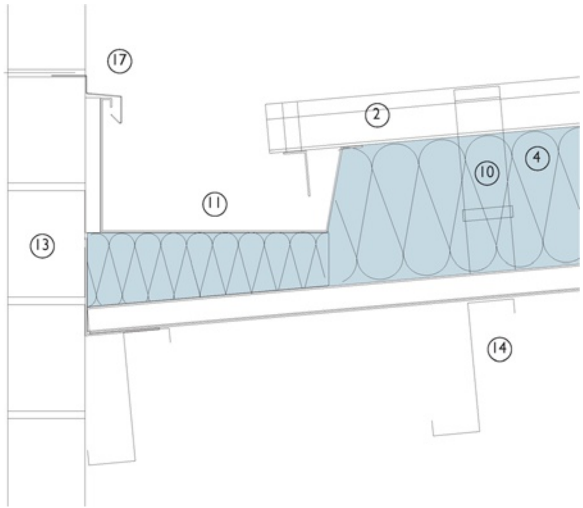
metal upstand around the opening so that the rooflight projects up around 150mm above the level of the roof, or by setting it level with the roof finish and forming a gutter around the edges of the rooflight. This second method avoids the need for rooflights to appear as projecting box-like forms in 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' flashing 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

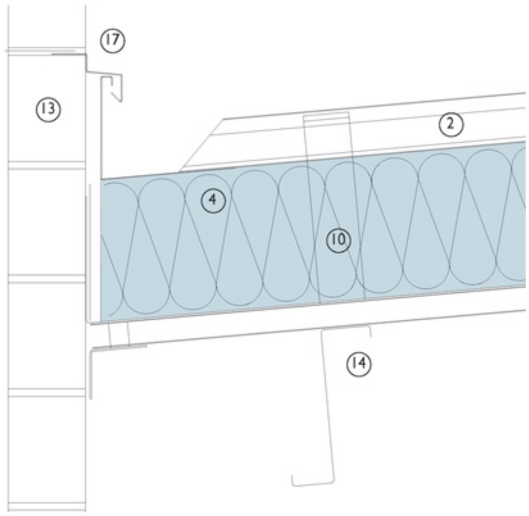
Ridges are formed by a variety of methods. In some cases a folded or curved metal sheet is set over the gap between the two sides of the roof on the level of the top of the standing seam. The gap between the top and bottom of the standing seam is closed with a formed metal filler piece, or strip. Elsewhere, a sharp ridge line can be formed as a stand-



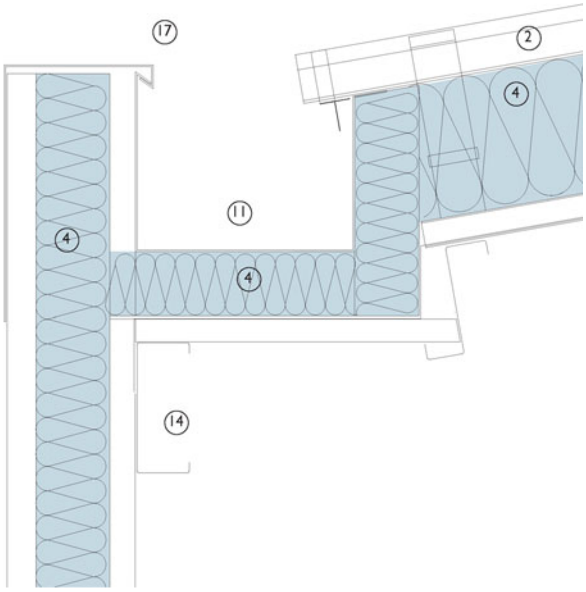
3-D view showing eaves condition on pitched metal standing seam roof assembly



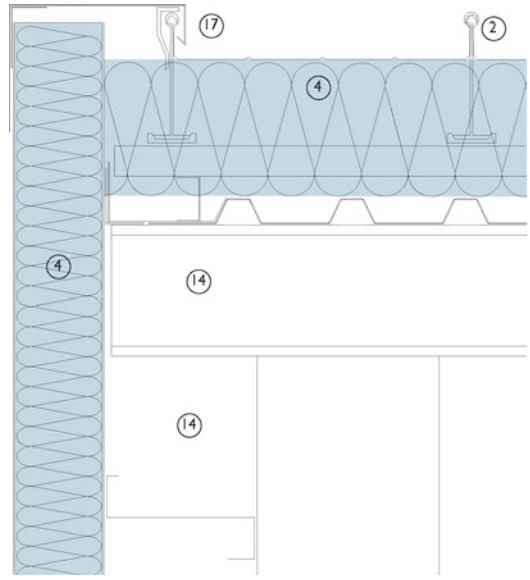
Vertical section 1:10. Gutter at abutment



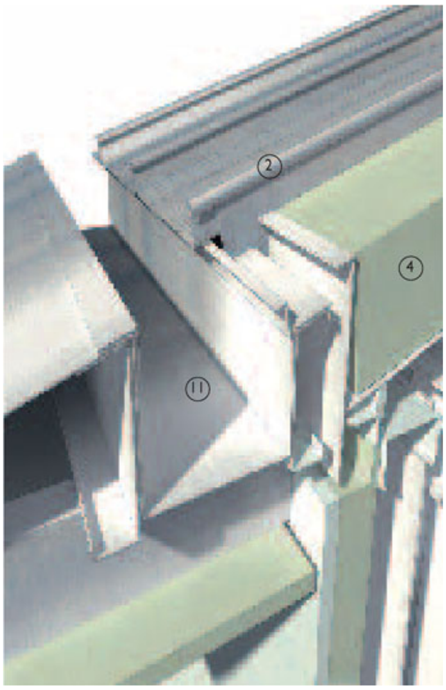
Vertical section 1:10. Parapet gutter at abutment



Vertical section 1:10. Gutter detail



Vertical section 1:10. Parapet



3-D view of gutter detail

ing seam joint, with the seams meeting the ridge being terminated to avoid the need for visually bulky filler that could be seen from below. Alternatively, the ridge can be 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 previously discussed versions, 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 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.

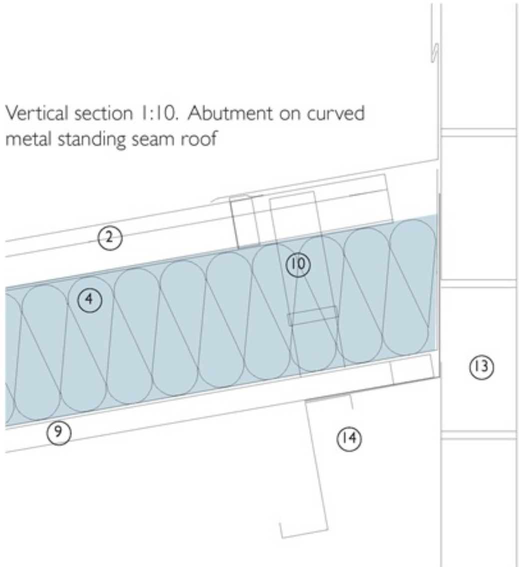
Eaves and parapets

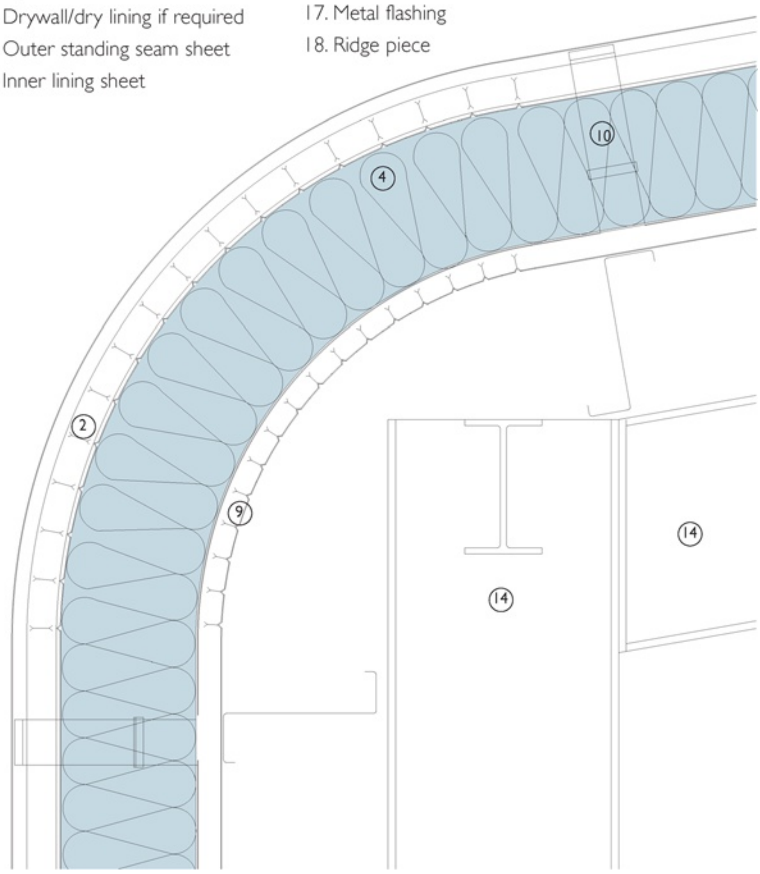
Eaves are formed in a similar way to a valley, with a gutter set at the edge of the roof.

Details

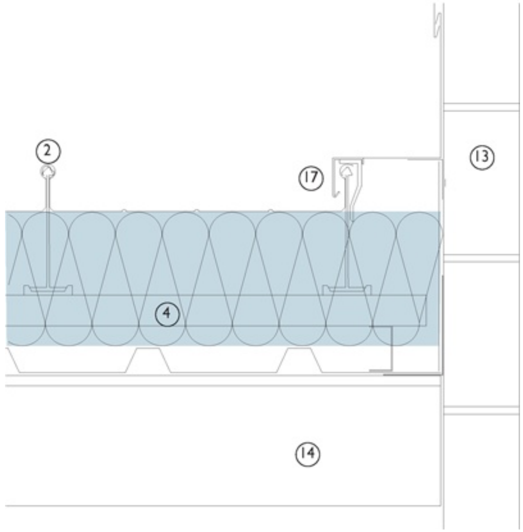
1. Metal sheet
2. Standing seam joint
3. Breather membrane
4. Thermal insulation
5. Substrate, typically timber/metal rafters with plywood facing
6. Vapour barrier
7. Drywall/dry lining if required
8. Outer standing seam sheet
9. Inner lining sheet
10. Clips at centres
11. Folded metal gutter
12. Curved eaves sheet
13. External wall
14. Structural frame
15. Outer sheet fixing bracket
16. Rooflight
17. Metal flashing
18. Ridge piece

Vertical section 1:10. Abutment on curved metal standing seam roof





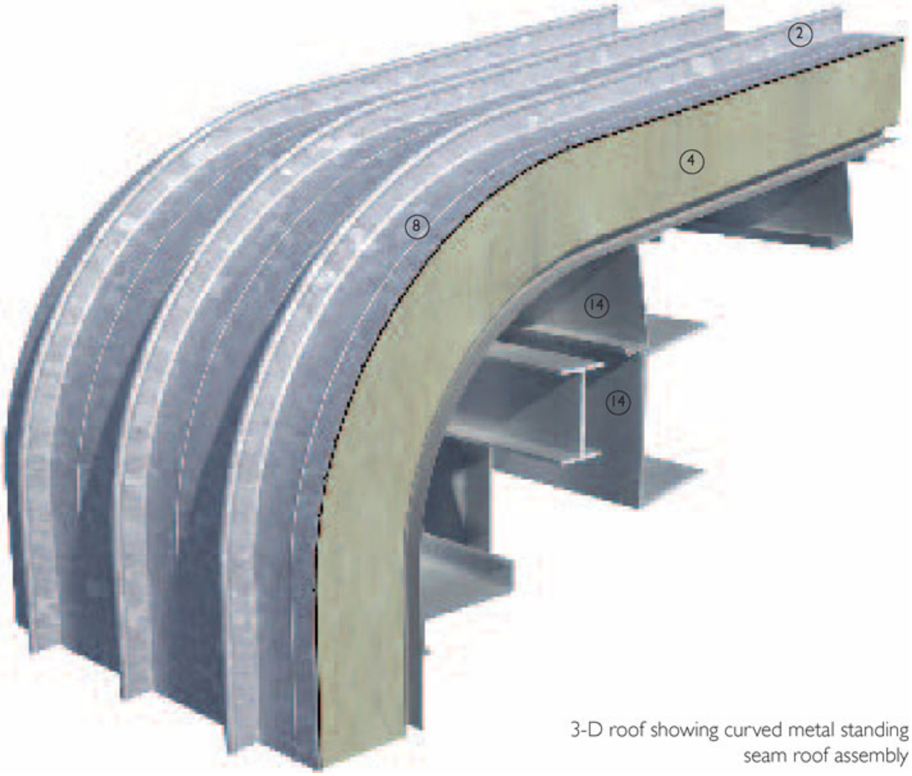
Vertical section 1:10. Eaves on curved metal standing seam roof assembly



Vertical section 1:10. Abutment on metal standing seam roof

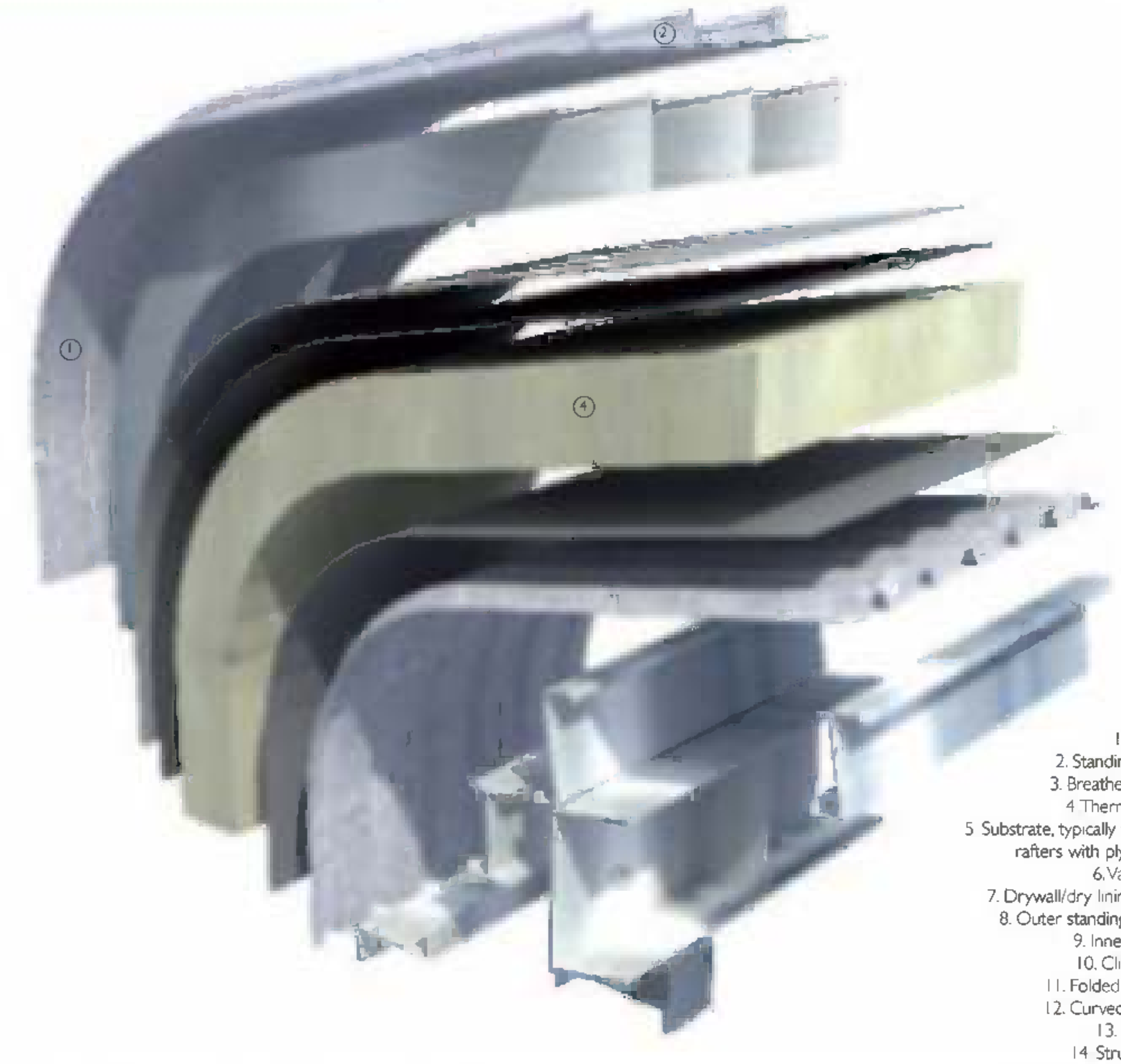
Increasingly, gutters are being integrated into roof forms in order to avoid a weak visual line formed by a gutter which is not continuous with the smooth lines of the roof. When additional closer pieces are used, such as bull nose profiles, the metal panels are usually designed to be drained and ventilated 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.



3-D roof showing curved metal standing seam roof assembly

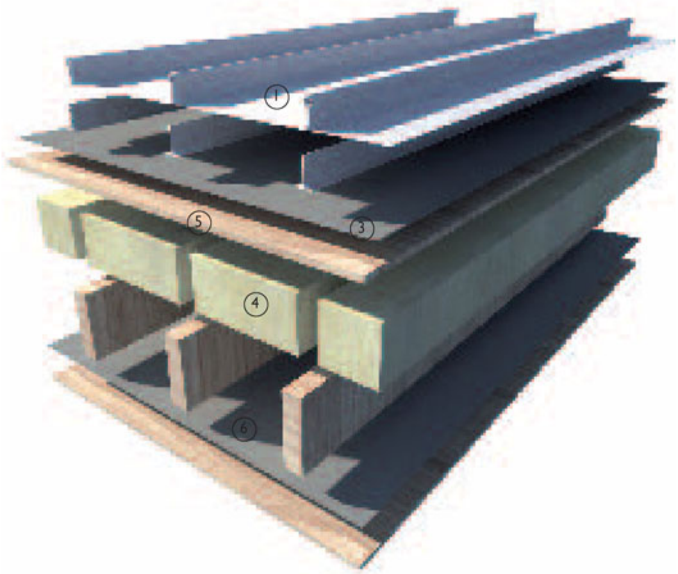
Metal standing seam



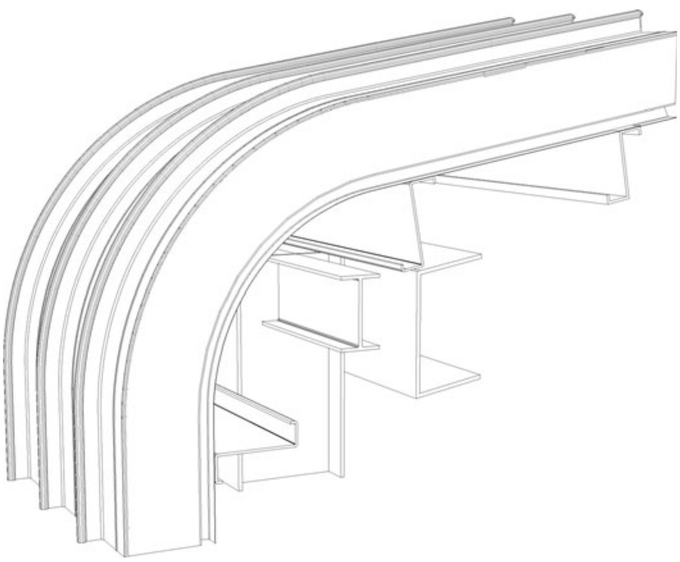
3-D exploded view of curved metal standing seam roof assembly

Detail

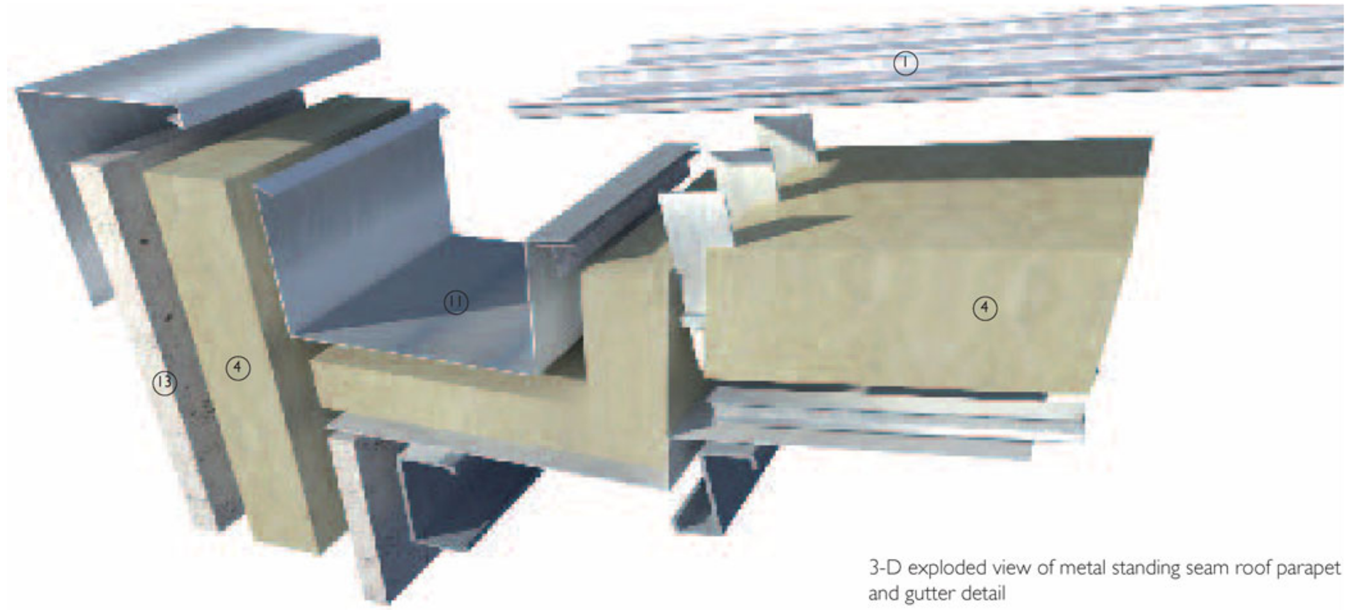
1. Metal shee
2. Standing seam join
3. Breather membran
4 Thermal insulatio
5 Substrate, typically timber/meta rafters with plywood facin
6. Vapour barrie
7. Drywall/dry lining if require
8. Outer standing seam shee
9. Inner lining shee
10. Clips at centre
11. Folded metal gutte
12. Curved eaves shee
13. External wa
14 Structural fram
15. Outer sheet fixing bracke
16. Rooflígh
17. Metal flashin
18. Ridge piec



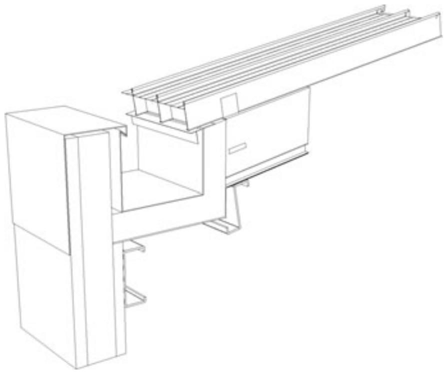
3-D exploded view of metal standing seam roof assembly with timber frame



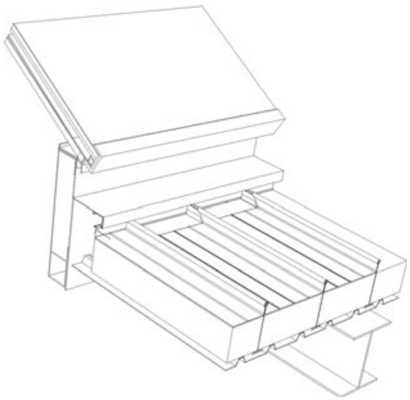
3-D view of curved metal standing seam roof assembly



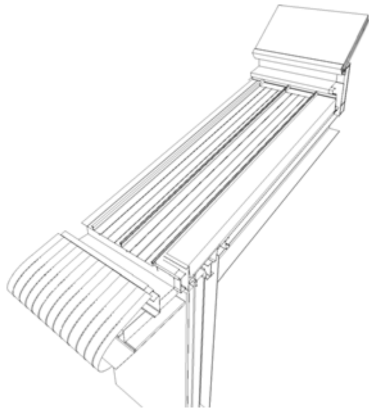
3-D exploded view of metal standing seam roof parapet and gutter detail



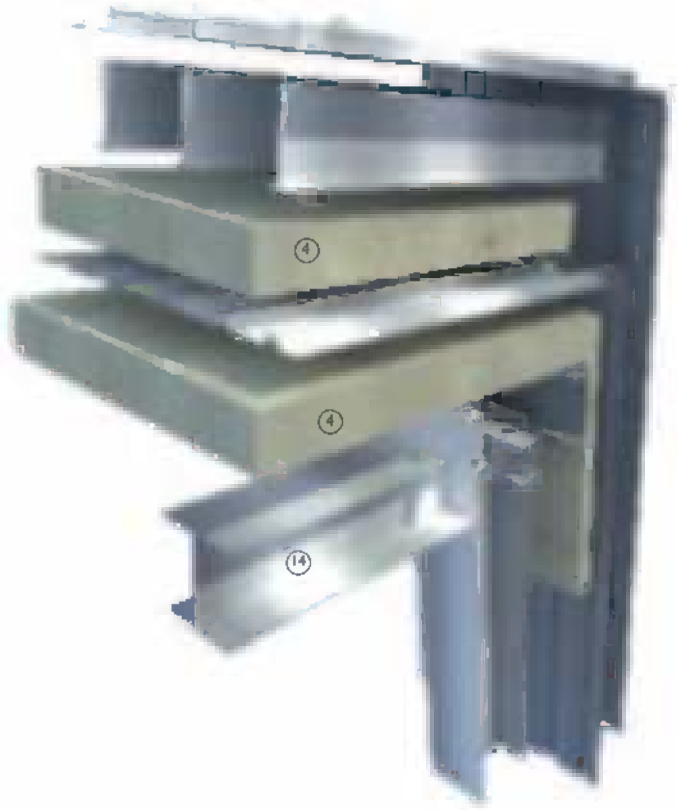
utter detail



3-D view of metal standing seam roof parapet and gutter detail

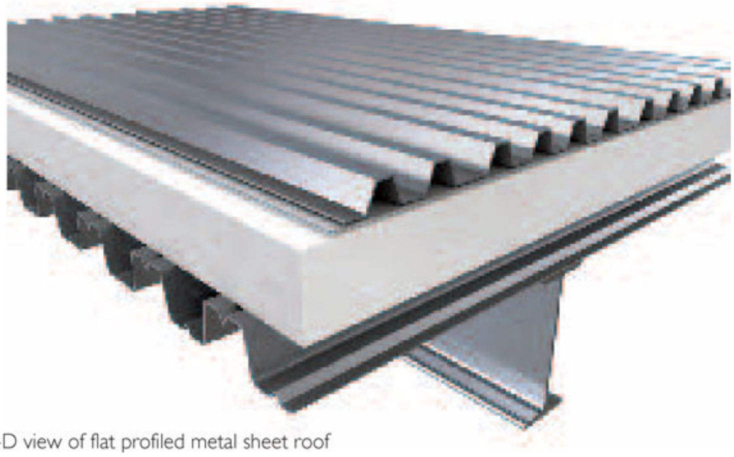


3-D view of metal standing seam roof parapet and gutter detail

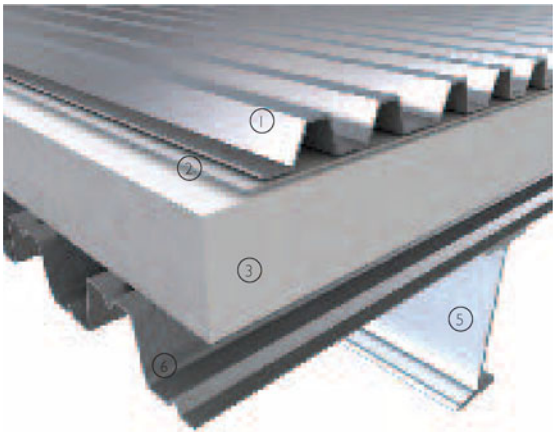


3-D exploded view of metal standing seam roof parapet and gutter detail for curved roof edge

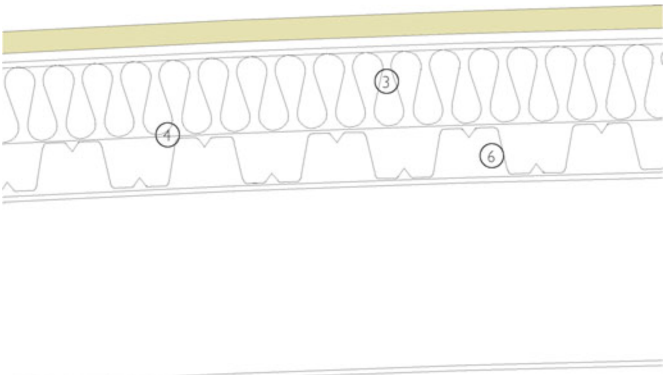
3-D exploded view of metal standing seam roof assembly



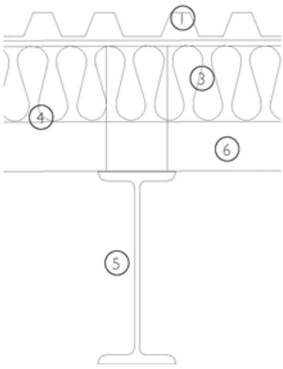
3-D view of flat profiled metal sheet roof



3-D detail view of flat profiled metal sheet roof



Vertical section 1:10. Typical profiled metal sheet roof construction



Vertical section 1:10. Typical profiled metal sheet roof construction

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, allows for it 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.

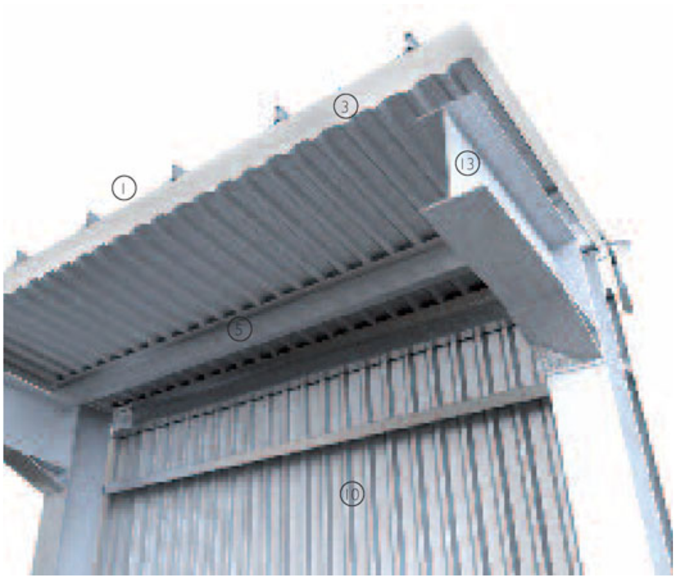
When used as a substrate, profiled metal sheet can be cut to form complex geometries, typically supported by a steel frame to create a three dimensional form. Profiled sheet with an overall depth of 50mm is used typically, but much deeper sections are used for spans above 3.5 metres to around 6.0 metres,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

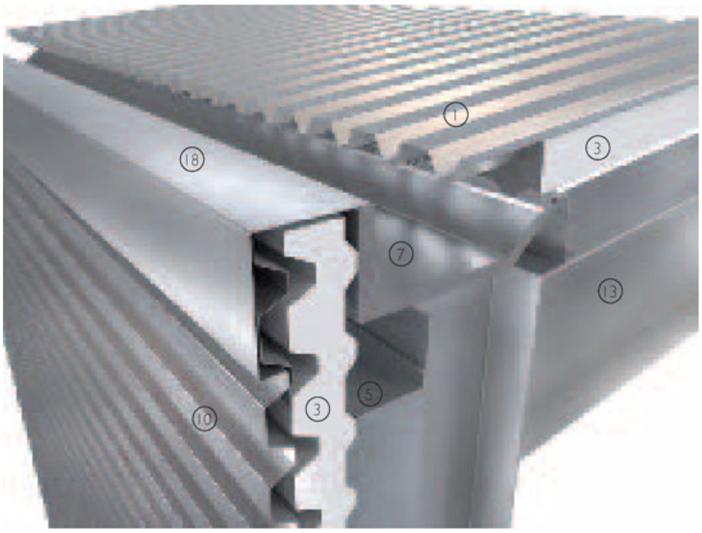
Where profiled metal is used as a deck rather than as a roofing material, a lightweight build-up is usually applied, since the metal decking is chosen where a lightweight roof is required. The lightweight finishes used are typically an additional layer of profiled sheet, metal standing seam (discussed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

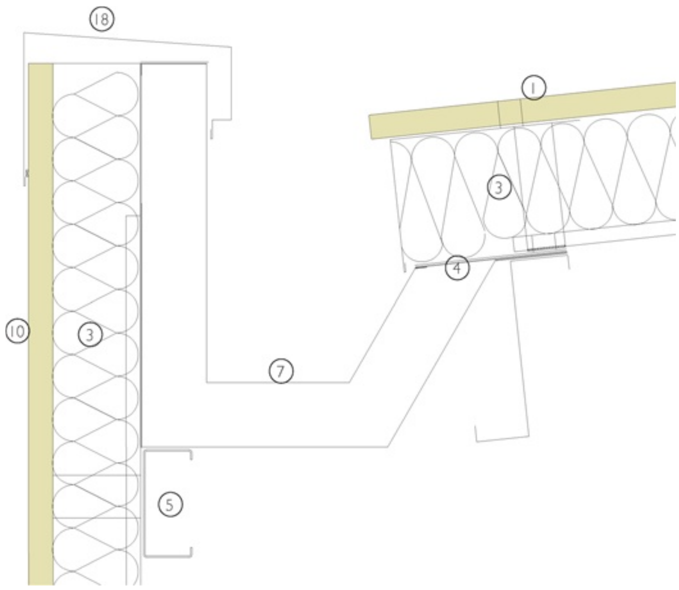


3-D view of flat profiled metal sheet roof construction



3-D view of gutter detail

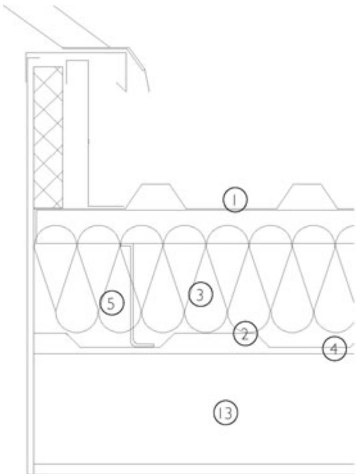
3-D view of flat profiled metal sheet roof construction



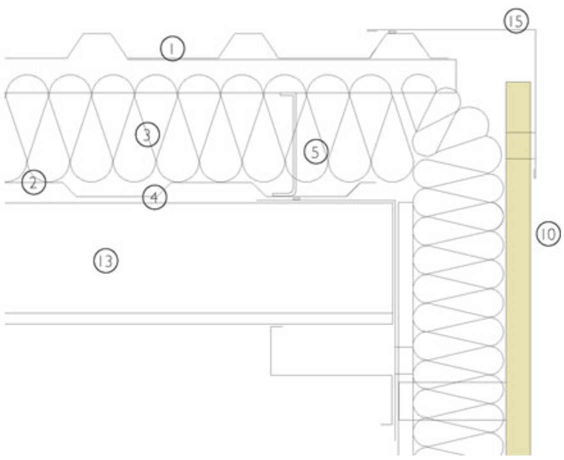
Vertical section 1:10. Concealed gutter junction

Details

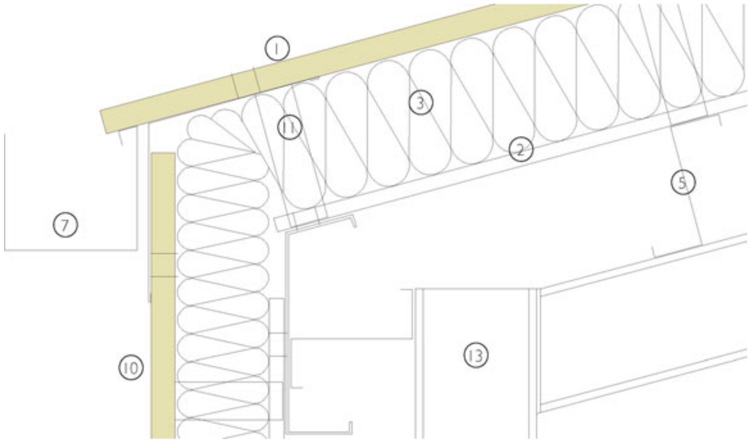
1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved eaves sheet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



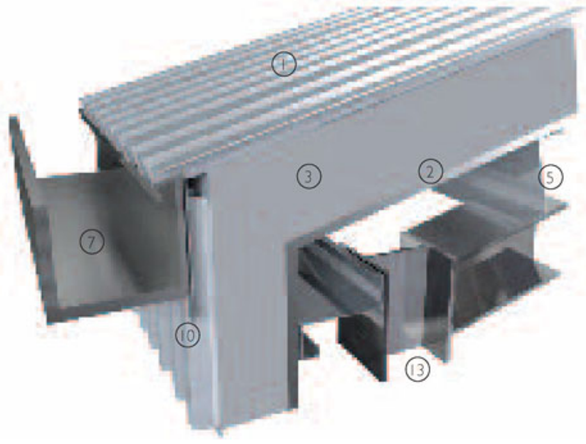
Vertical section 1:10. Profiled metal sheet roof with parapet



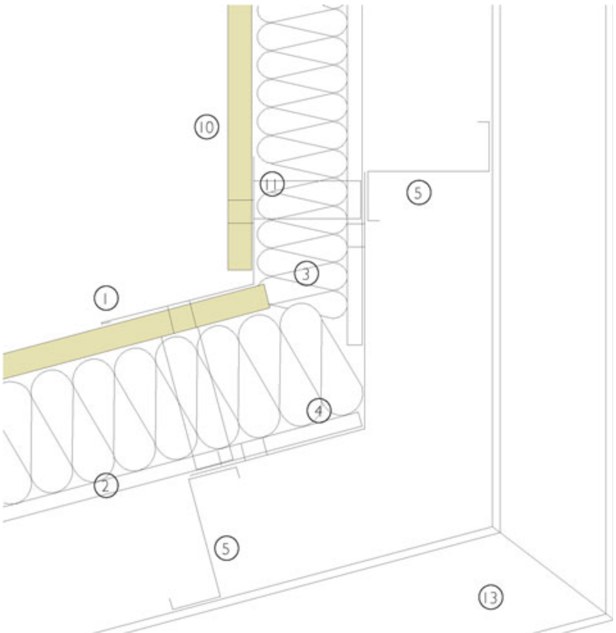
Vertical section 1:10. Edge detail



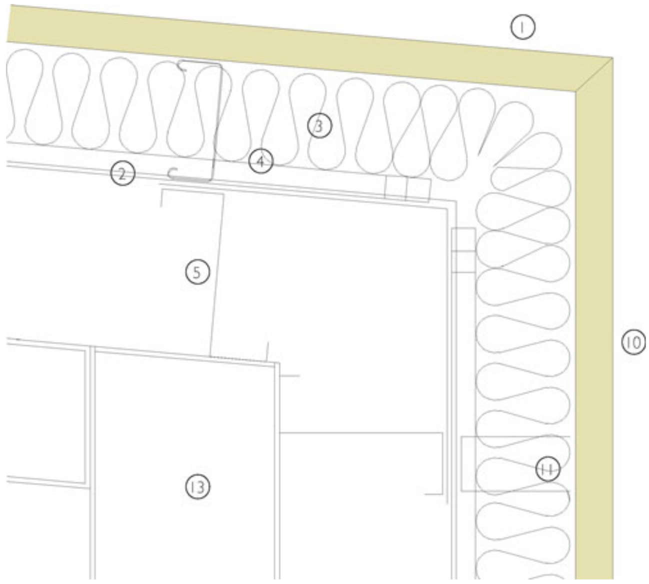
Vertical section 1:10. Eaves detail with gutter



3-D view of eaves detail with gutter



Vertical section 1:10. Connection to vertical roof panel



Vertical section 1:10. Eaves detail

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

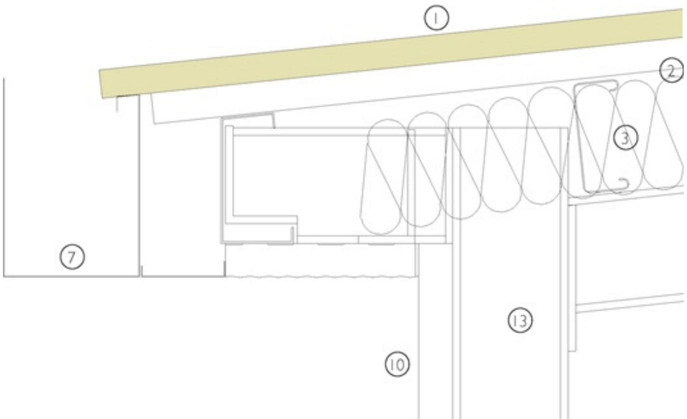
sheet. Even simple rectilinear openings have few standard profiles to close off the gap between the flat flashing and the gaps between the peak and trough of the profile. However, one of the main advantages of profiled metal sheet is its ability to be curved easily, where the supporting structure beneath 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

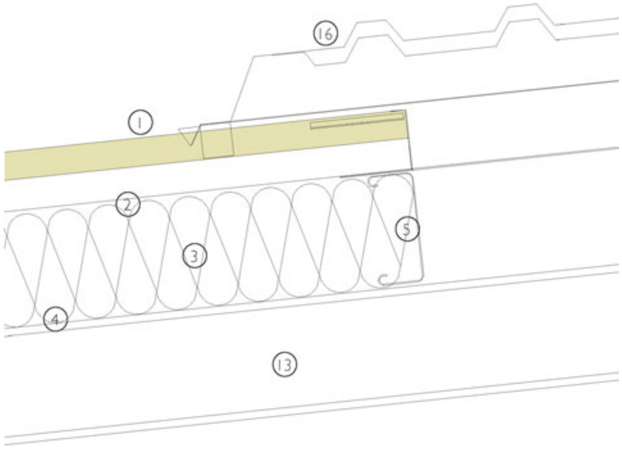
In common with standing seam roofing, profiled metal roofs can be used as a roof covering in either sealed or ventilated construction. Ventilation is used mainly where a timber supporting structure is used, with the timber being ventilated to avoid rot in the material from moist air in the void that 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.

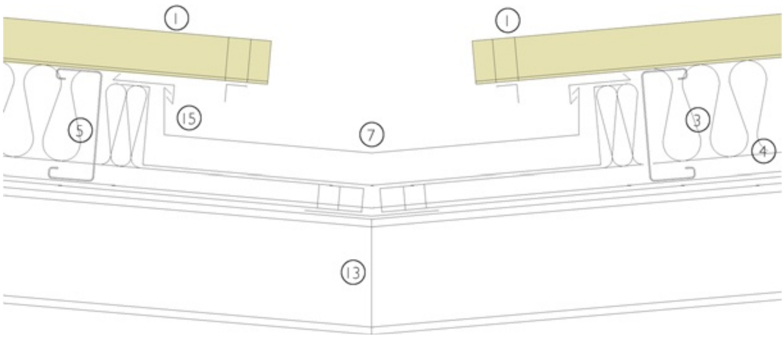
Because the inner lining sheet presents a hard surface under the roof, perforated sheets are used to improve sound absorption. Sound is allowed to be absorbed partly by



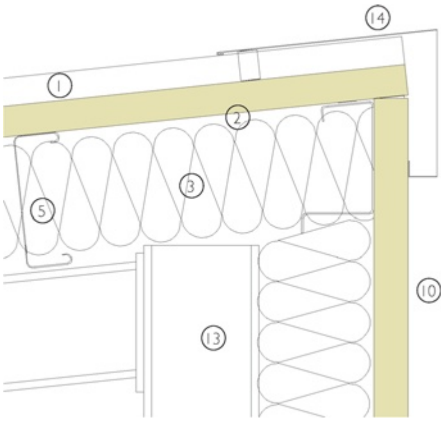
Vertical section 1:10. Eaves with partially concealed gutter



Vertical section 1:10. Profiled metal sheet connection with rooflight



Vertical section 1:10. Valley gutter



Vertical section 1:10. Monopitch edge detail

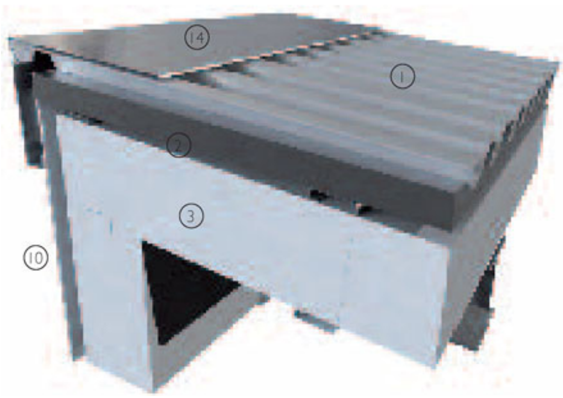
the insulation quilt. This helps to reduce reverberation, particularly in noisy internal environments. A vapour barrier is set between the thermal insulation and the thin layer of acoustic insulation beneath.

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 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.

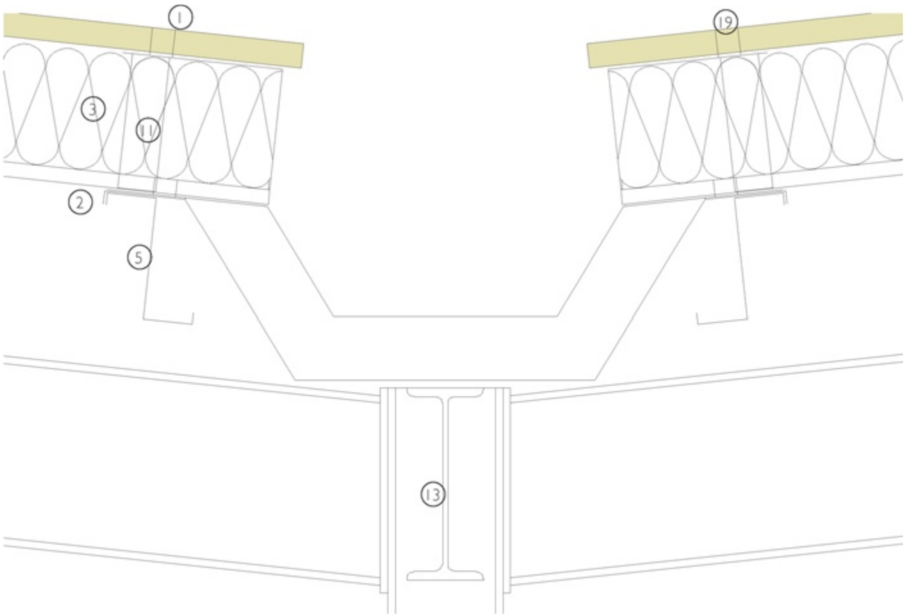
This construction method contrasts with composite panels, where the outer skin, mineral fibre thermal insulation quilt and inner lining are combined into a single panel that is fixed onto a supporting structure which remains visible. The supporting roof structure, visible from below the roof, is either 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

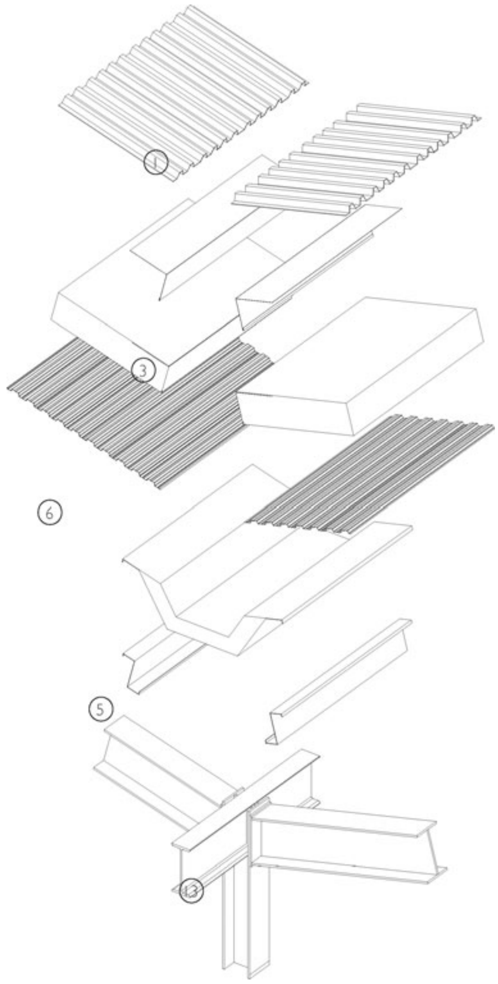


3-D view of monopitch edge detail

3-D view of profiled metal sheet roof with gutter detail



Vertical section 1:10. Prefabricated valley gutter



Exploded axonometric view of gutter detail

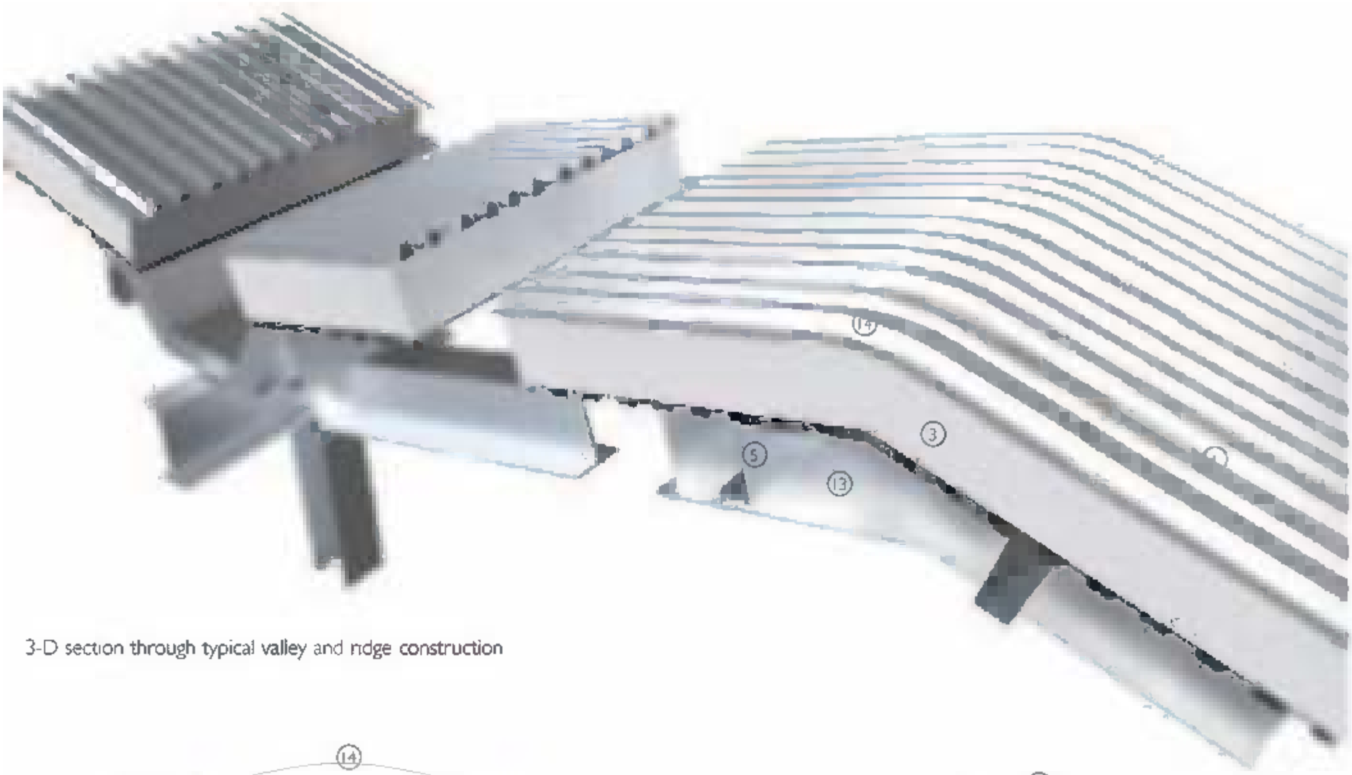
Details
1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved 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

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.

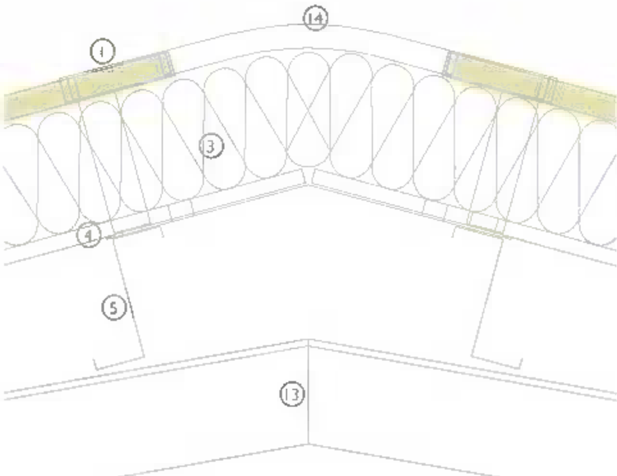
Ridges

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.

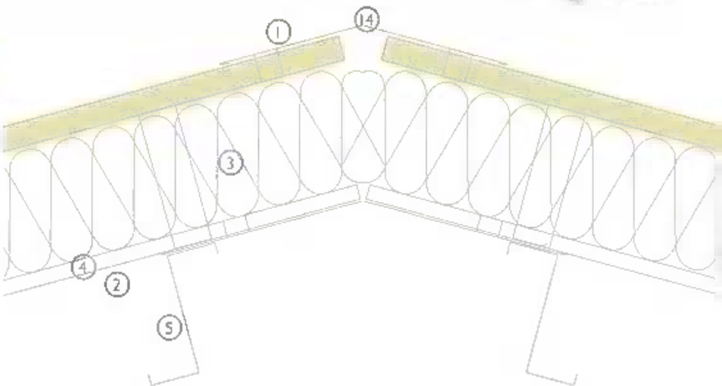
Where a pitched roof meets an abutment with an adjacent wall, the cover strip between wall and roof is folded up the wall and is fixed to it. A flashing projecting from the wall is lapped over the outside of the ridge strip in order to direct rainwater over it and down onto the roof.



3-D section through typical valley and ridge construction



Vertical section 1:10. Ridge detail



Vertical section 1:10. Ridge detail

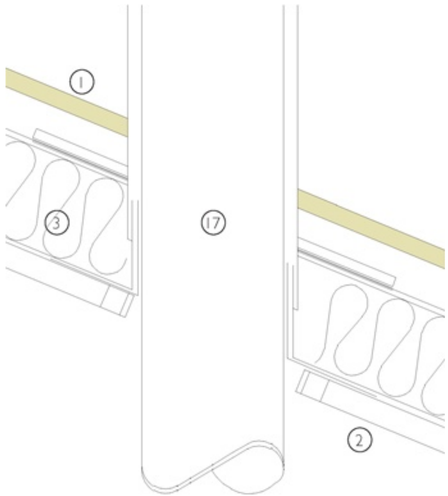
Openings

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 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 which carry only 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.

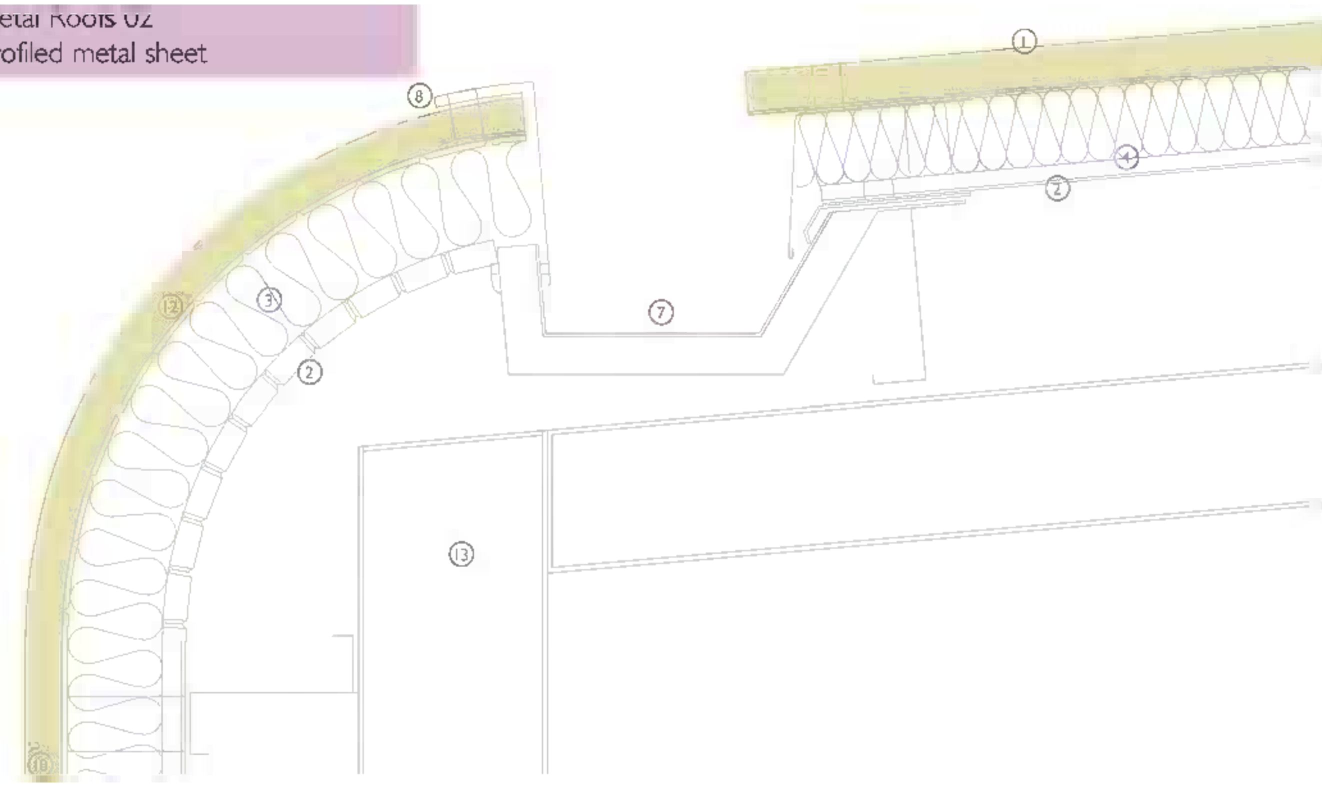
Penetrations for small ducts and pipes through the roof are sealed with a flashing, usually welded to form a single upstand collar around the pipe and fixed to the roof deck. Also in common with standing seam roofs, a counter flashing is welded or bonded to the upper part of the pipe, above the roof, which laps down over the flashing to protect it from rainwater running down the pipe above the roof level.

Eaves and parapets

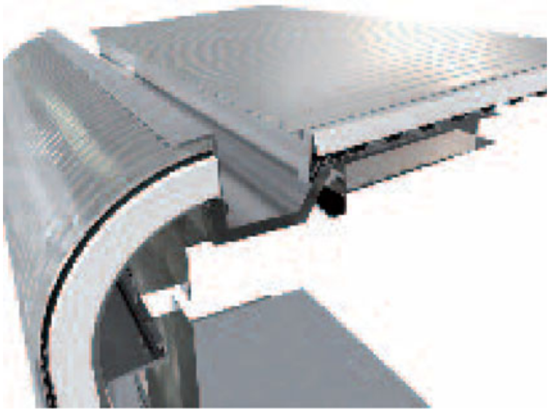
Parapets are formed by creating a gutter at the base of the profiled sheet, then continuing the line of the gutter up to a parapet coping with laps over the top. The gutter is formed from a single folded sheet to avoid the possibility of leaks, and is lapped under the vertical sheet that forms the seal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



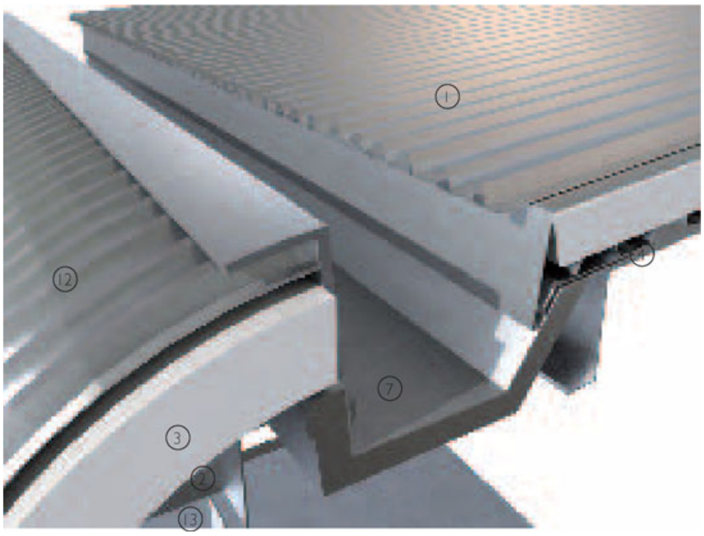
Vertical section 1:10. Roof penetration



Vertical section 1:10. Curved profiled metal sheet roof with concealed gutter



3-D view of curved profile metal sheet roof with gutter



3-D detail view of curved profile metal sheet roof with gutter

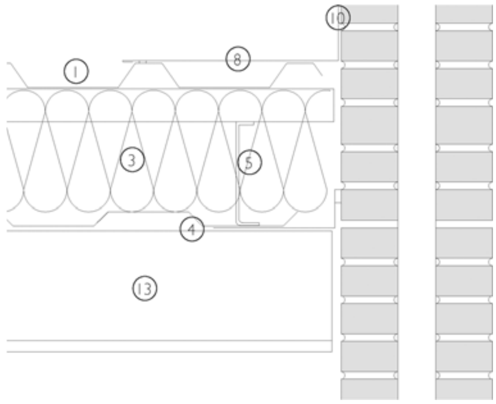
Details
1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved 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

external wall is formed in a different material, 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 allow 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 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.

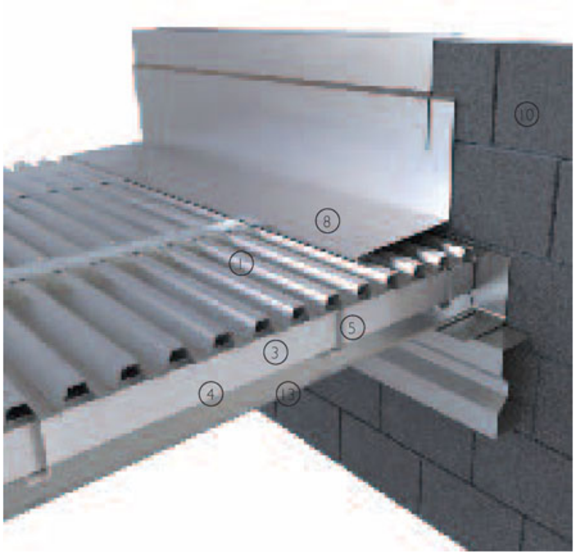
Ridges and valleys

These folds in metal roofs are formed using the same methods discussed in the previous section on standing seam roofs. However, whereas standing seams can be cut down to form a flat ridge without a projecting ridge piece, this is 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

3-D view of profiled metal wall and roof with vertical gutter



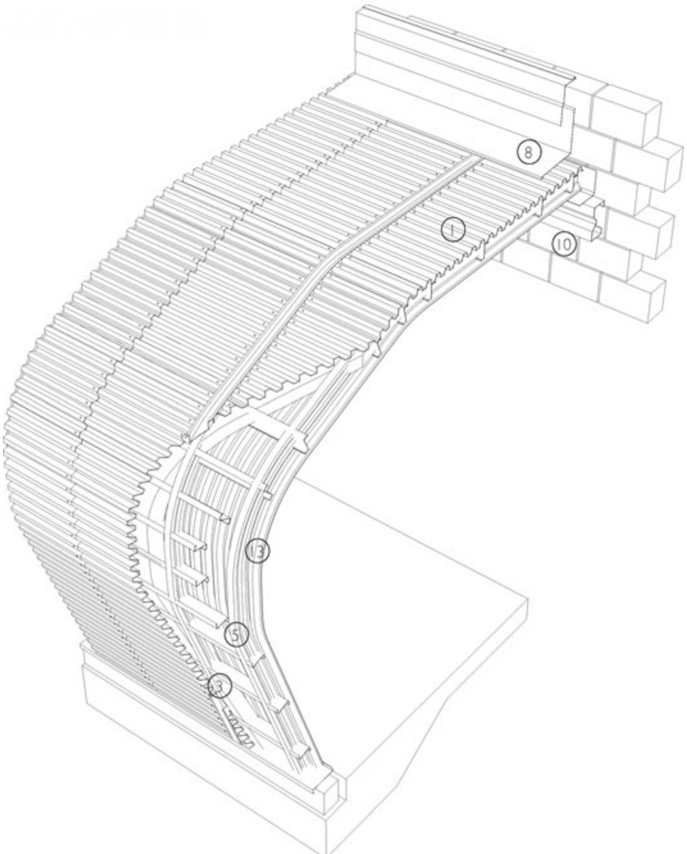
Vertical section 1:10. Connection to masonry wall.



3-D view of junction between profiled metal roof and wall

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.

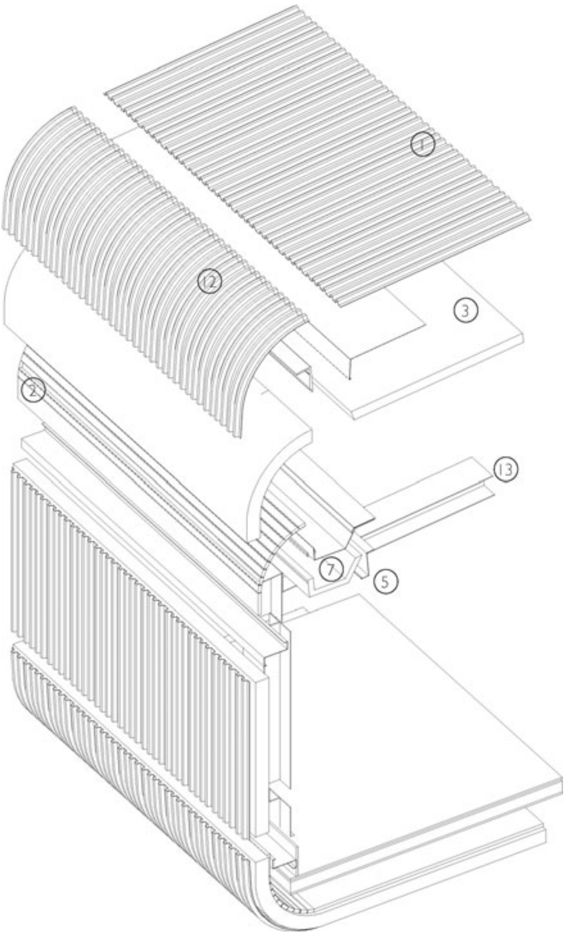
Valleys are also formed in a similar way to that discussed in standing seam roofs, with a ventilation gap provided in the gap between the gutter and the underside of the roofing sheet.



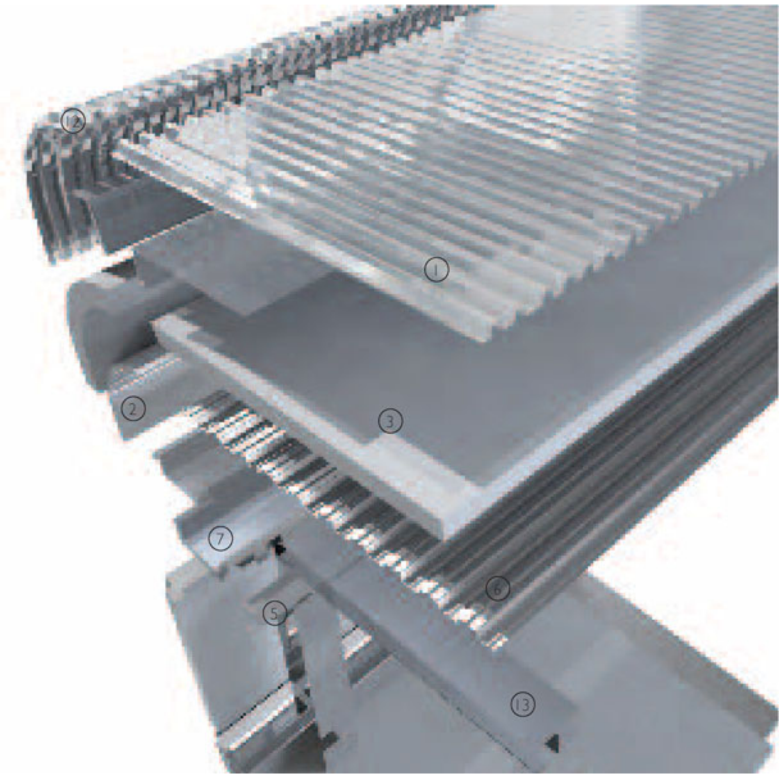
3-D cutaway view of profiled metal roof with vertical gutter

3-D cutaway view of profiled metal sheet roof with gutter

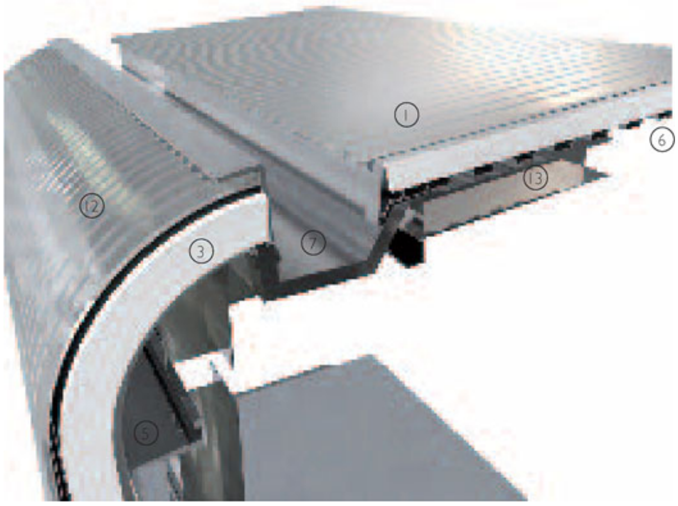
3-D view of profiled metal sheet roof construction



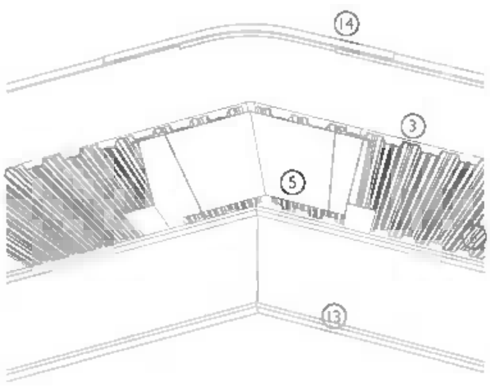
Exploded axonometric view of profiled metal sheet roof with gutter



3-D exploded view of profiled metal sheet roof with gutter

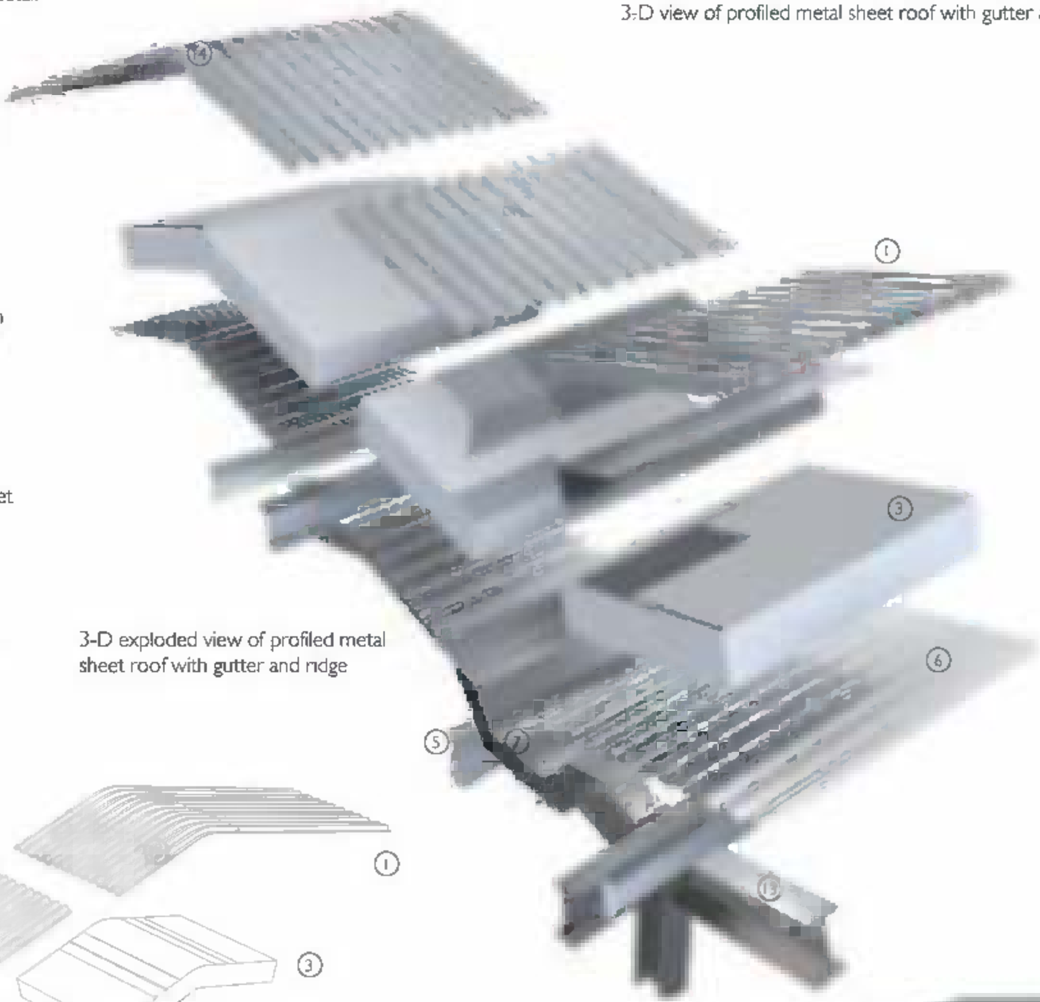


3-D view of profiled metal sheet roof with gutter



3-D line drawing of ridge detail

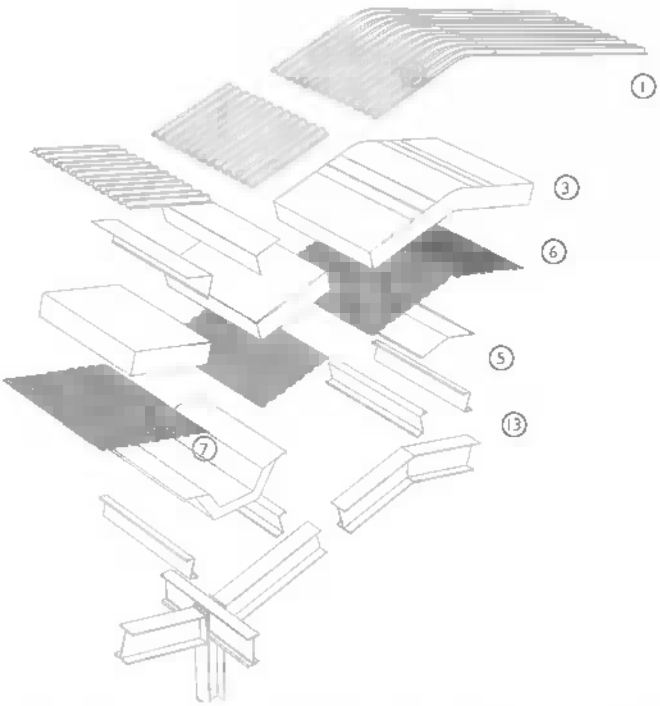

3-D view of profiled metal sheet roof with gutter and ridge



3-D exploded view of profiled metal sheet roof with gutter and ridge

Details

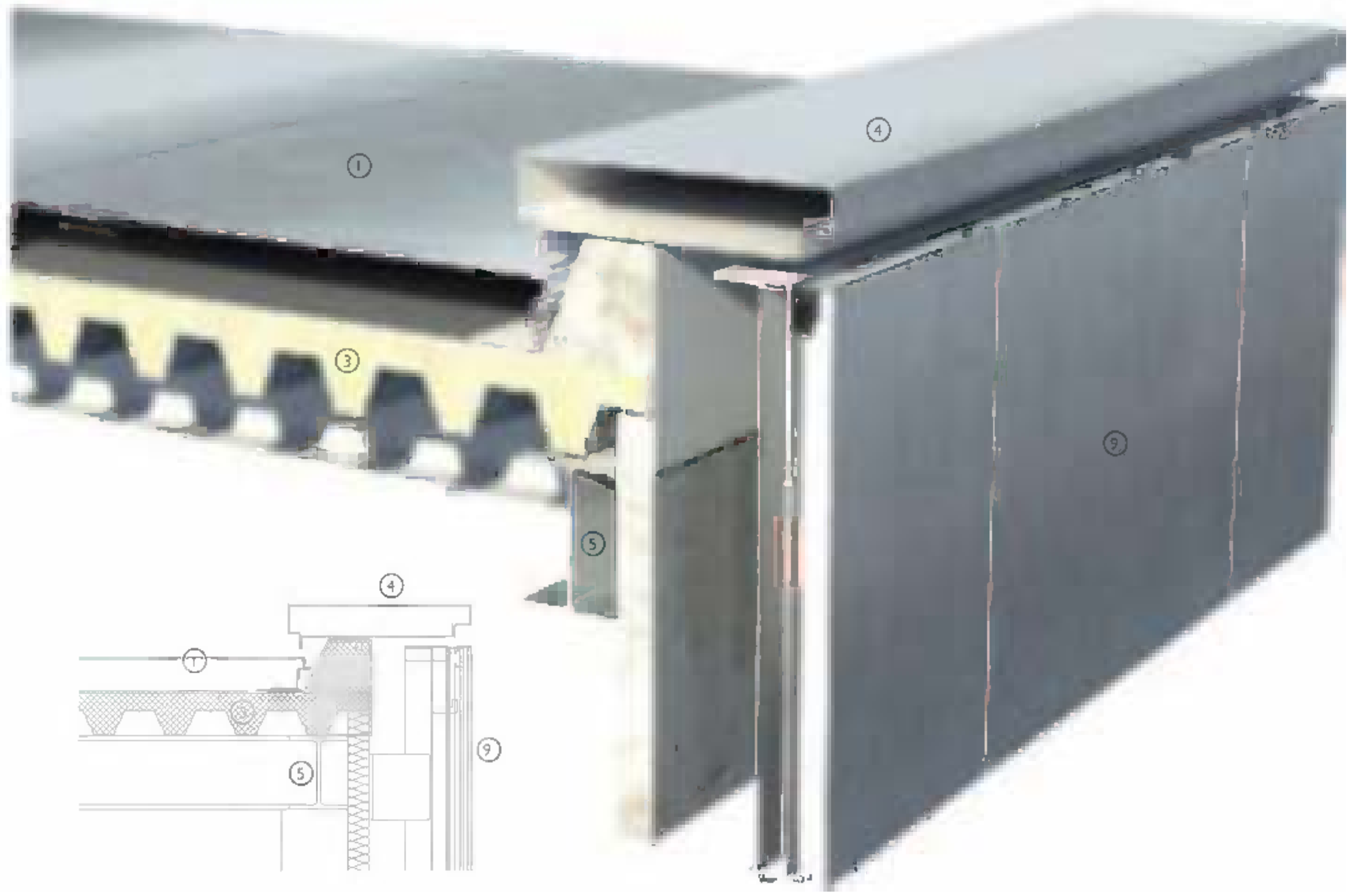
1. Outer profiled metal sheet
2. Inner lining sheet
3. Fibre quilt thermal insulation
4. Vapour barrier
5. Purlin or structural beam
6. Profiled metal structural deck
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Curved eaves sheet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



Exploded axonometric view of profiled metal sheet roof with gutter and ridge

3-D cutaway view of profiled metal sheet roof with gutter and ridge

3-D view showing parapet edge and composite panel roof assembl



Vertical section 1:25. Composite panel parapet condition

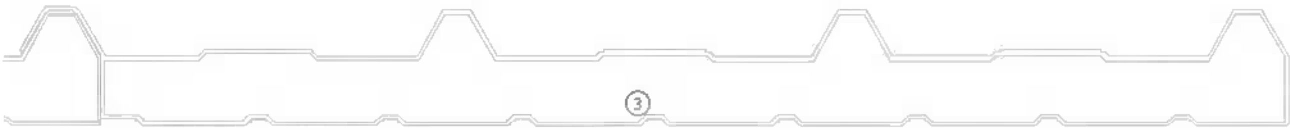
There are two types of composite panel used for roofs: twin wall and single wall panels. The first is a development of profiled metal sheet, where outer sheet, thermal insulation and inner sheet are combined into a single panel. These are used in pitched roofs and have an appearance very similar to that 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

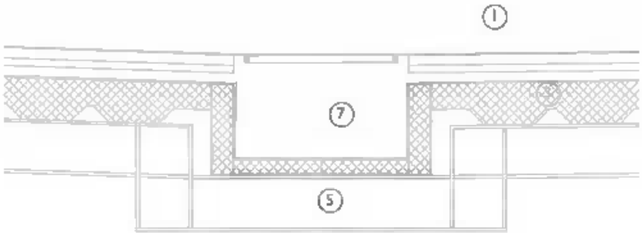
This panel type has a single sheet of profiled metal on the lower loadbearing face of the panel which is bonded to a foam-based insulation that fills all the voids in the profiled sheet, providing a smooth, flat upper surface. The depth of the thermal insulation is determined by the U-value required, 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 usually 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

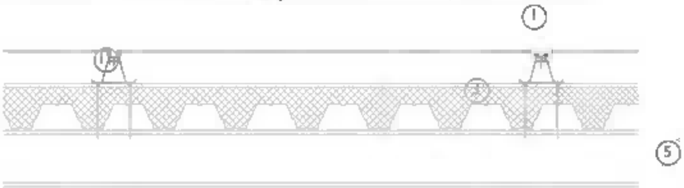


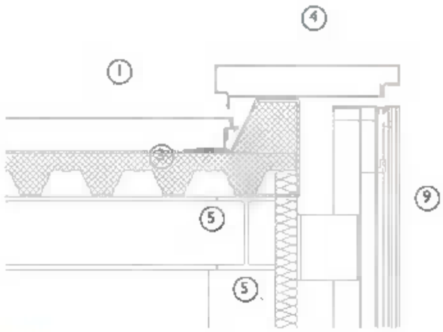
Vertical section 1:5: Composite panel showing panel to panel junction

3-D view of vertical section through parapet edge and folded metal gutter between panels

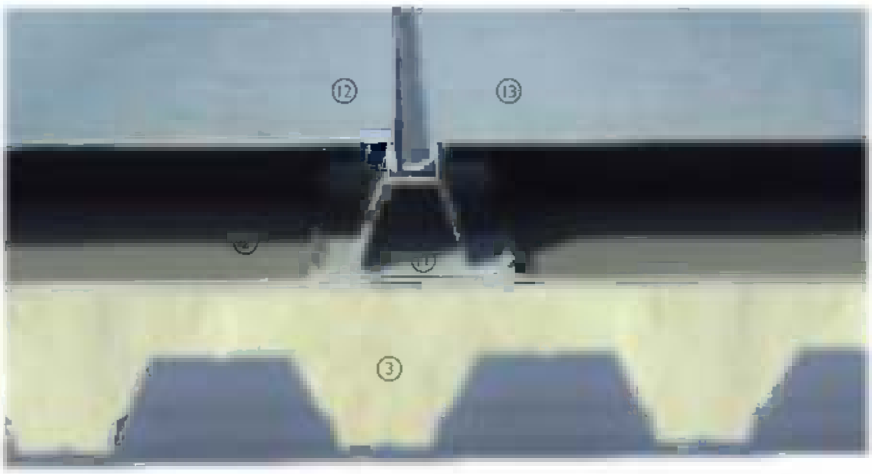


Vertical section 1:25. Folded metal gutter between composite roof panels





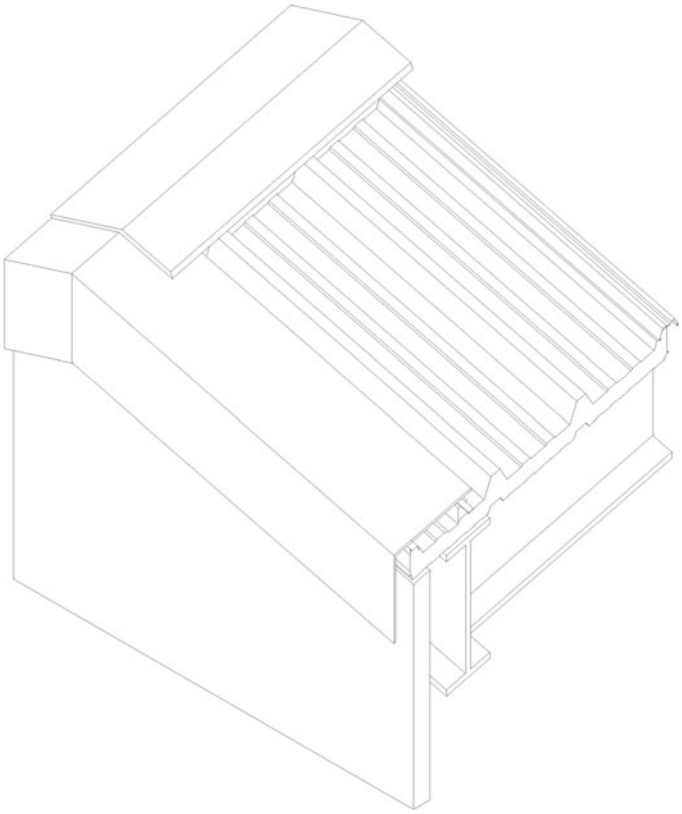
Vertical sections 1:25. Composite panel configuration and parapet edge condition



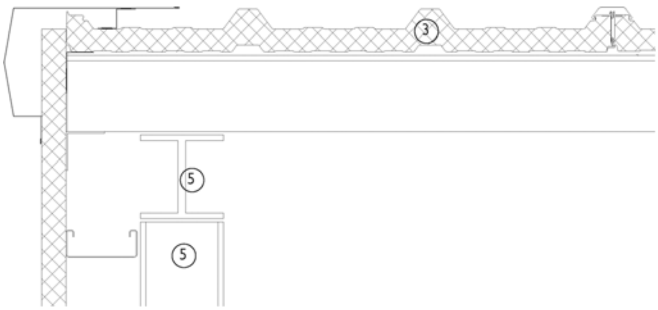
3-D view of panel connection

Details

1. Metal rainscreen panel
2. Single layer membrane
3. Composite panel
4. Folded metal coping
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



Isometric view showing composite panel roof system with metal flashing



Vertical section 1:10. Composite panel roof system with metal flashing

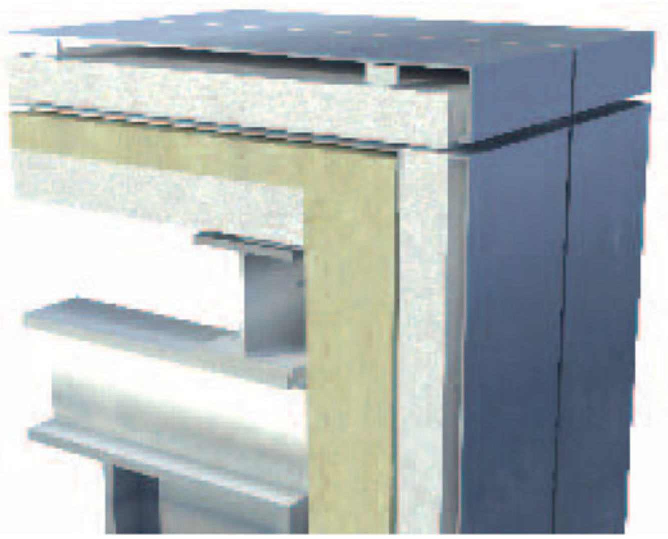
3-D view showing composite panel roof system beneath metal rainscreen

Details
1. Metal rainscreen panel
2. Single layer membrane
3. Composite panel
4. Folded metal coping
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

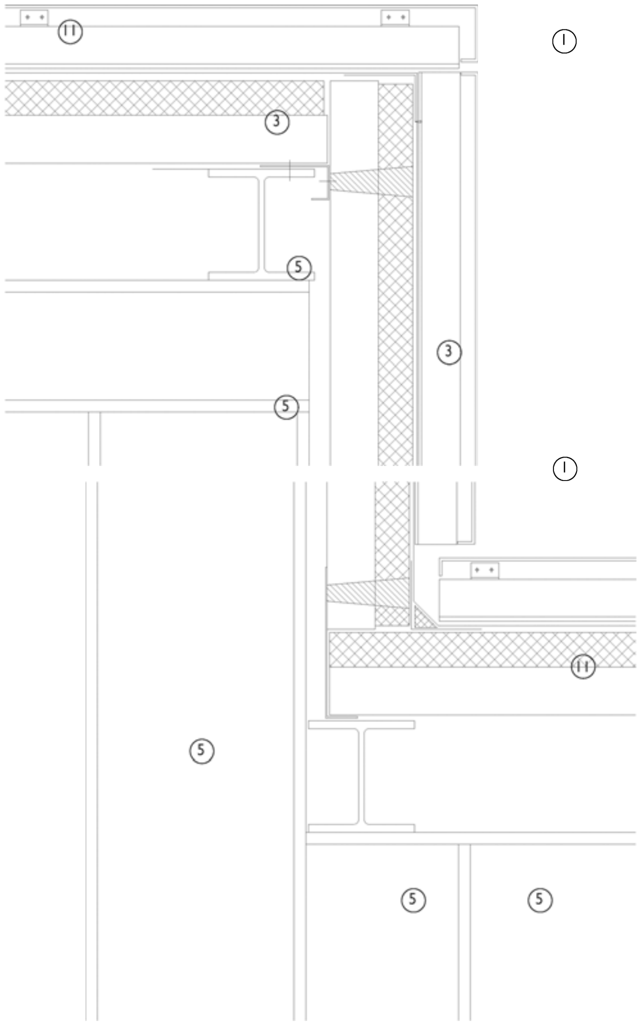
material is bonded along the joint to provide a weathertight seal.

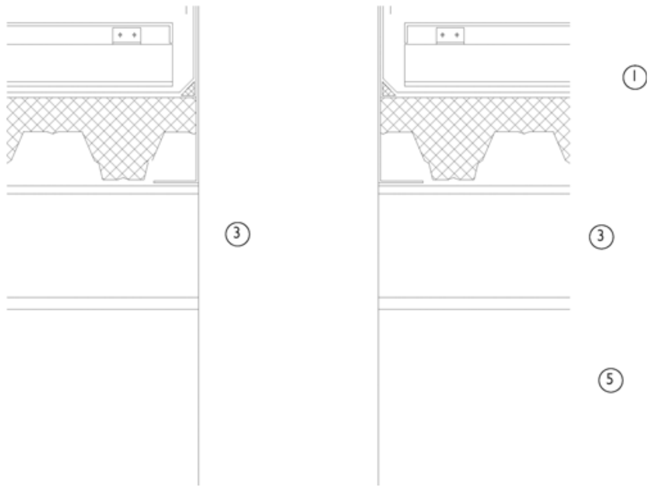
At parapet gutters, an upstand is formed in the same insulation material as that used in the composite panels, the upstand being bonded to the composite panel beneath. The outer edge of the upstand is sealed and stiffened with a metal strip fixed to the underside of the composite roof panel or the supporting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

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 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 mem-



3-D view showing metal rainscreen roof parapet condition





Vertical section 1:10. Composite panel roof system beneath metal rainscreen

brane, which is typically bonded to the base and edges of the gutter in order to closely follow its shape.

Twin wall panels

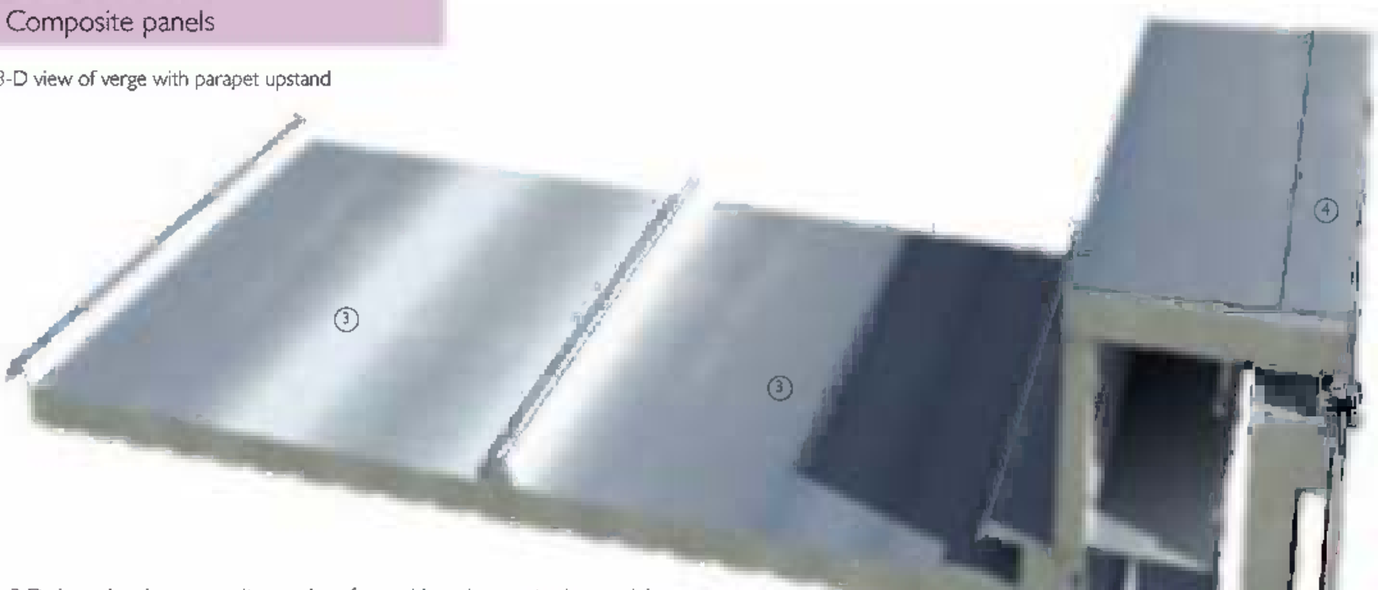
This panel type, which combines the separate components of profiled metal sheet, has two joint types: a double seam with a cap on top in the manner of standing seam roofing, or a single lap of profile in the manner of profiled metal decking. With the first method, panels have raised edges on their long sides running down the slope. The raised edges are butted together and sealed with butyl tape. A metal capping is fixed over this joint to provide a weathertight 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, 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.

Ridges

Ridges for twin wall composite panels are formed by fixing a metal flashing over the junction between the panels. The flashing is

3-D view corner condition of composite panel roof system beneath metal rainscreen

3-D view of verge with parapet upstand



3-D views showing composite panel roof assembly and parapet edge condition

profiled to match the profile 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 on 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 conceal, 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

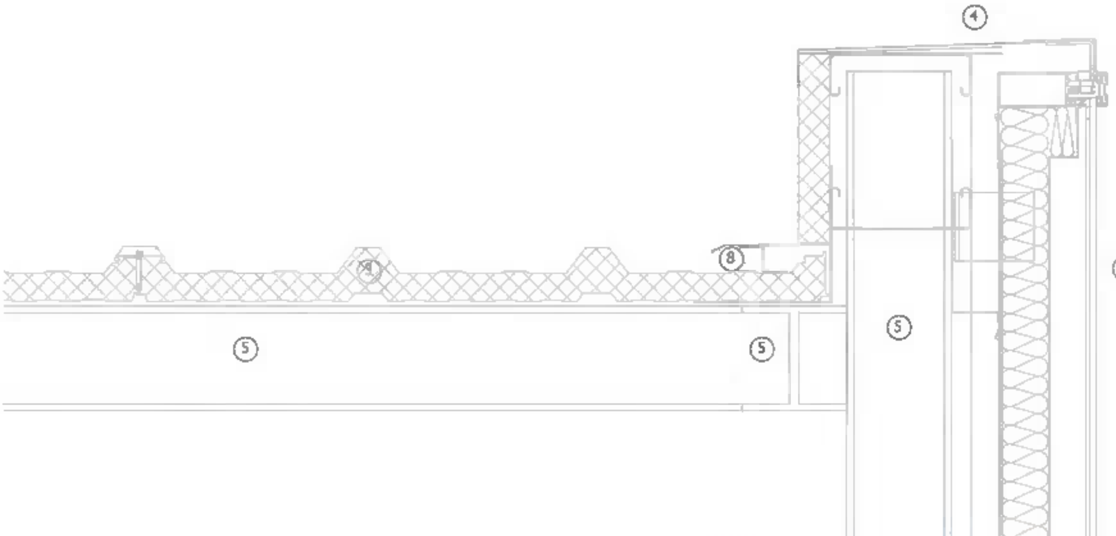
Verges between composite panels and the adjacent wall construction are formed with a folded metal closer. Where composite panels form the wall construction, a folded metal strip is sealed to the top of the last 'peak' on the roof panel and is then sealed against the wall panel. Alternatively, a Z-section 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 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.

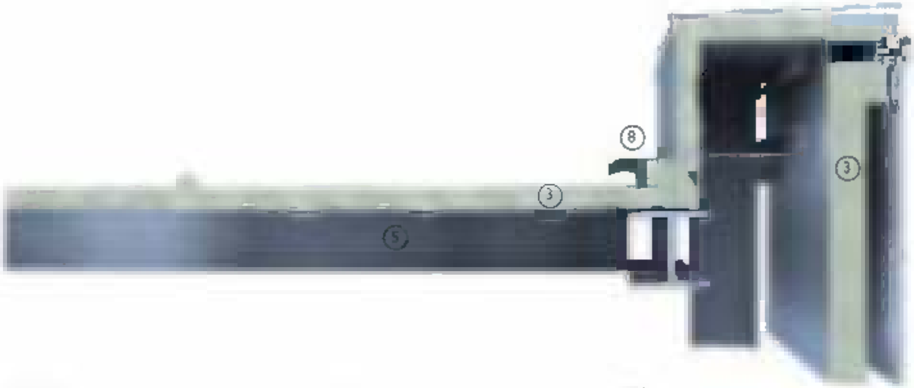
Verges that terminate in a parapet use a flashing that is set behind the vertical panel, or onto it to avoid a thermal bridge, and is folded to be sealed onto the composite roof panel in the same way as for the eaves detail. The inner face of the joint is sealed with a folded metal closer strip to provide 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, 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



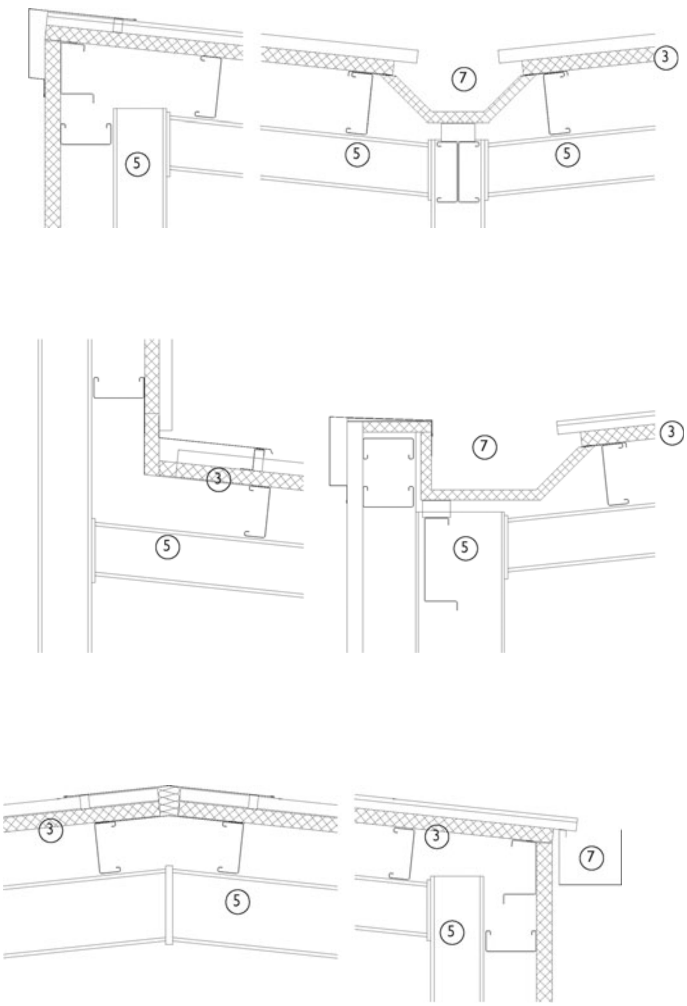
Vertical section 1:10. Composite panel configuration and parapet edge condition



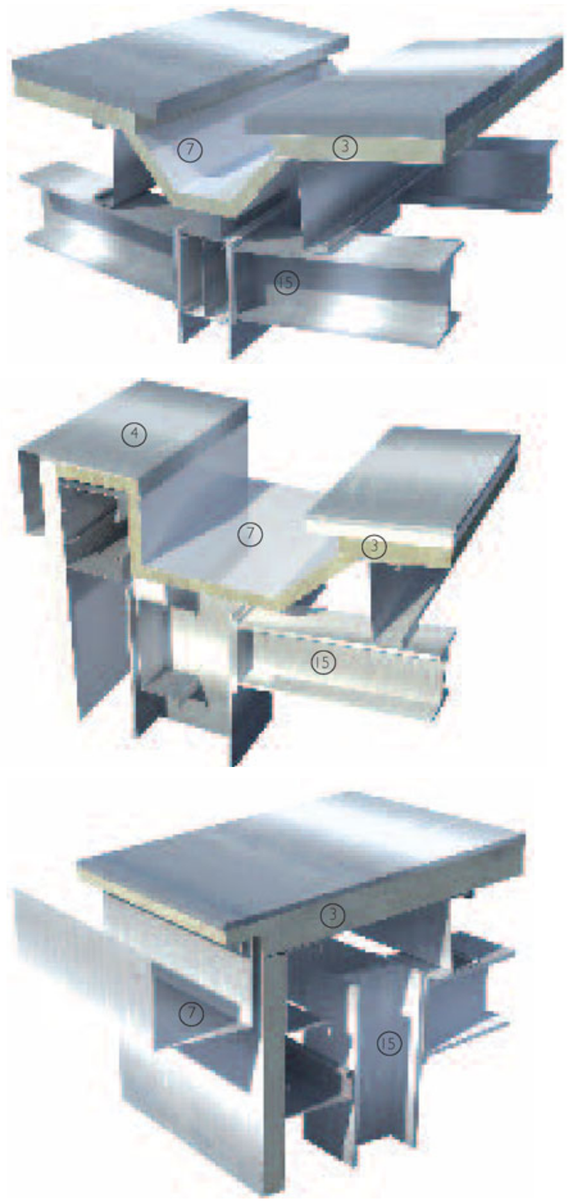
3-D views showing composite panel roof assembly and parapet edge condition

Details

1 Metal rainscreen panel
2 Single layer membrane
3. Composite panel
4 Folded metal coping
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



Vertical sections 1:10. Various gutter configurations in composite roof panels



3-D views showing various gutter configurations in composite roof panels

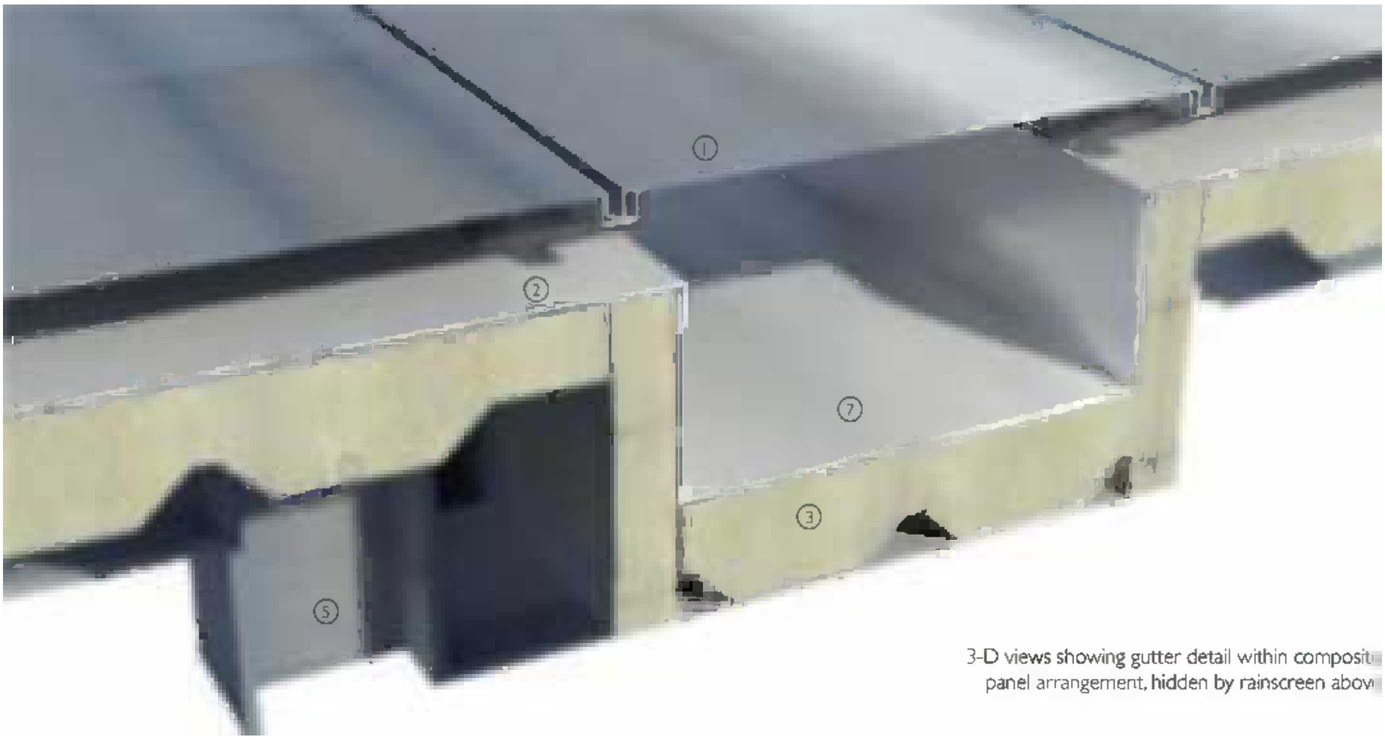
3-D view showing potential gutter configuration in composite panel roof assembly

to the primary structure, or by a metal support arm set onto the top of the composite panels '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.

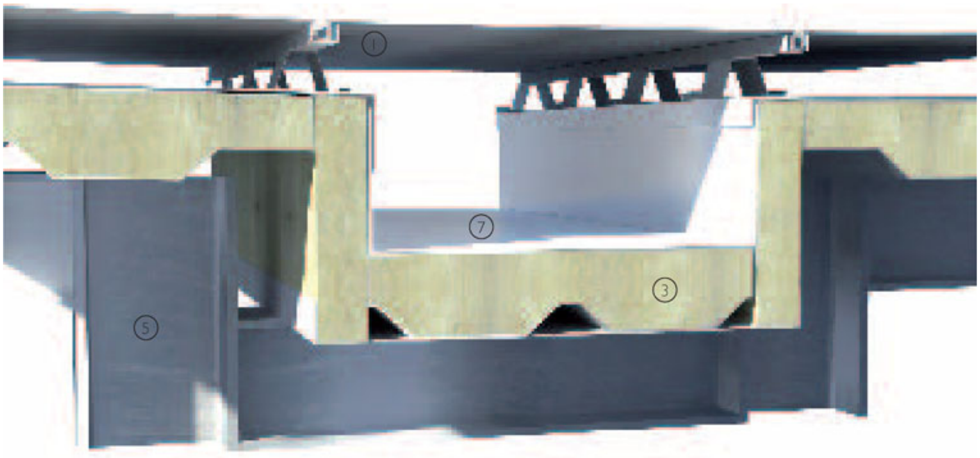
Parapets and valley gutters

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 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 than 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



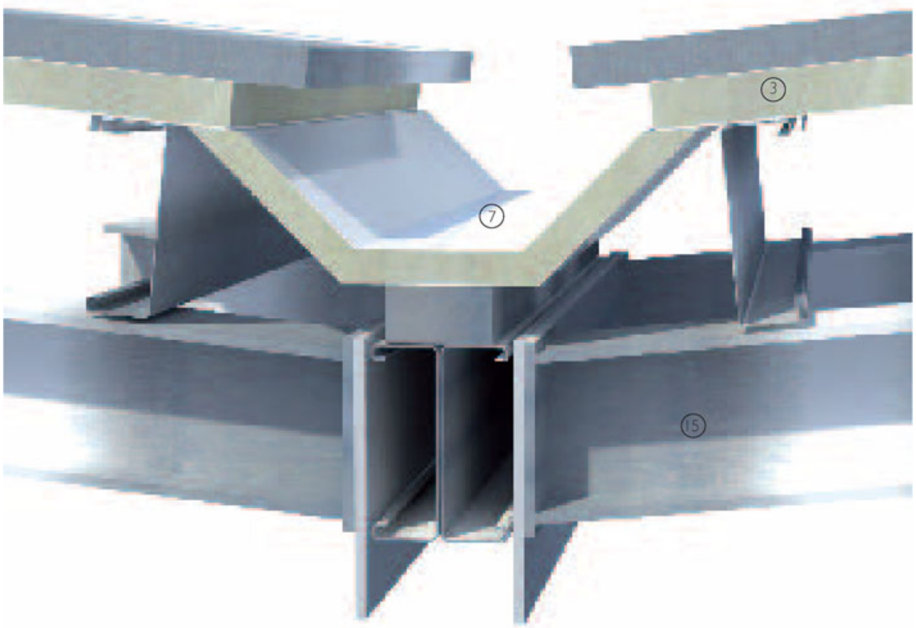
3-D views showing gutter detail within composit
panel arrangement, hidden by rainscreen abov



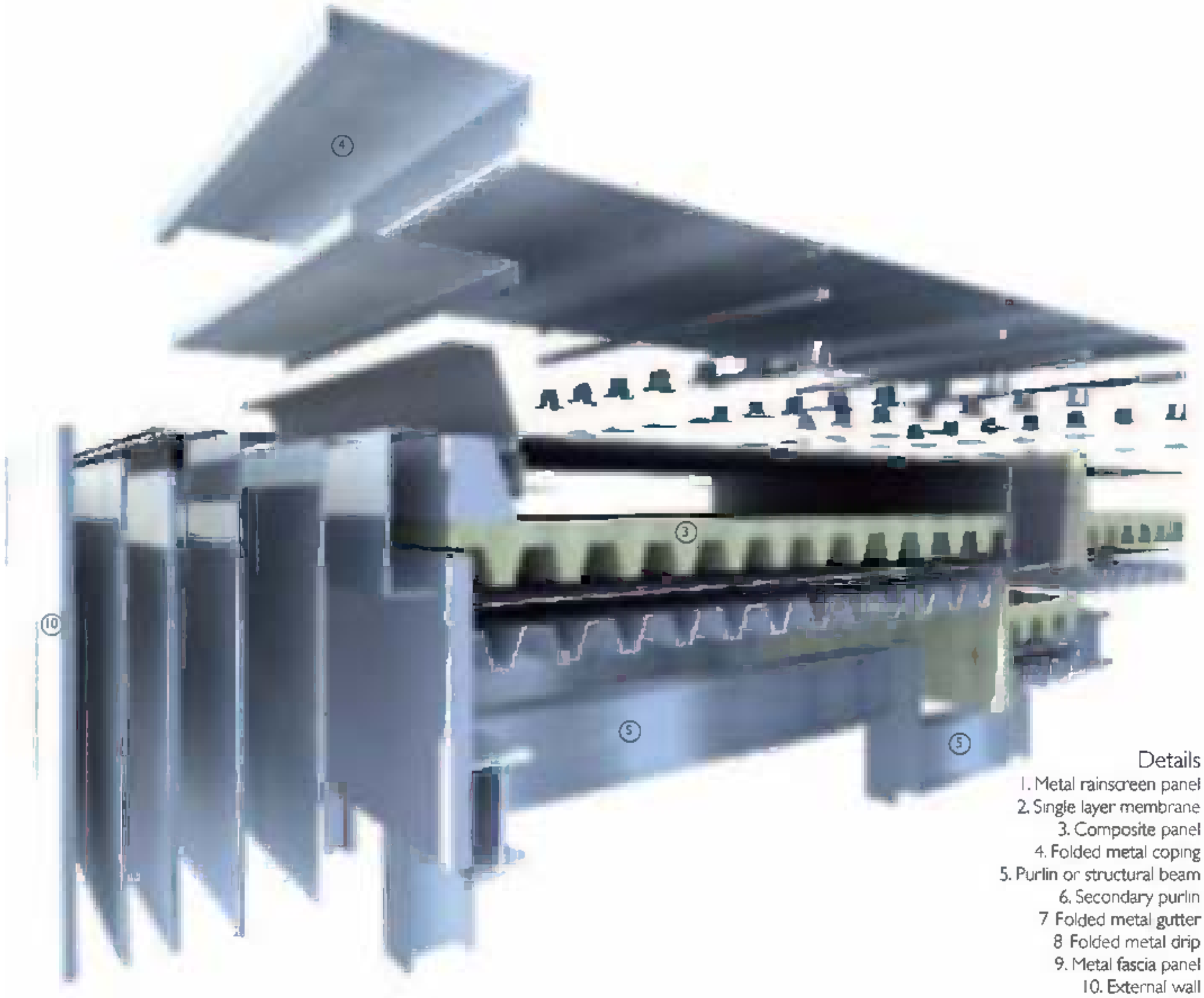
Details
1. Metal rainscreen panel
2. Single layer membrane
3. Composite panel
4. Folded metal coping
5. Purlin or structural beam
6. Secondary purlin
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Panel 1
13. Panel 2
14. Ridge piece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

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.

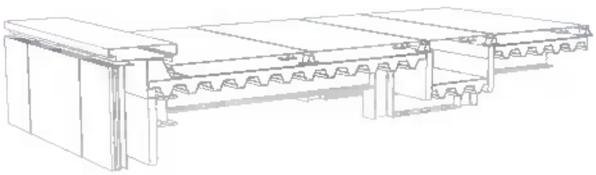


3-D view showing gutter detail in centre of composite panel roof assembly

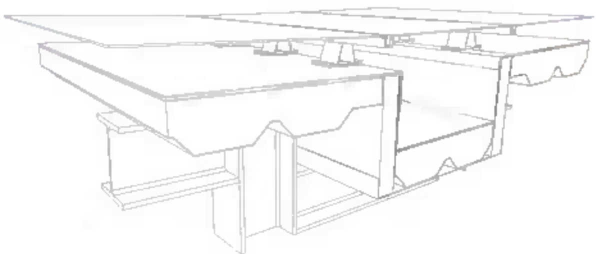


3-D exploded view showing composite panel roof assembly beneath metal rainscreen

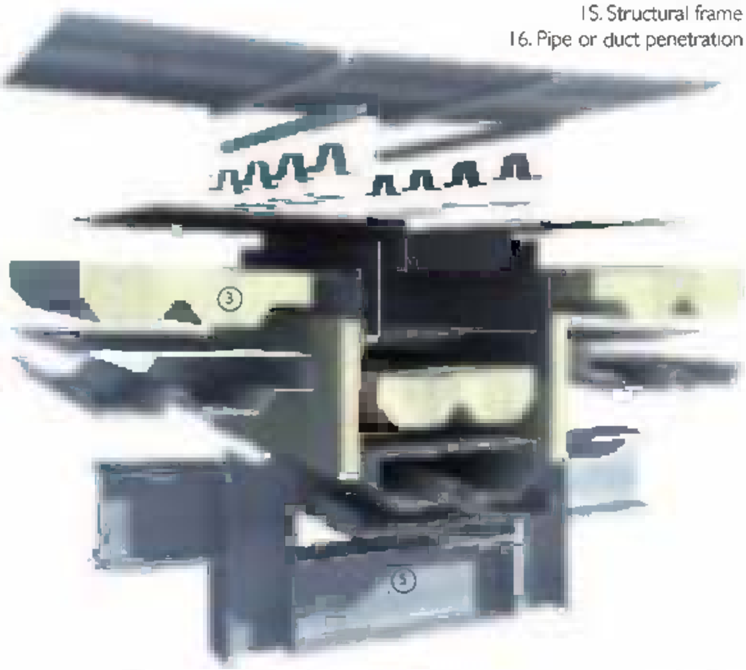
Details
1. Metal rainscreen panel
2. Single layer membrane
3. Composite panel
4. Folded metal coping
5. Purlin or structural beam
6. Secondary purlin
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Panel 1
13. Panel 2
14. Ridge piece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



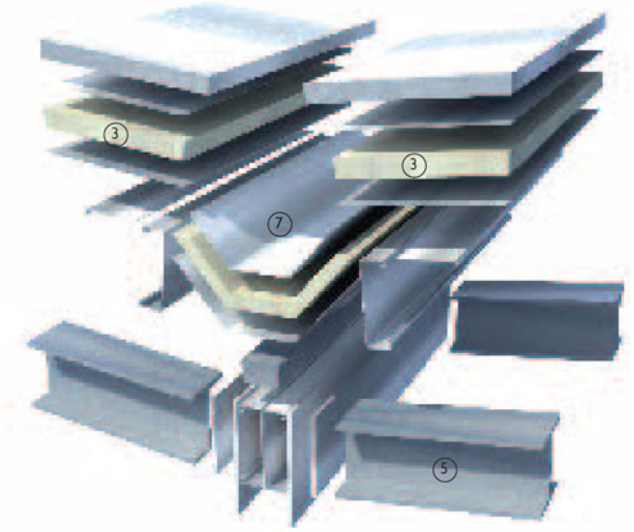
3-D view showing composite panel roof arrangement, hidden by rainscreen above



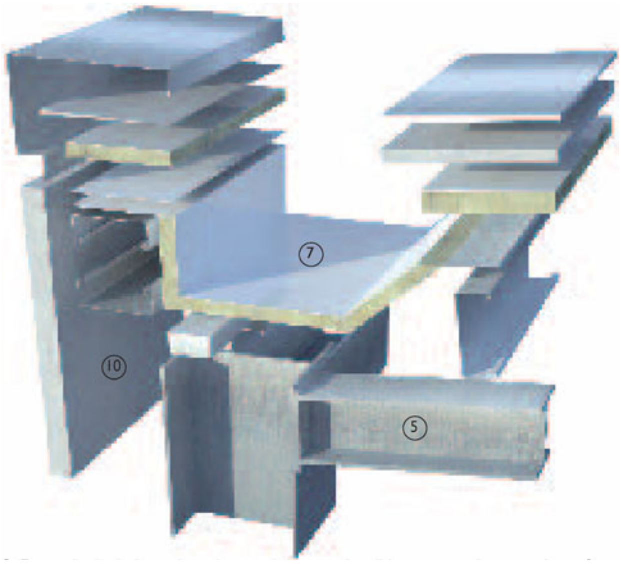
3-D view showing gutter detail within composite panel arrangement, hidden by rainscreen above



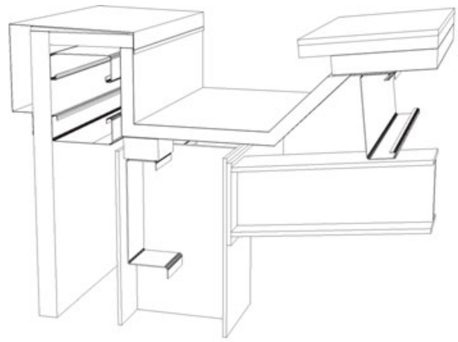
3-D exploded view showing gutter detail within composite panel arrangement, hidden by rainscreen above

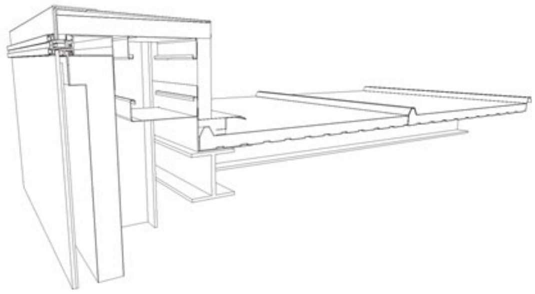


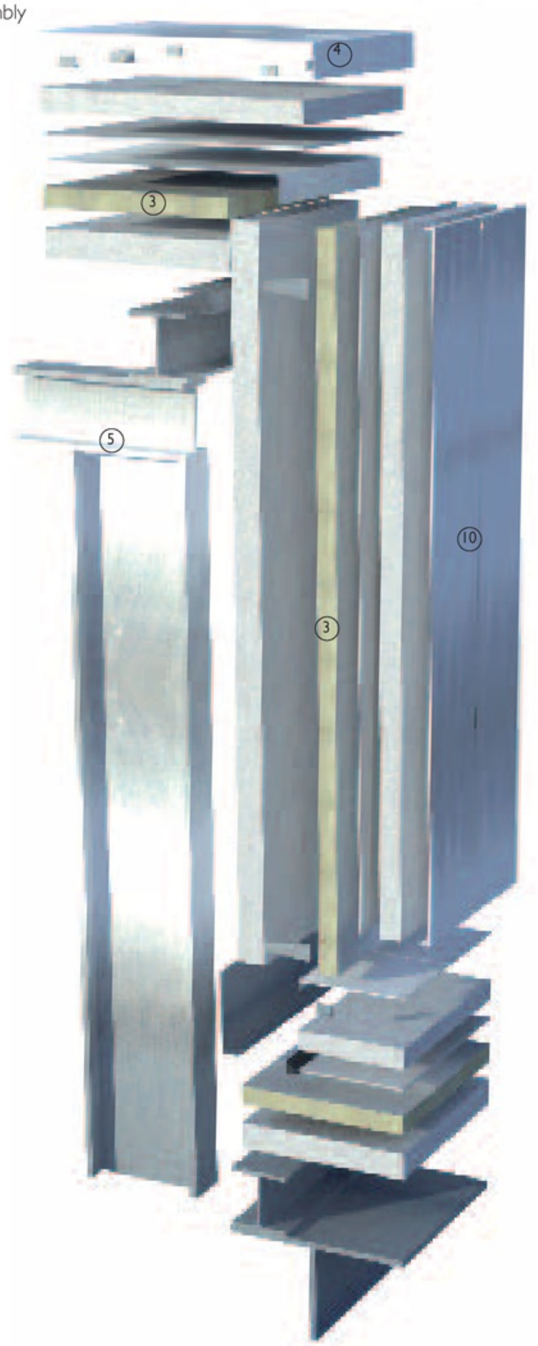
3-D exploded view showing central gutter detail in composite panel roof assembly



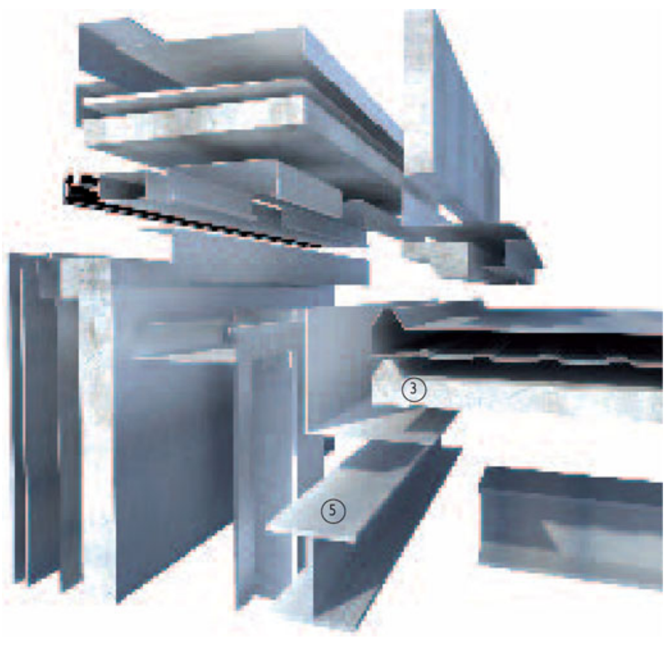
3-D exploded view showing end gutter detail in composite panel roof assembly



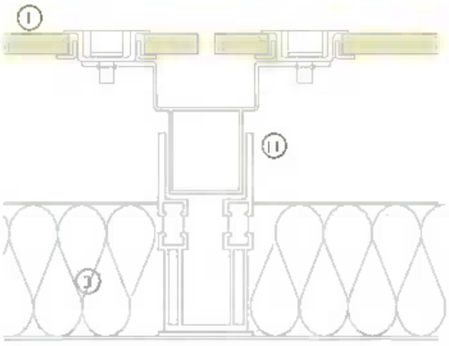




3-D exploded view showing gutter detail within composite panel arrangement, hidden by rainscreen above

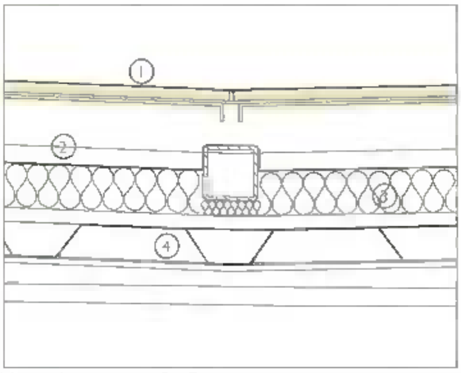


3-D exploded view showing parapet detail in composite panel roof assembly

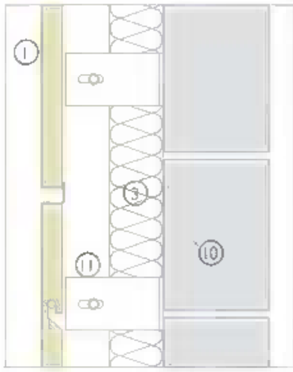


Vertical section 1:10 through roof assembly

3-D view of metal rainscreen roof assembly



Vertical section 1:10. Connection between metal sheets

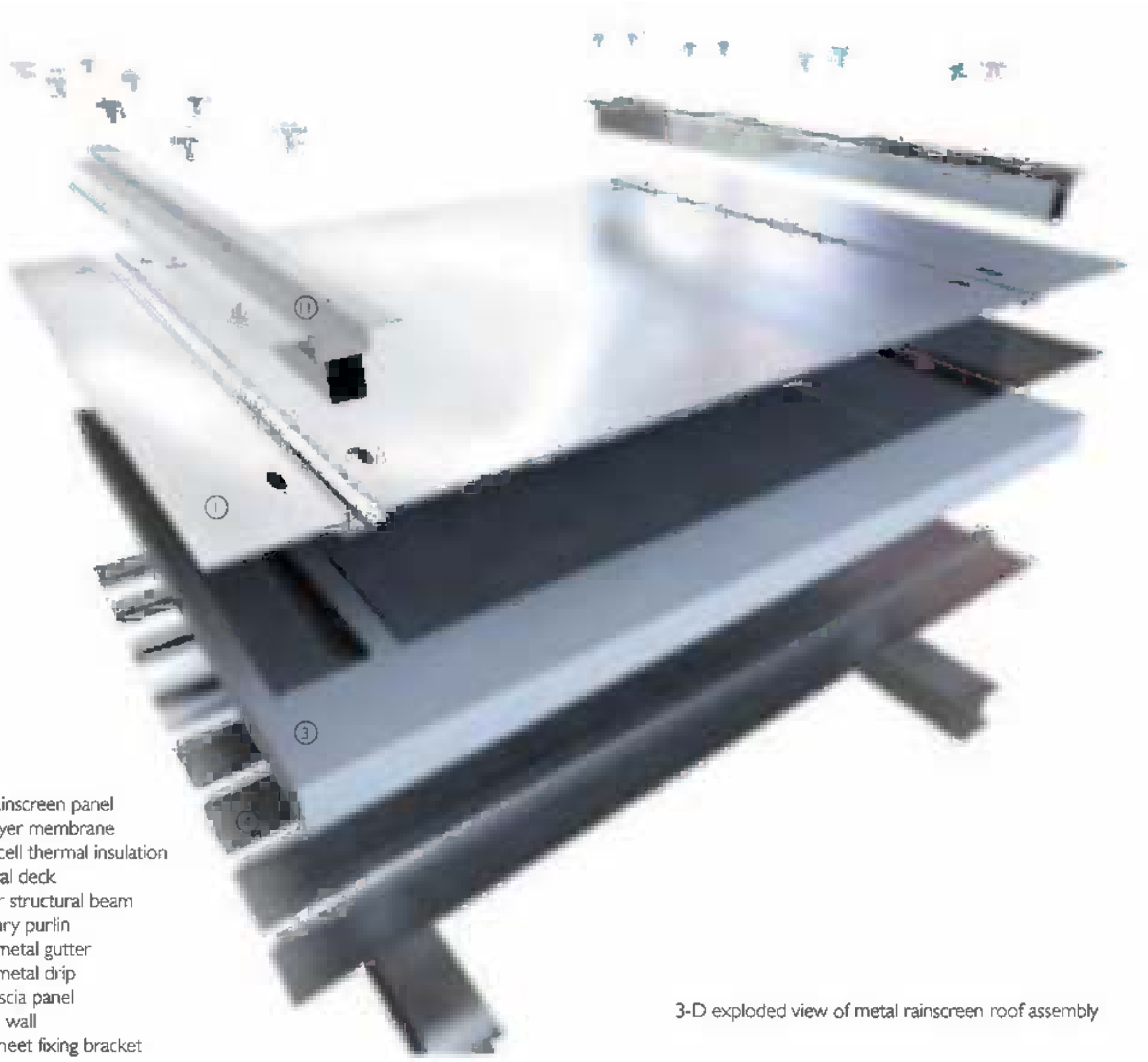


Vertical section 1:10. Rainscreen cladding typ. construction

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.

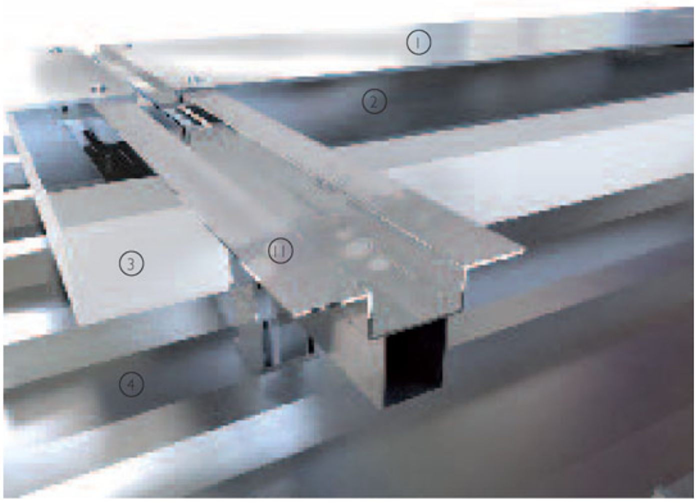
In contrast, metal rainscreens for roofs vary considerably from the configuration used in external walls. Firstly, most of the rain falling onto a metal rainscreen roof is not usually drained away on the outer layer of panels, unless the roof has a relatively steep pitch or curved section. Rainwater 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 provide 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 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 lifecycle of the roof.

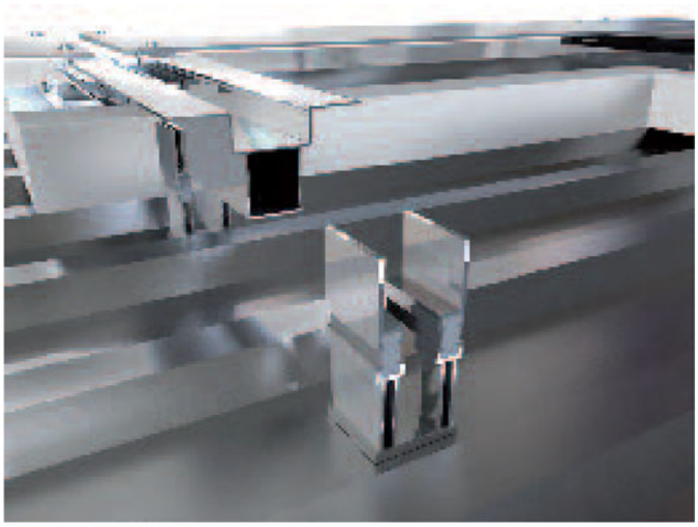


Details
- Metal rainscreen panel
- Single layer membrane
- Closed cell thermal insulation
- Structural deck
- Purlin or structural beam
- Secondary purlin
- Folded metal gutter
- Folded metal drip
- Metal fascia panel
0. External wall
1. Outer sheet fixing bracket
2. Panel 1
3. Panel 2
4. Ridge piece
5. Structural frame
6. Pipe or duct penetration

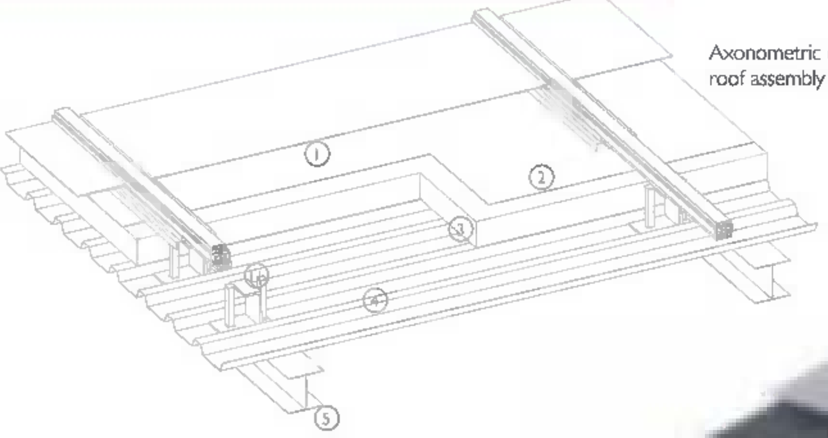
3-D exploded view of metal rainscreen roof assembly



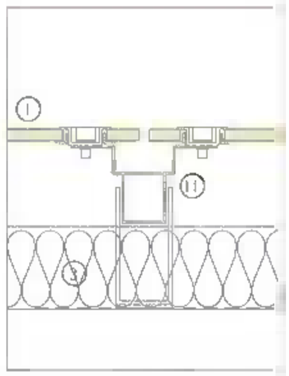
3-D view of metal rainscreen roof fixing channel



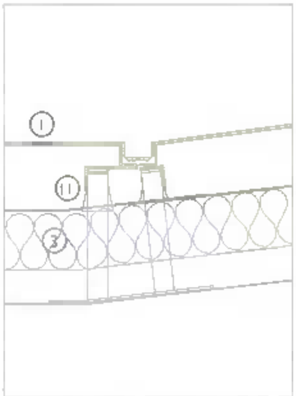
3-D view of metal rainscreen roof support system



Axonometric drawing of metal rainscreen roof assembly with capping to seam



Vertical section 1:10 Metal panel fixed to support rail system



Vertical section 1:10 Fixing detail of metal panels

3-D view of metal rainscreen roof assembly with capping to seam

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 panels 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 ten 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. 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.

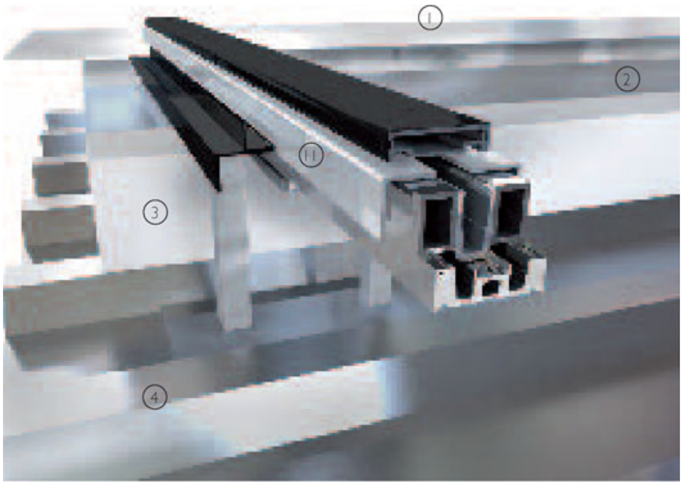
An alternative fixing method for panels is to set screws in each corner of the face of the panel onto a support rail system. Screw heads are difficult to coat in a colour that matches the panel, and even if this is achieved, then scratching of the panel is likely as a result of removing panels for maintenance 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

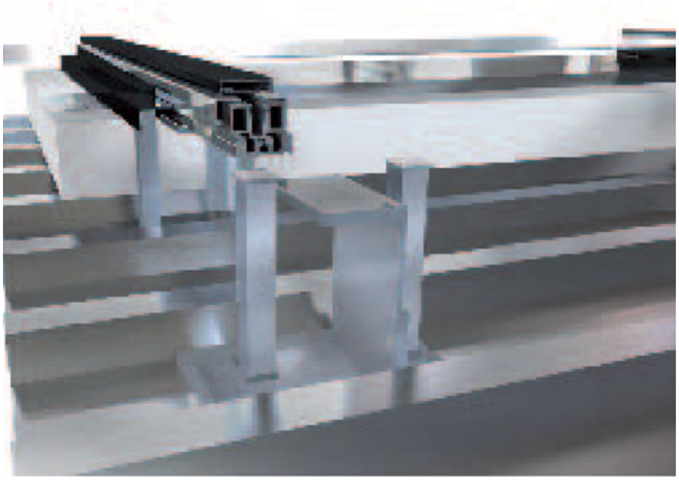
An advantage of rainscreen panels for parapets is that the gutter and upstand can be made without either element being visible. Consequently, eaves, monopitch ridges and verges can have a similar outward appearance of an uninterrupted panel layout extending from roof down to the external wall. Parapets 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 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,

3-D exploded view of metal rainscreen roof fixing channel with capping to seam

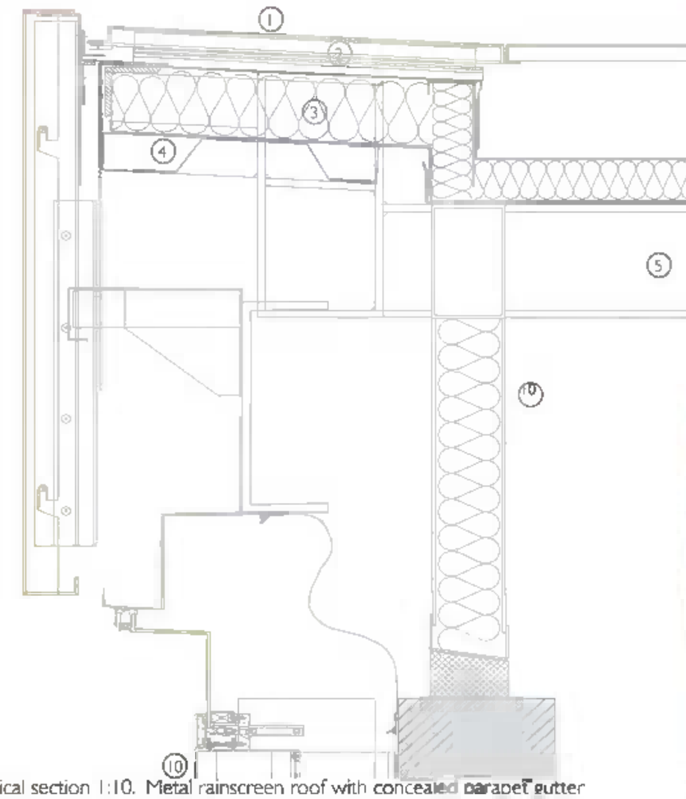


3-D view of metal rainscreen roof fixing channel with capping to seam

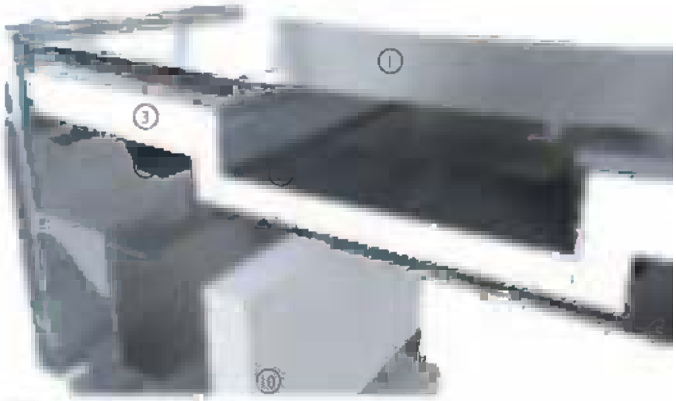


3-D view of metal rainscreen roof support system with capping to seam

3-D view of metal rainscreen roof with concealed parapet gutter



Vertical section 1:10. Metal rainscreen roof with concealed parapet gutter



concealed parapet gutter

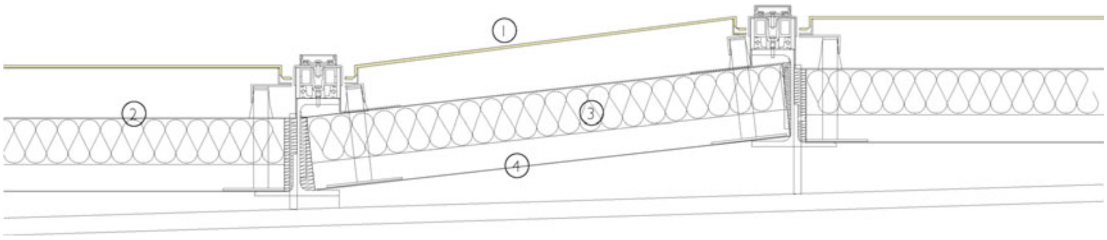
Details
1. Metal rainscreen panel
2. Single layer membrane
3. Closed cell thermal insulation
4. Structural deck
5. Purlin or structural beam
6. Secondary purlin
7. Folded metal gutter
8. Folded metal drip
9. Metal fascia panel
10. External wall
11. Outer sheet fixing bracket
12. Panel 1
13. Panel 2
14.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

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.

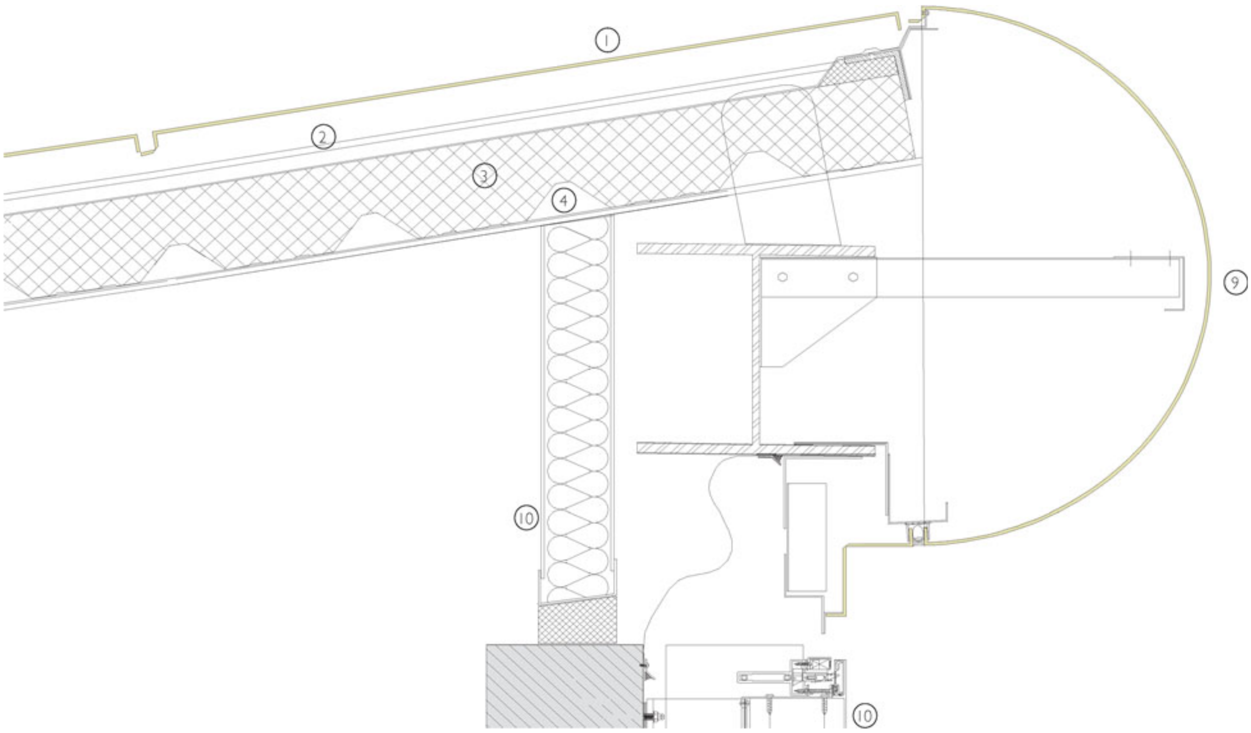
The parapet gutter can be covered with a perforated or slotted metal cover in the same material and finish as the adjacent rainscreen panels. Since rainwater runs off each panel at its edges onto the membrane below, there is no need to leave the gutter uncovered, as is the case with other metal roof 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 are formed by sealing the waterproof membrane against the side of the roof deck to provide a watertight enclosure that is continuous with the external wall beneath. The rainscreen panel at the edge of the roof is linked directly to a fascia panel. Where a curved panel is structurally independent of the external wall beneath, the roof deck is allowed 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 an extent that would



Vertical section 1:10. Typical long section through metal rainscreen roof



Vertical section 1:10. Typical long section through metal rainscreen roof with curved panel

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.

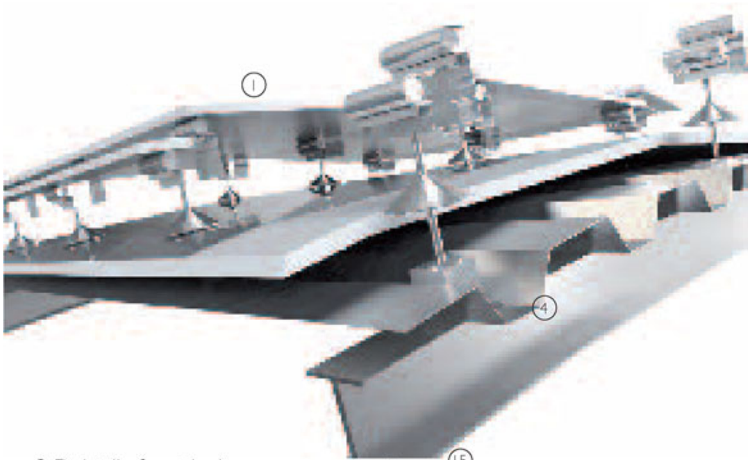
A seal between the external wall and the underside of the roof is provided by two layers of EPDM sheet with flexible insulation quilt set between them. Folded metal sheet can also be used, but is less flexible in the longitudinal direction (along the length of the roof) than EPDM sheet.

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. 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.

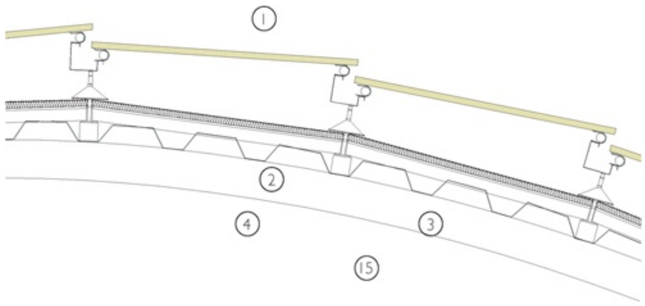
Roof geometry

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

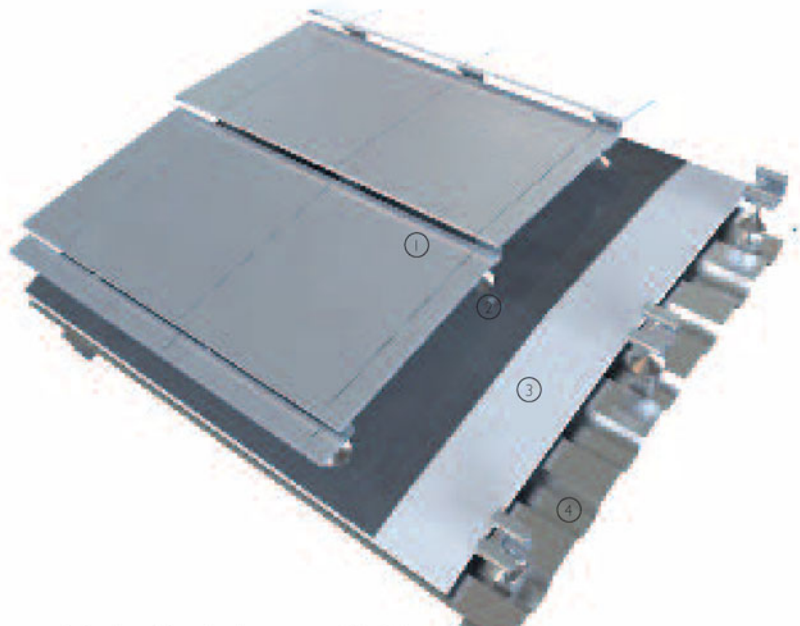
3-D view of metal rainscreen roof with concealed parapet gutter



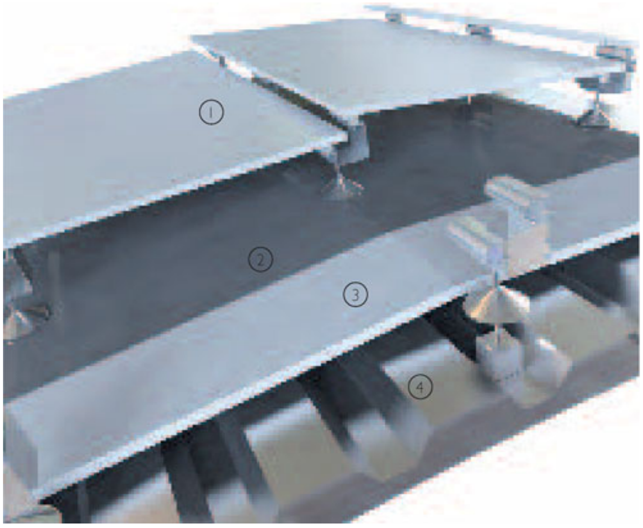
3-D detail of metal rainscreen support system 15



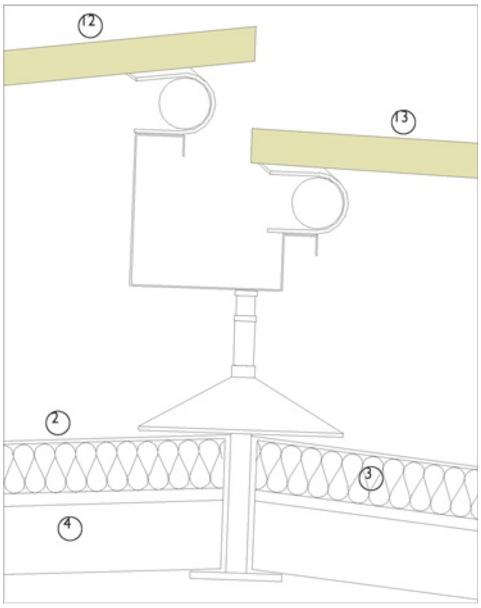
Vertical section 1:25 typical section with rainscreen panels draining from panel to panel



3-D view of metal rainscreen roof draining from panel to panel 15



3-D detail of metal rainscreen support system



Detail of metal rainscreen support system

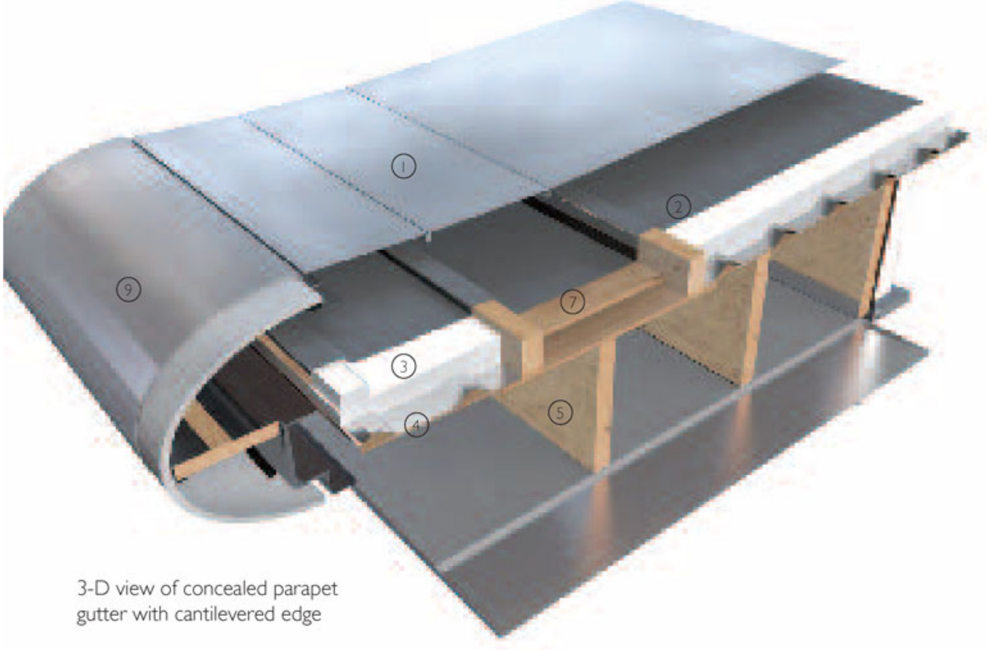
to create a set of gently curved panels that are turned in either one or two directions. Panels are increasingly being twisted in two directions in order to create genuinely curved roof finishes. Alternatively, panels can be set flat but with each panel set at different angles to create a facetted roof 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 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

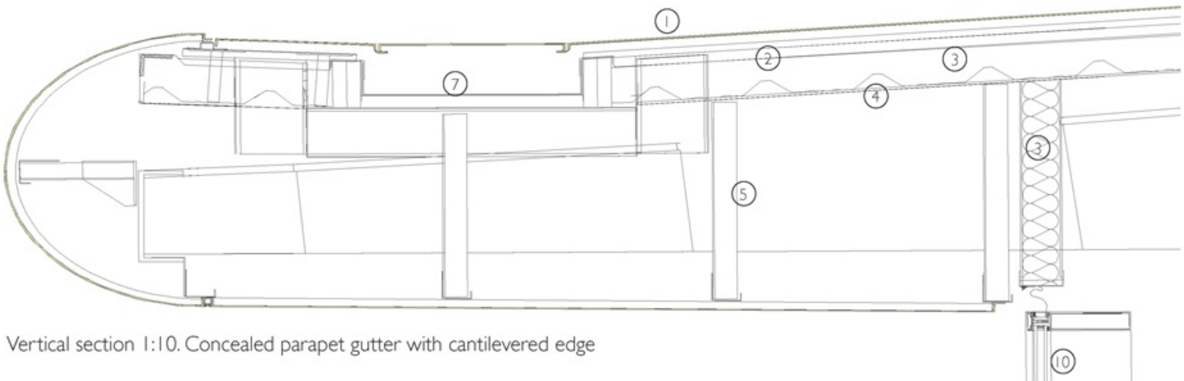
Metal rainscreen roof panels can also be used as soffit panels to either an overhanging eaves or parapet, or alternatively to form a complete soffit to the underside of a roof. When mixed with perforated or slotted panels and louvres, a roof can become a single



3-D view of concealed parapet gutter with cantilevered edge

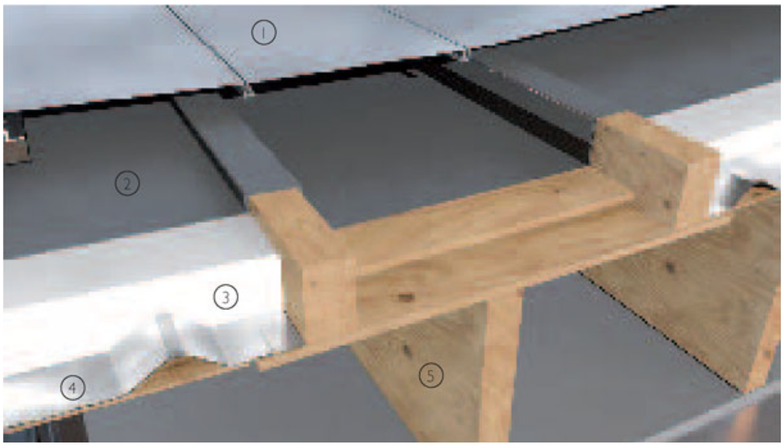
Details

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

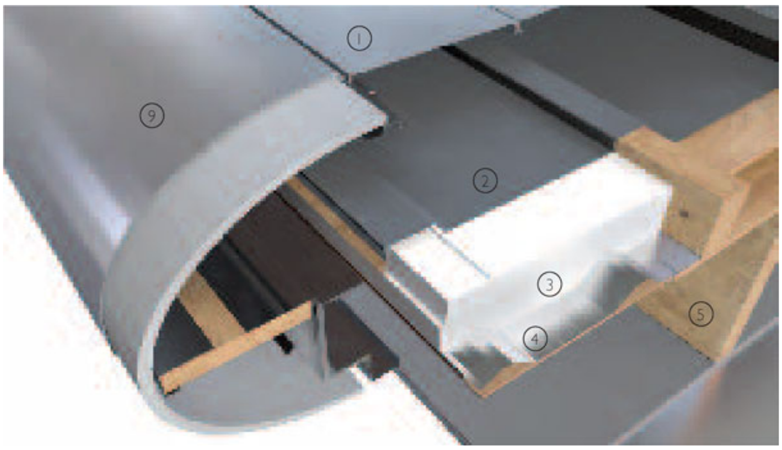


Vertical section 1:10. Concealed parapet gutter with cantilevered edge

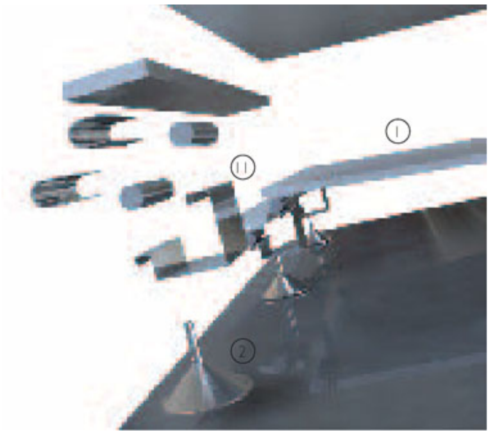
visual entity, set above its external walls as a separate and distinct element. This can be achieved without the need for an expensive structure, or for an expensive waterproofing layer, since the membrane is concealed from view and is chosen for its performance rather than for its visual qualities. 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 ten years, making this a roofing method set for new developments.



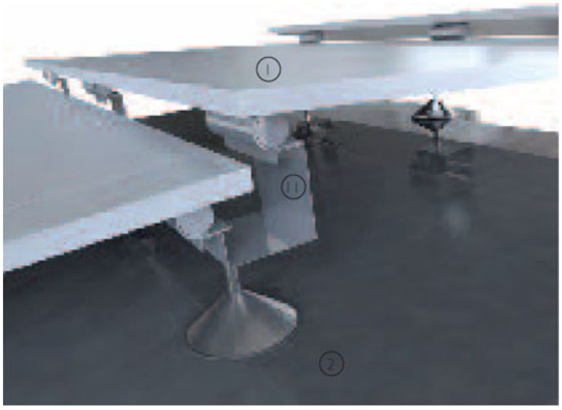
3-D view of gutter detail



3-D view of cantilever detail



3-D exploded detail of metal rainscreen support system



3-D detail of metal rainscreen support system

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
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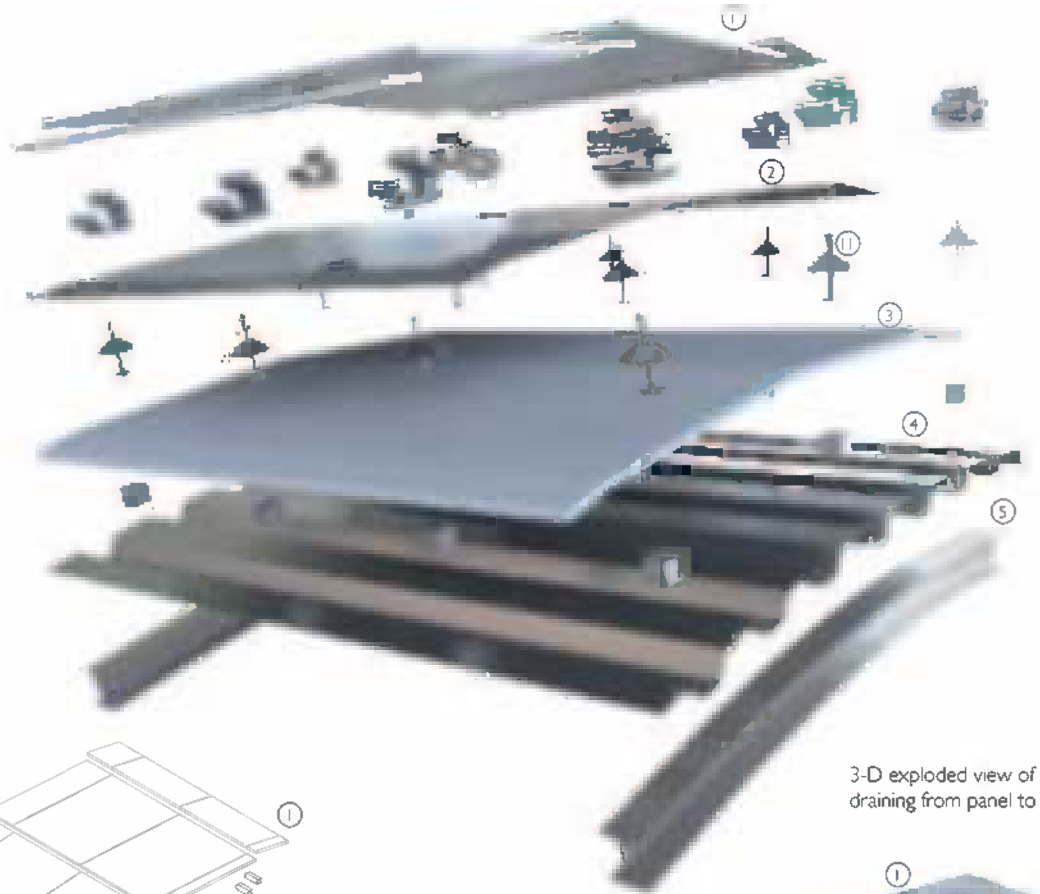
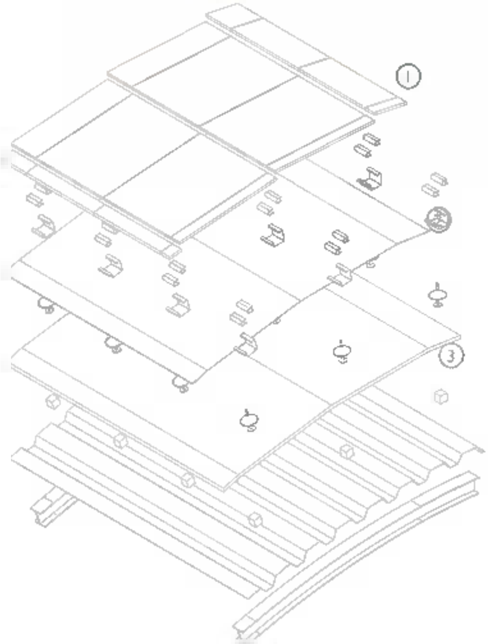
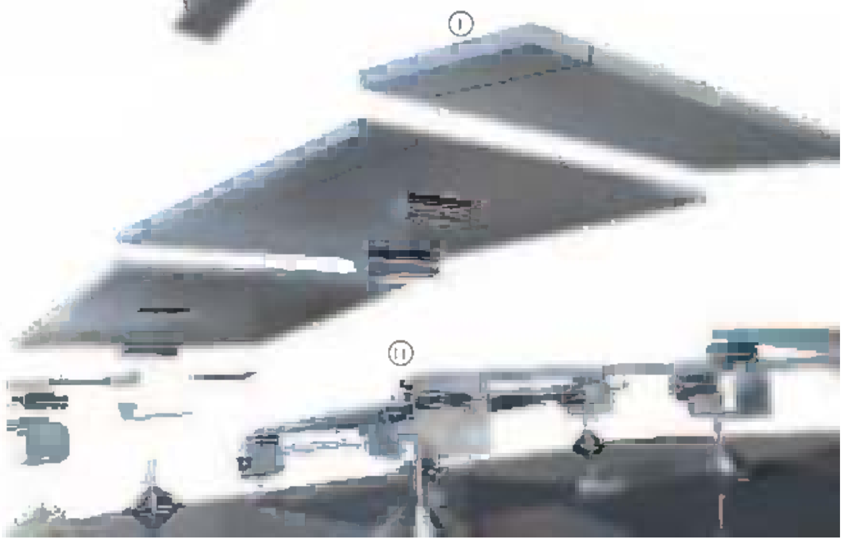


3-D exploded view of metal rainscreen roof draining from panel to panel

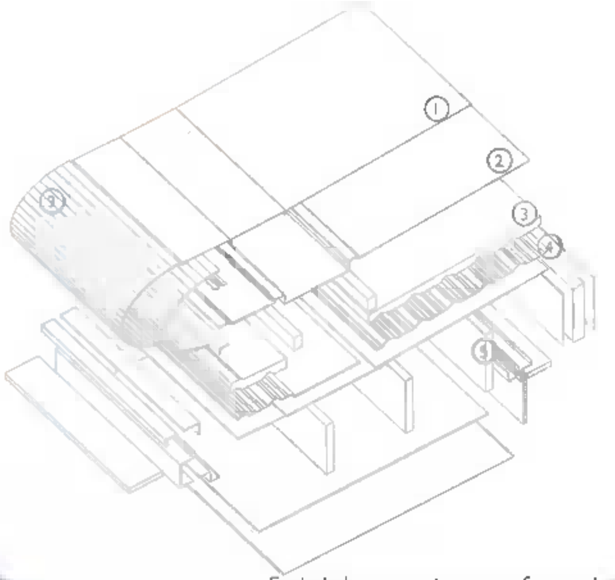


Exploded axonometric drawing of metal rainscreen roof draining from panel to panel

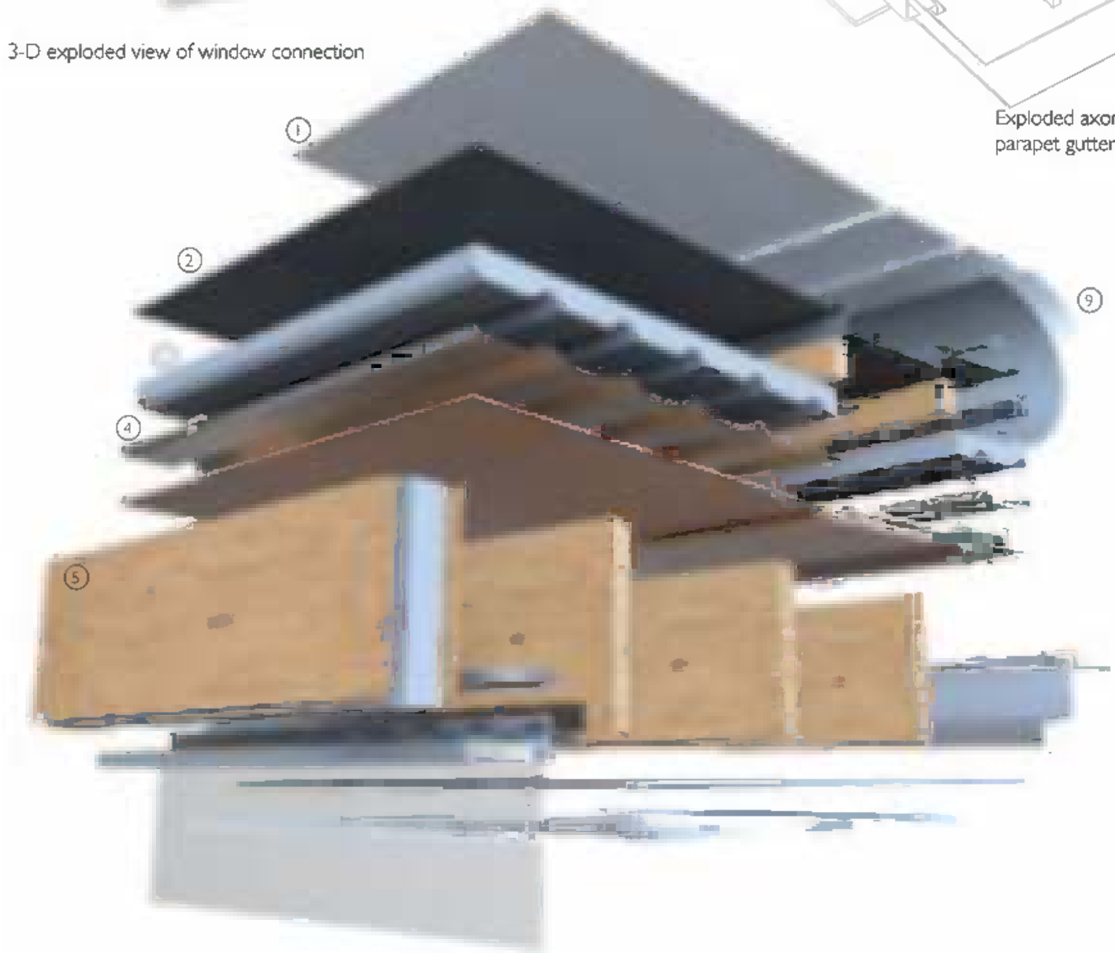


Exploded 3-D view of metal rainscreen support system

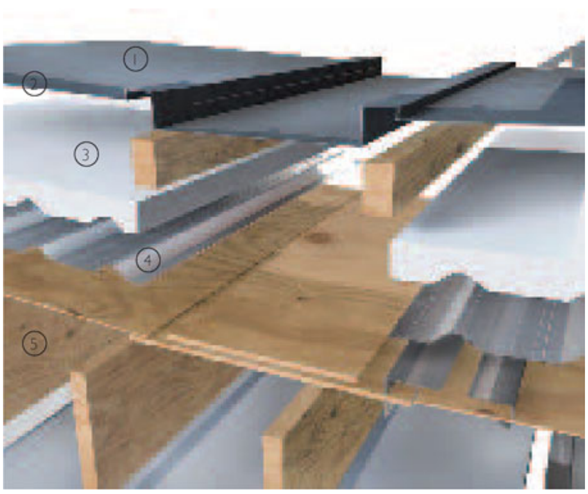
3-D exploded view of window connection



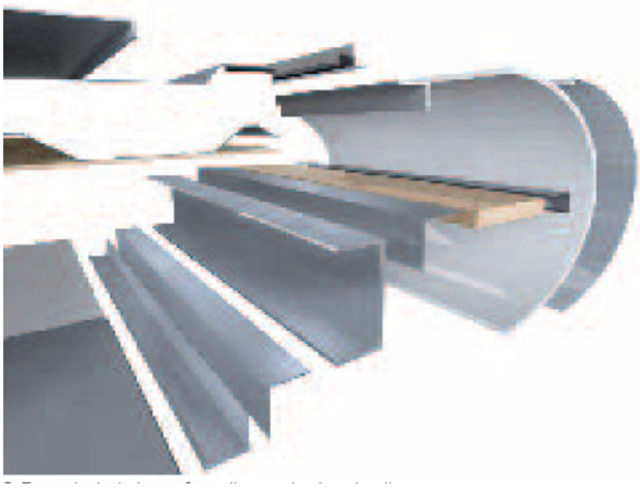
Exploded axonometric view of concealed parapet gutter with cantilevered edge



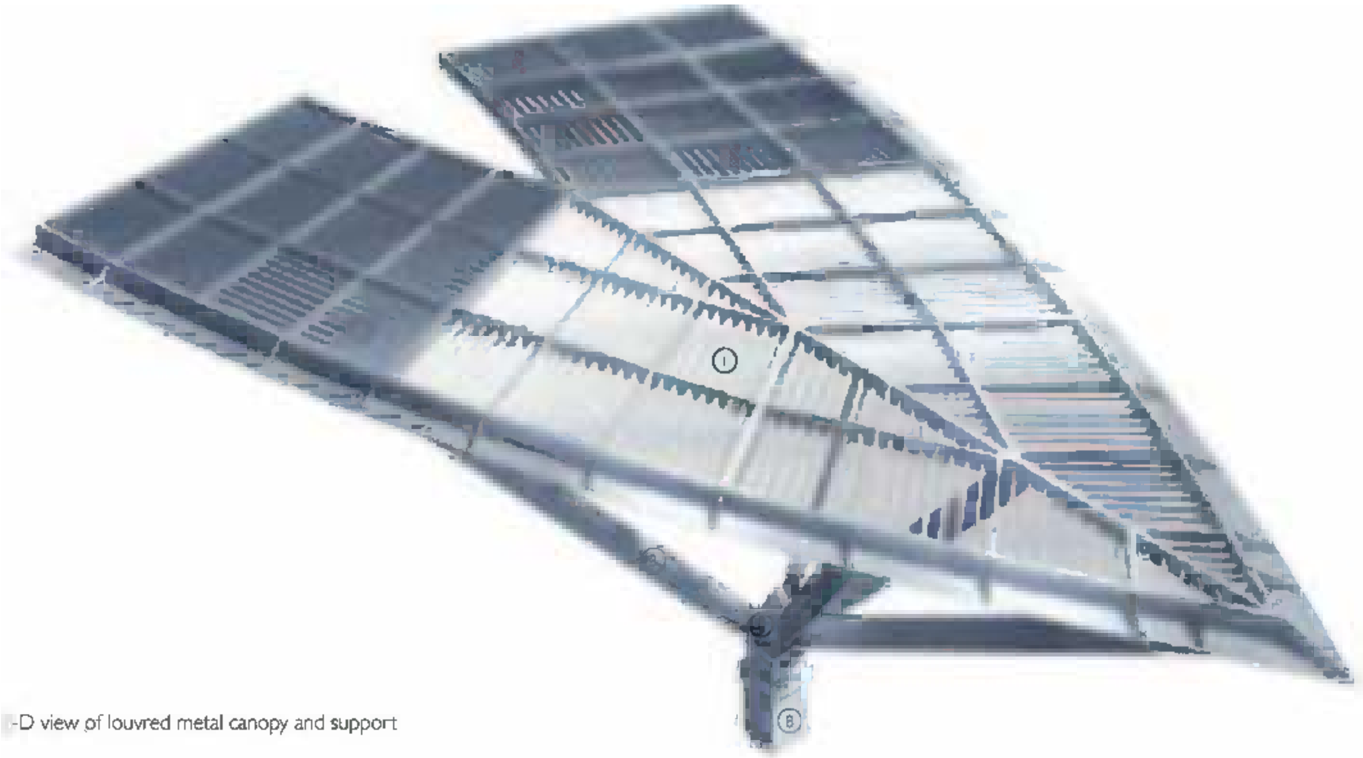
3-D exploded view of concealed parapet gutter with cantilevered edge



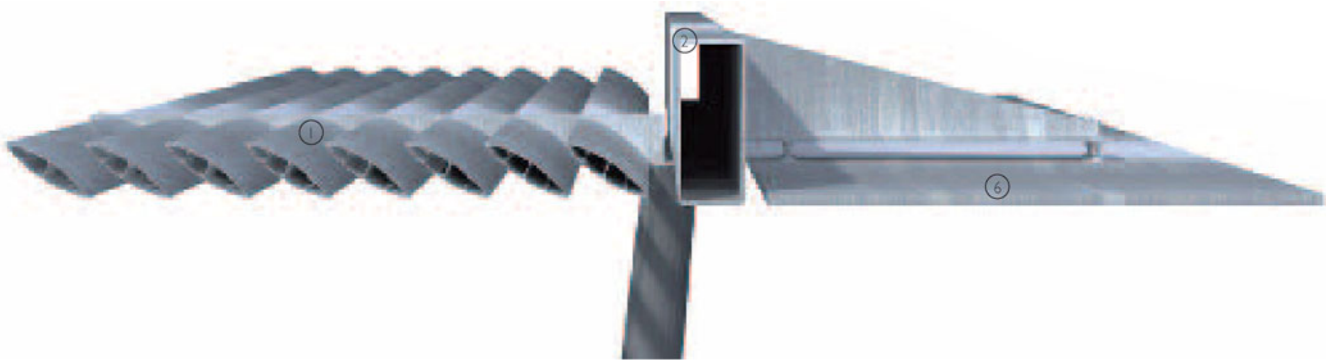
3-D exploded view of concealed gutter detail



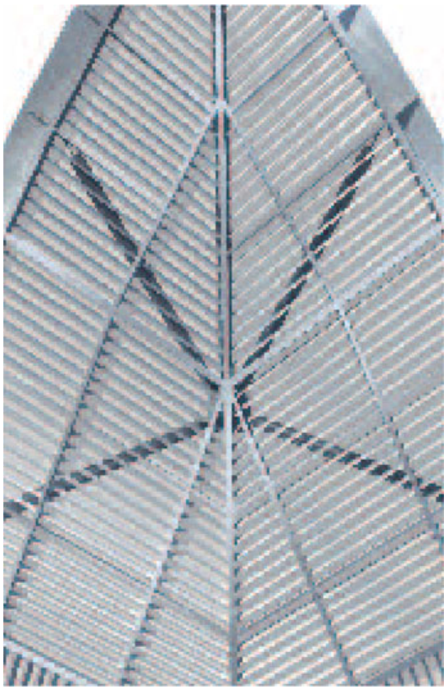
3-D exploded view of cantilevered edge detail



-D view of louvred metal canopy and support



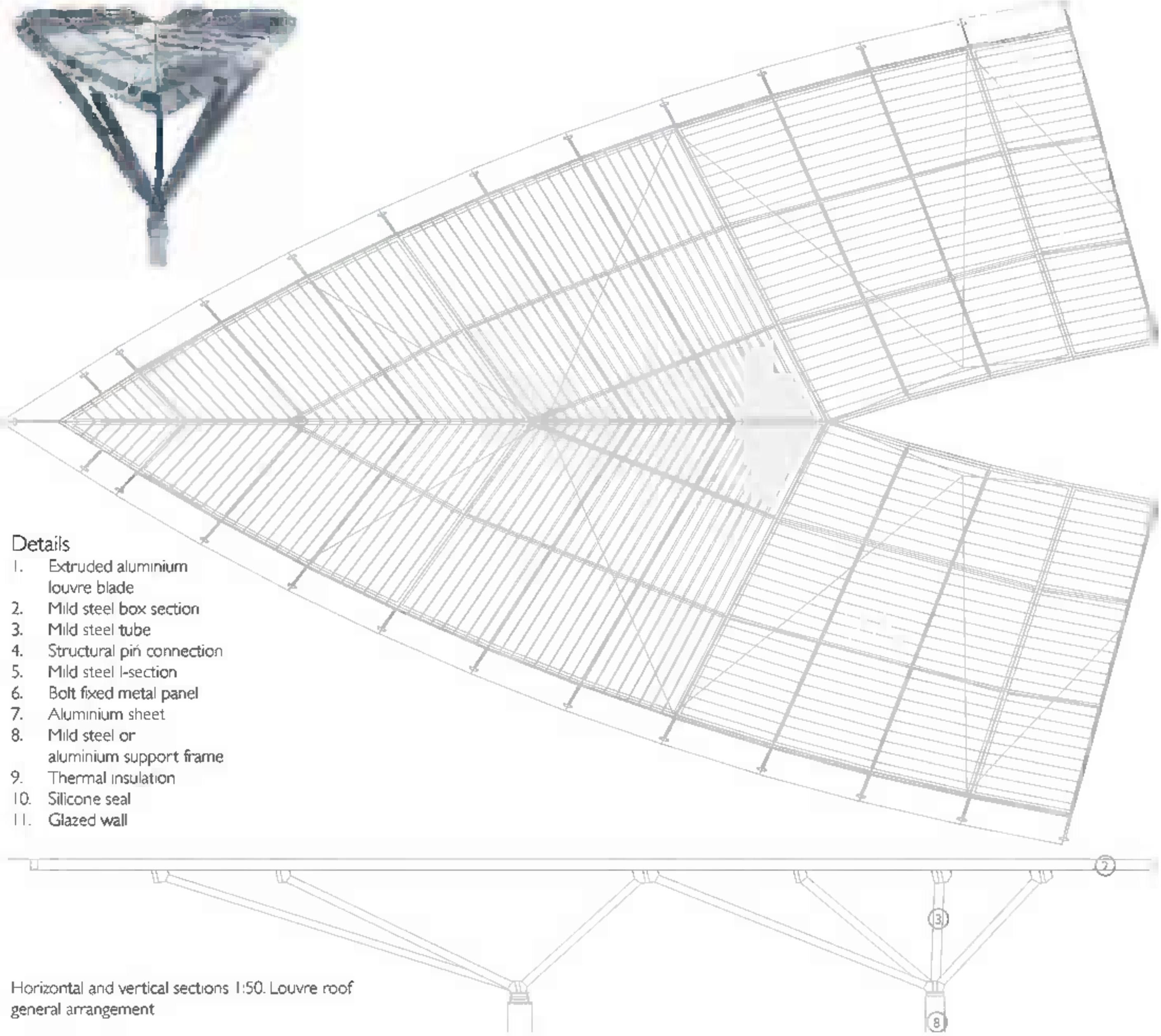
3-D section through louvred canopy edge and support



3-D top view of louvred canopy

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 structures, 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 examples, 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 alternative method of joining metal panels together is by riveting them together, leaving a hairline joint between the sheets. This is

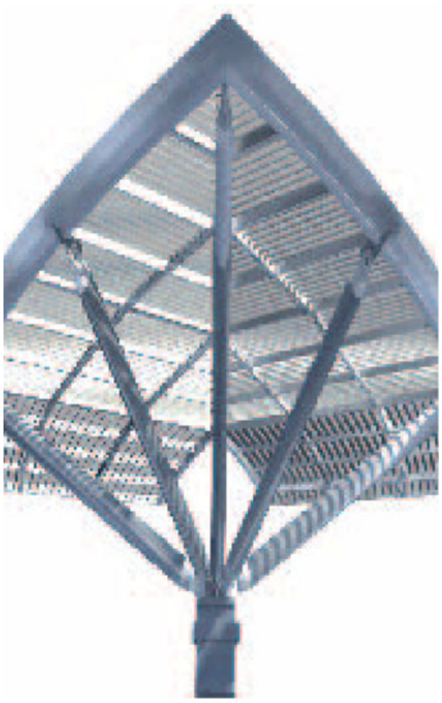


Details
1. Extruded aluminium louvre blade
2. Mild steel box section
3. Mild steel tube
4. Structural pin connection
5. Mild steel I-section
6. Bolt fixed metal panel
7. Aluminium sheet
8. Mild steel or aluminium support frame
9. Thermal insulation
10. Silicone seal
11. Glazed wall

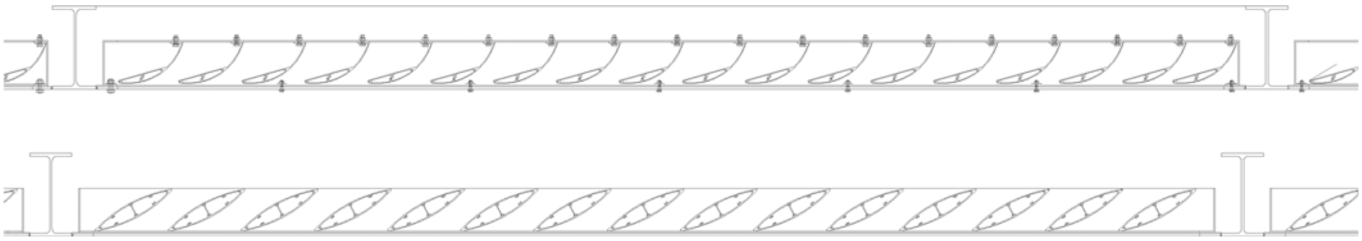
Horizontal and vertical sections 1:50. Louvre roof general arrangement

done either by butting flat sheet together and riveting the two sides together, or by folding the sheets down and riveting the underside. In some situations, 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. Alternatively, a similar sheet material can set between the riveted panels to provide a seal. In practice, both seals discussed are difficult to achieve where a high weathertight performance is required. Instead, a silicone seal around10mm wide is used between 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

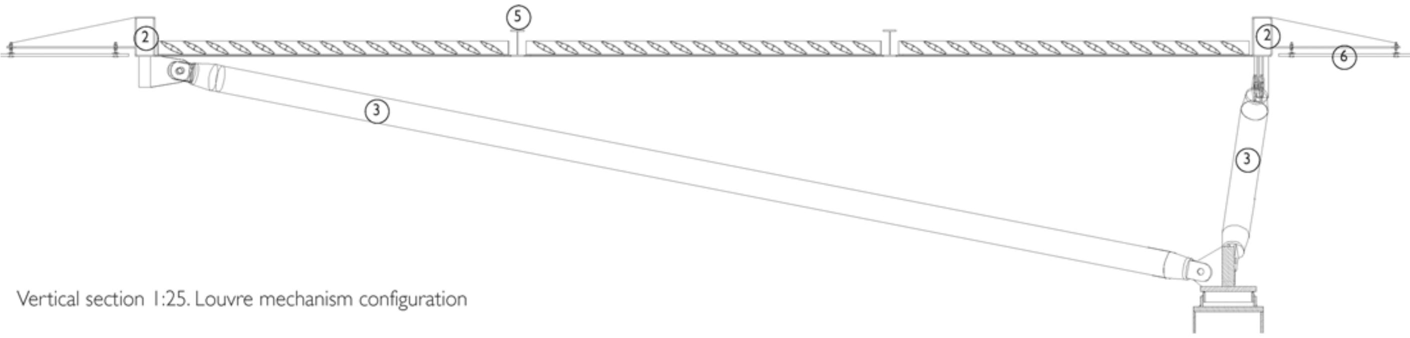


3-D bottom view of louvred canopy



Vertical sections 1:10. Louvre mechanism configuration

3-D Elevation. Louvre mechanism configuration



Vertical section 1:25. Louvre mechanism configuration

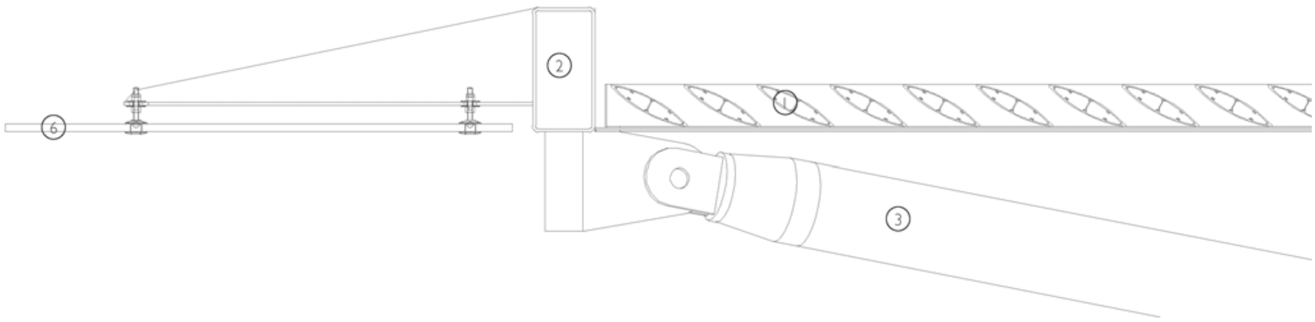
usually polyester powder coated only. The use of anodised aluminium as a finish on sheet has increased in recent years as a result of greater reliability of the finish, which until recently has suffered from uneven colour consistency. In many cases, the silicone used to seal the joints can be applied in a variety of monotone tints, ranging from white, to greys, to black. Some silver-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. 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.

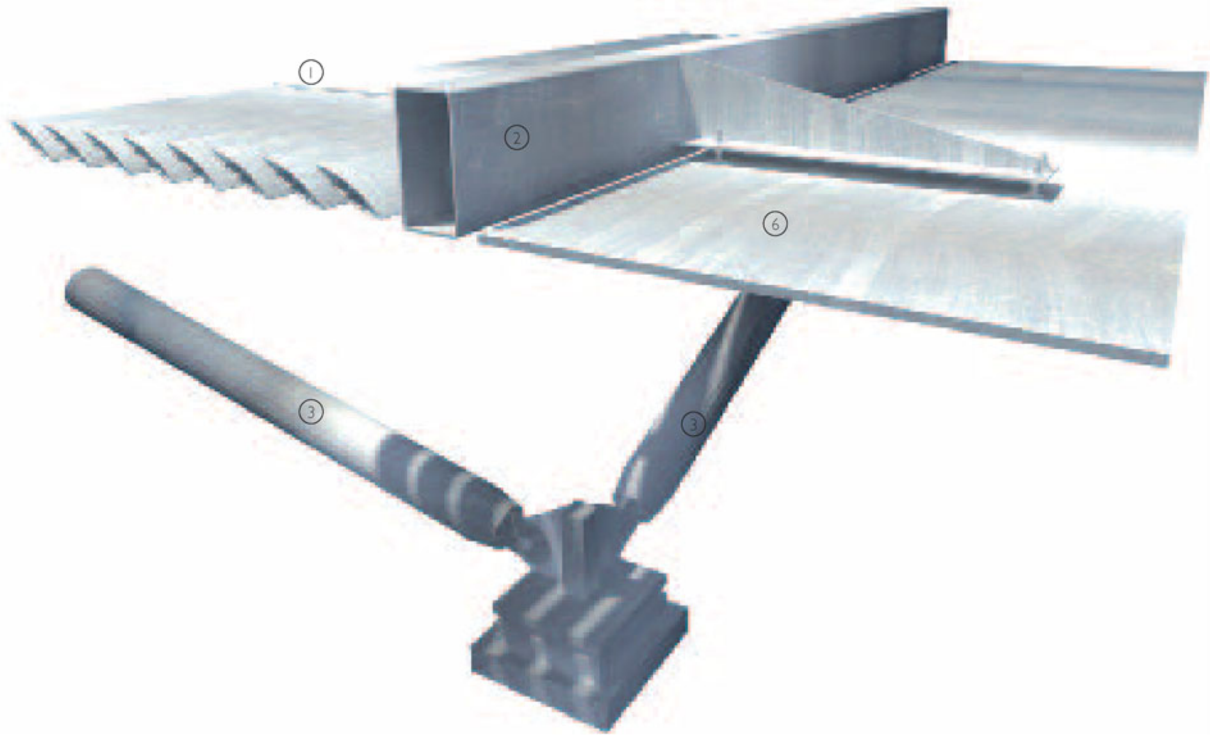
Metal panels can bring together the full set of assembly techniques available to the material within a single assembly. With folded panels, the edges are welded and ground smooth, and the complete panel is coated to a single consistent colour. The use of countersunk screws, painted on site in a colour matching that of the panels, enhances the overall appearance.

In generic examples, 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.

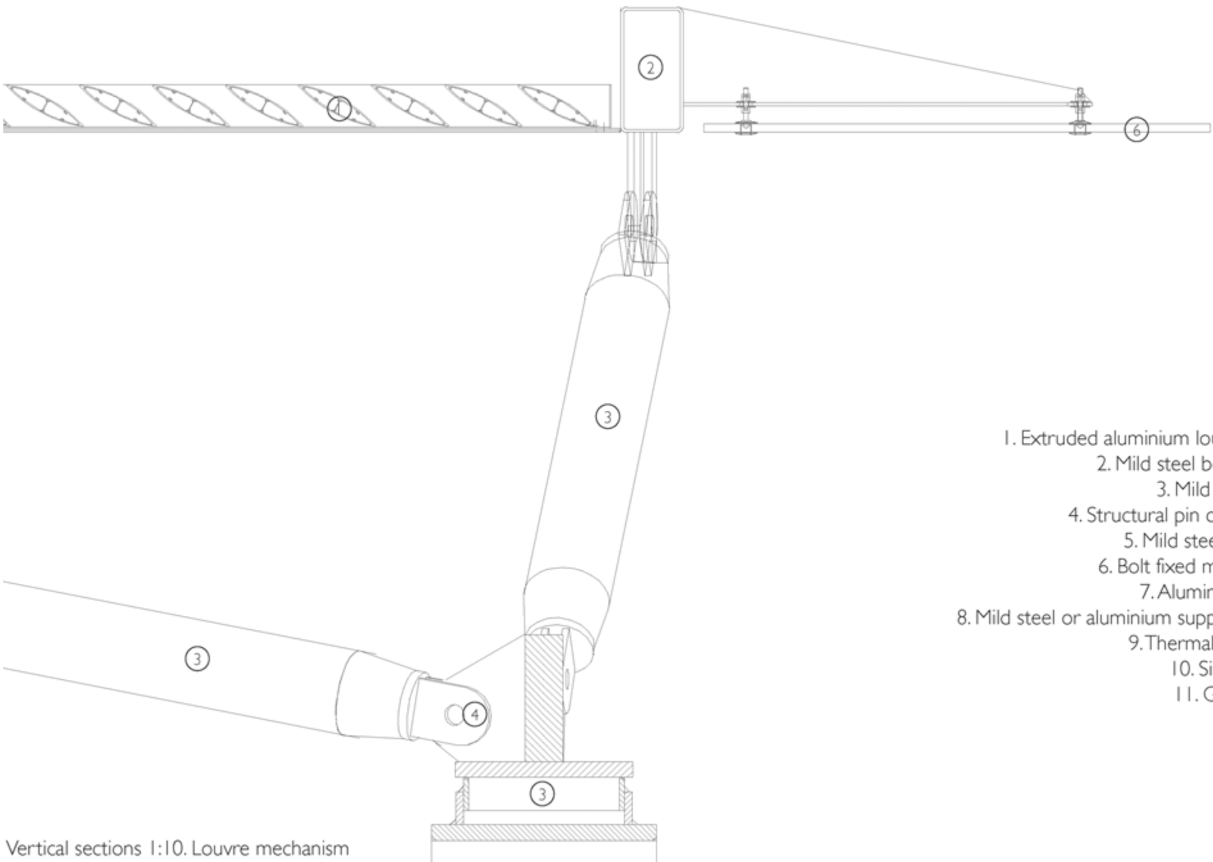
The glazed wall on the underside of the metal coping is joined in a way that disturbs the line of the canopy as little as possible as it passes it from outside to inside. The metal sheet on the exterior face of the wall is glazed into the top transom of the wall below. Any excess rainwater that is blown 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. If this is difficult to achieve, as where the edge of the panel has a small edge return, or where panels are not very rigid due to their geometry or manufacturing method, a second line of defence



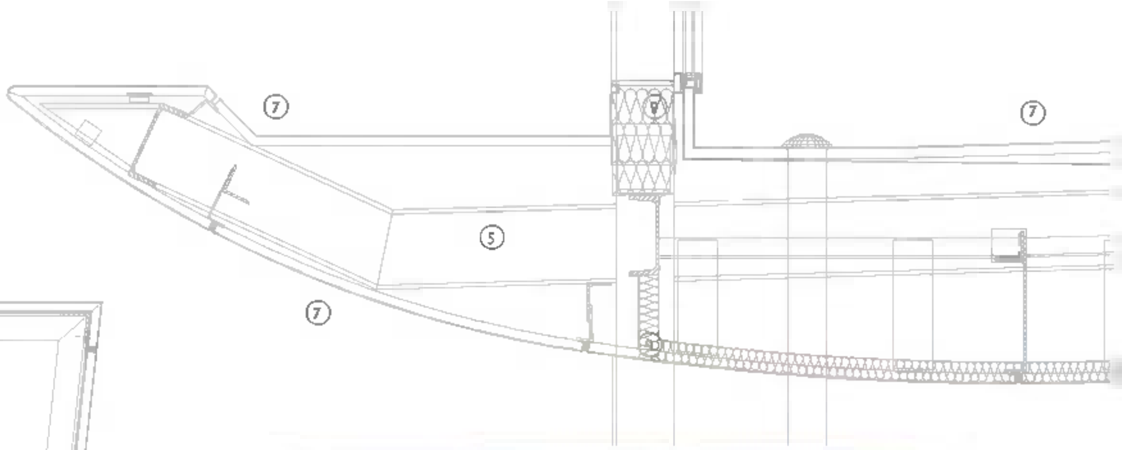


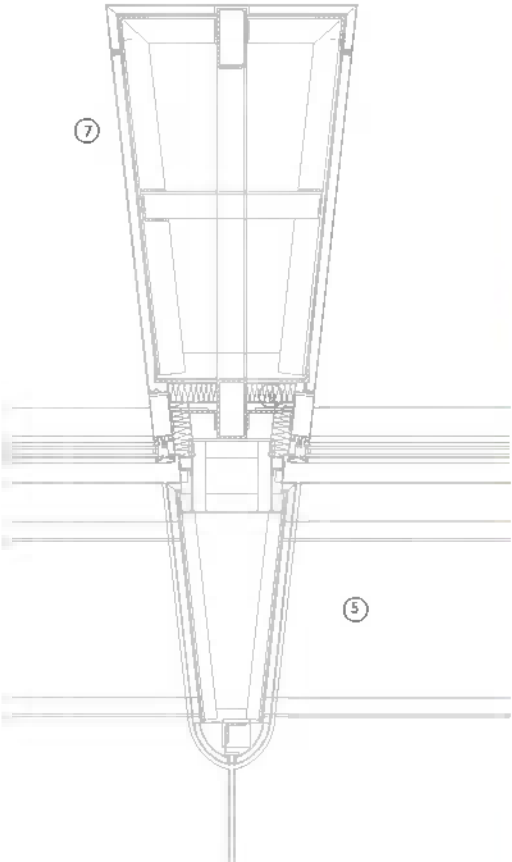
3-D detail of louvred canopy edge and support



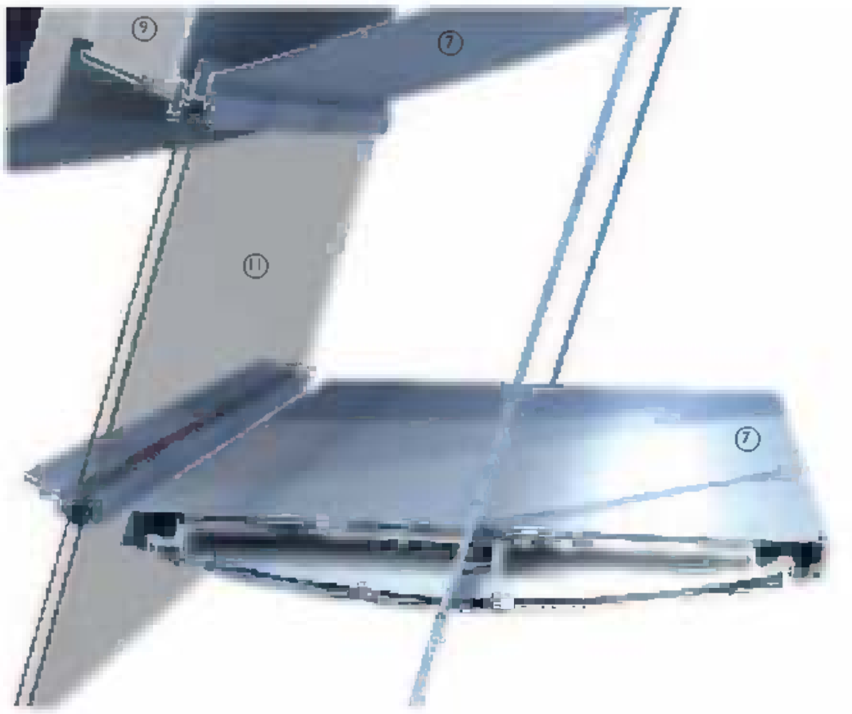
Details
1. Extruded aluminium louvre blade
2. Mild steel box section
3. Mild steel tube
4. Structural pin connection
5. Mild steel I-section
6. Bolt fixed metal panel
7. Aluminium sheet
8. Mild steel or aluminium support frame
9. Thermal insulation
10. Silicone seal
11. Glazed wall

Vertical sections 1:10. Louvre mechanism configuration

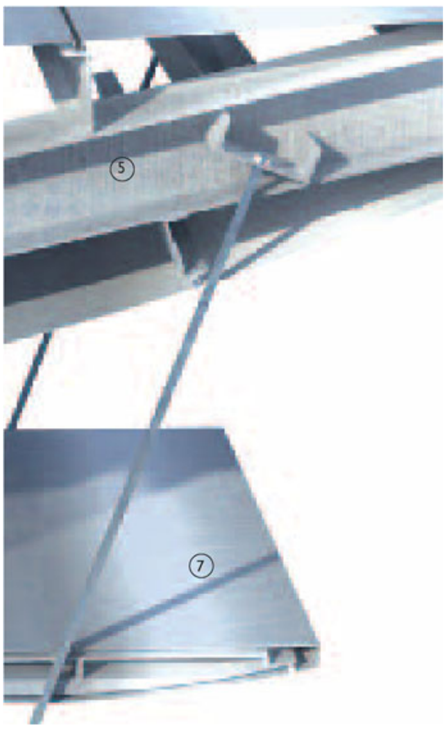




Horizontal section 1:20. Generic metal canopy serving as sealed roof to part of a glazed wall



3-D section view showing generic metal canopy serving as sealed roof to part of a glazed wall



for weather tightness is provided by an elastomeric or thermoplastic waterproof 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

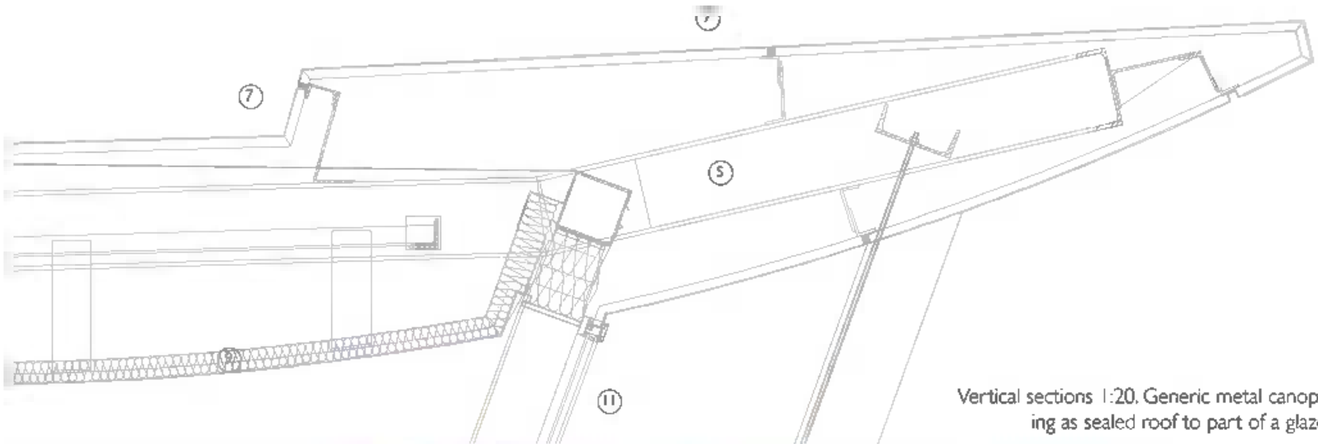
Metal panels can be bolt fixed onto the canopy edges. Flat panels, such as minimum 3mm thick aluminium sheet and metal / composite sheet, can be bolt fixed using proprietary systems destined for use in point fixed glazing. The use of oversized holes or slotted holes in the metal panel ensures that the metal panels can move with thermal expansion without bowing or bending.

Gutters and rainwater outlets can be formed in sheet metal. 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.

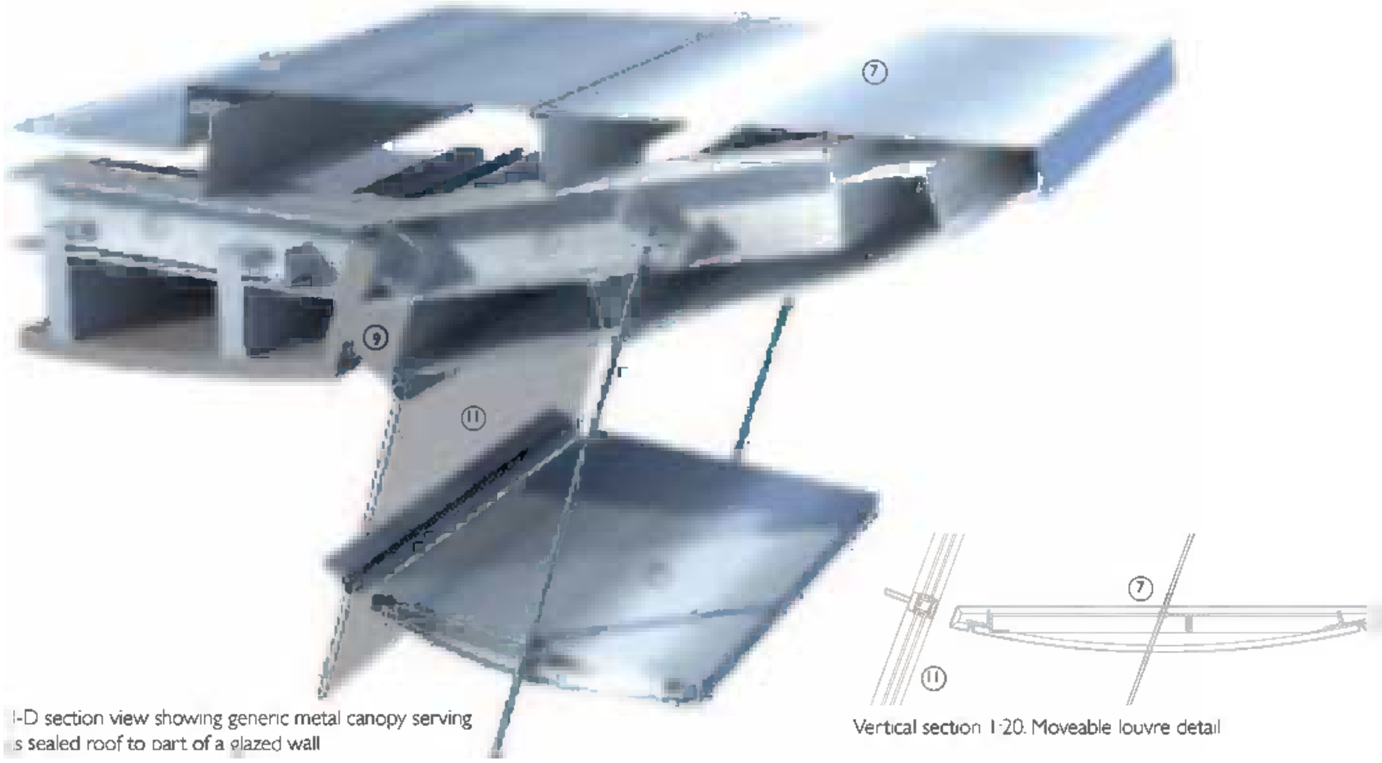
The canopy can form part of a glazed wall, and is so thermally insulated. The insulation usually follows the form of the outside of the canopy to keep the voids within the structure at a similar temperature to the internal temperature of the building. An alternative is to form the insulation with the 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



Vertical sections 1:20. Generic metal canopy serving as sealed roof to part of a glazed wall

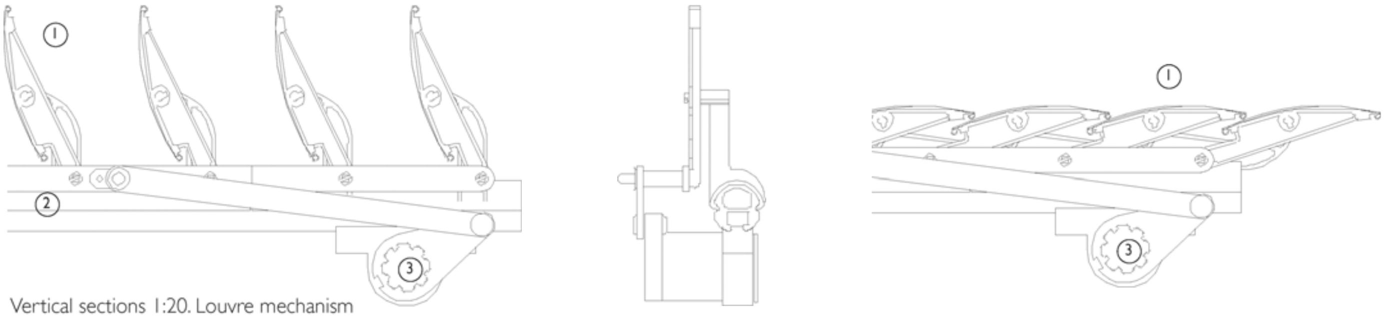


I-D section view showing generic metal canopy serving s sealed roof to part of a glazed wall

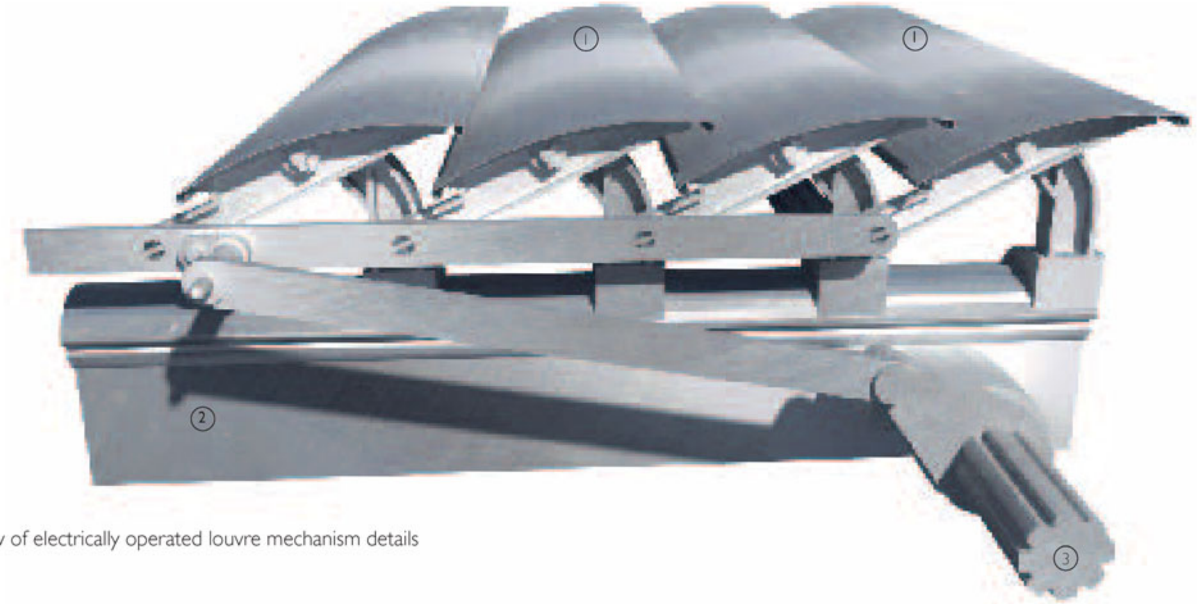
Vertical section 1:20. Moveable louvre detail

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 steel sheet, but these have limited stiffness and stability, requiring restraint along their length to hold their straightness. 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 or a full ellipse. 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. 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 relative loads. When fixed at their ends, a fixed louvre assembly can be made without visible fixings.

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



Vertical sections 1:20. Louvre mechanism details



3-D view of electrically operated louvre mechanism details

In some cases, the supporting structure 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 which is typical of this type of steel construction. The aluminium louvre panels are fixed to the 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.

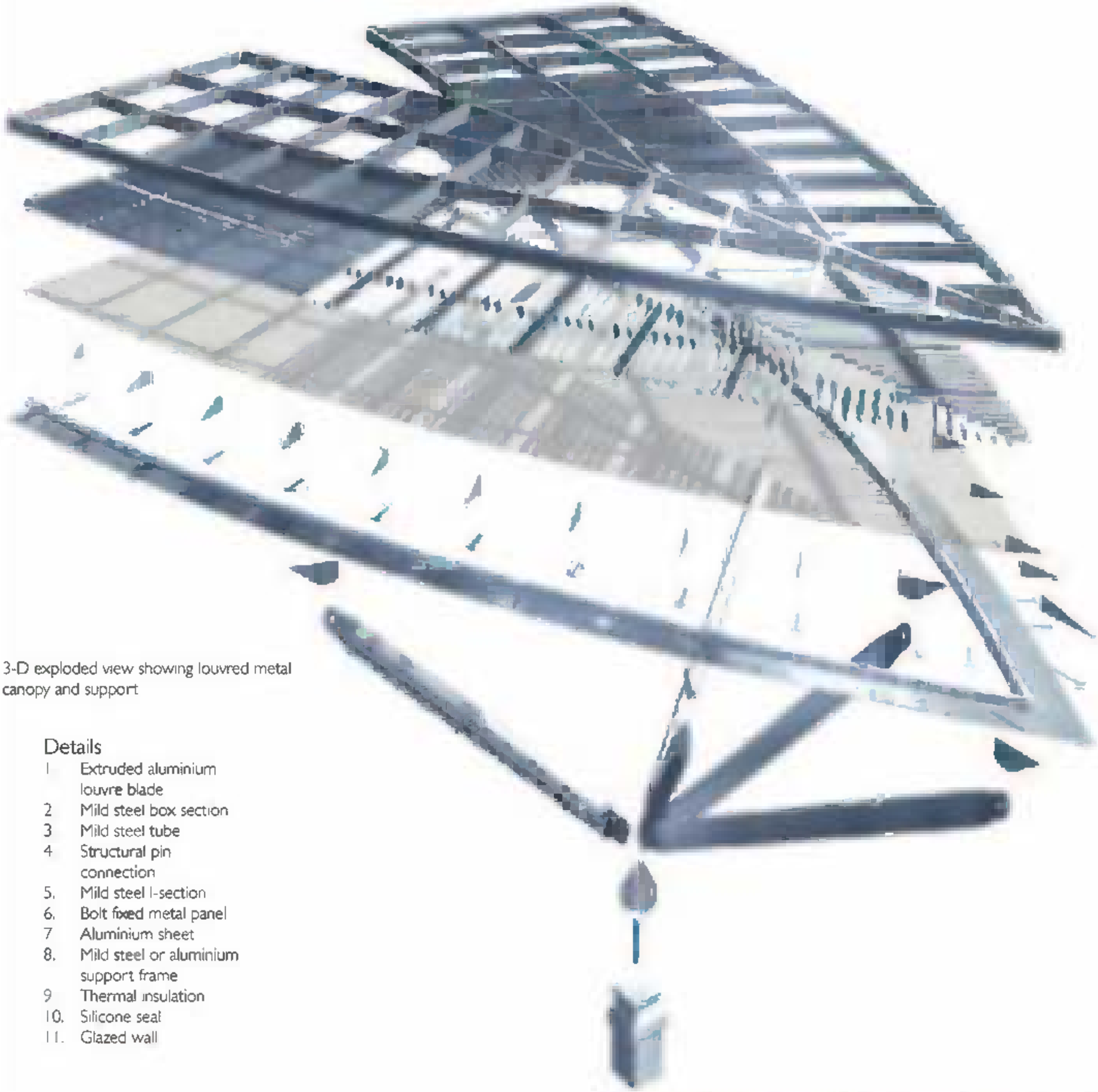
Louvres are fixed by steel pins into a sliding aluminium section at each end of the profile. The louvres are also fixed at their centre in section. As the sliding aluminium rod moves, the aluminium louvres move together, opening and closing together. The sliding rods are connected at each end of the louvres that 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.

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.

3-D views of electrically operated louvre panel
in open and closed positions

Details

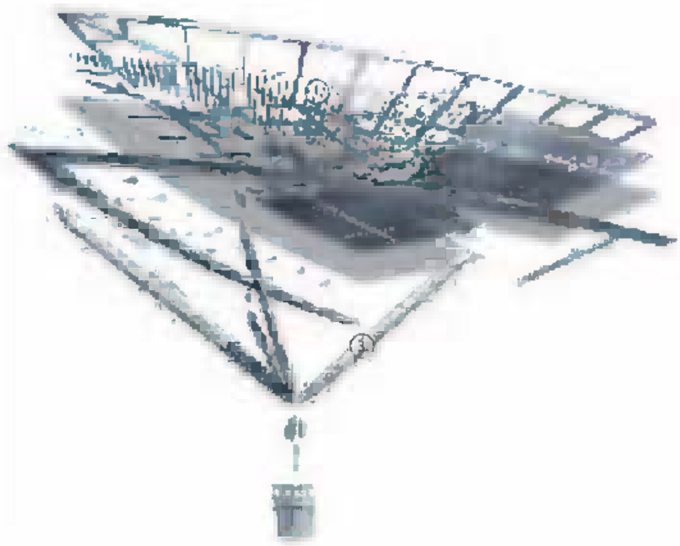
1 Extruded aluminium louvre blade
2 Mild steel box section
3. Mild steel tube
4. Structural pin connection
5. Mild steel I-section
6. Bolt fixed metal panel
7. Aluminium sheet
8. Mild steel or aluminium support frame
9. Thermal insulation
10. Silicone seal
11 Glazed wall



3-D exploded view showing louvred metal canopy and support

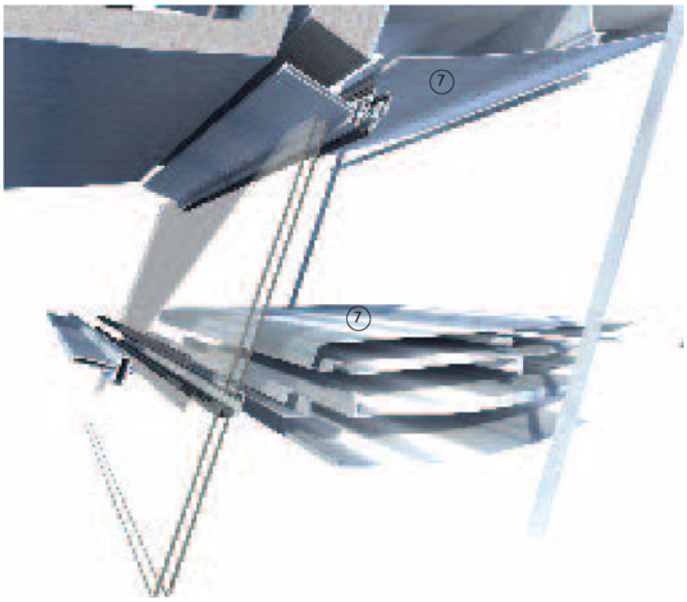
Details

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

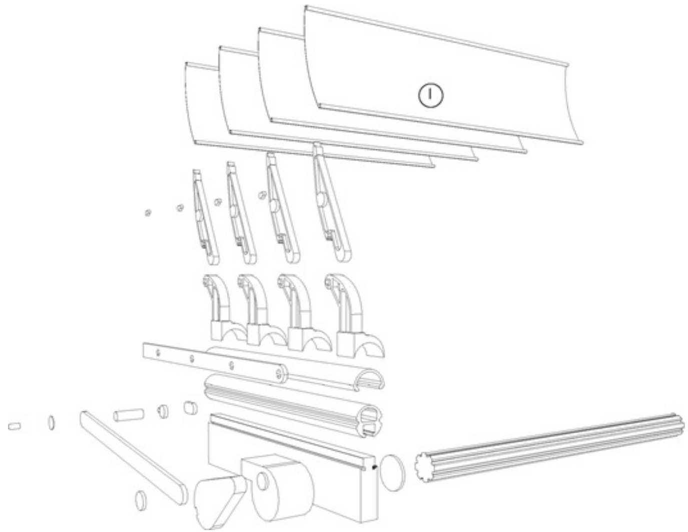


3-D exploded view showing louvred metal canopy and support

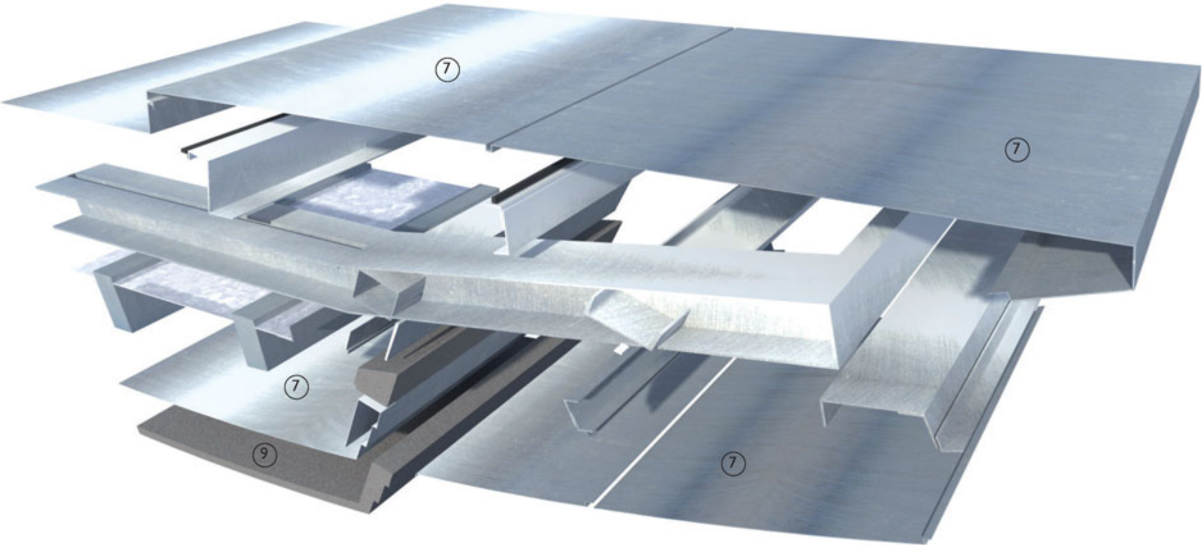
3-D view showing connection for louvred metal canopy and support



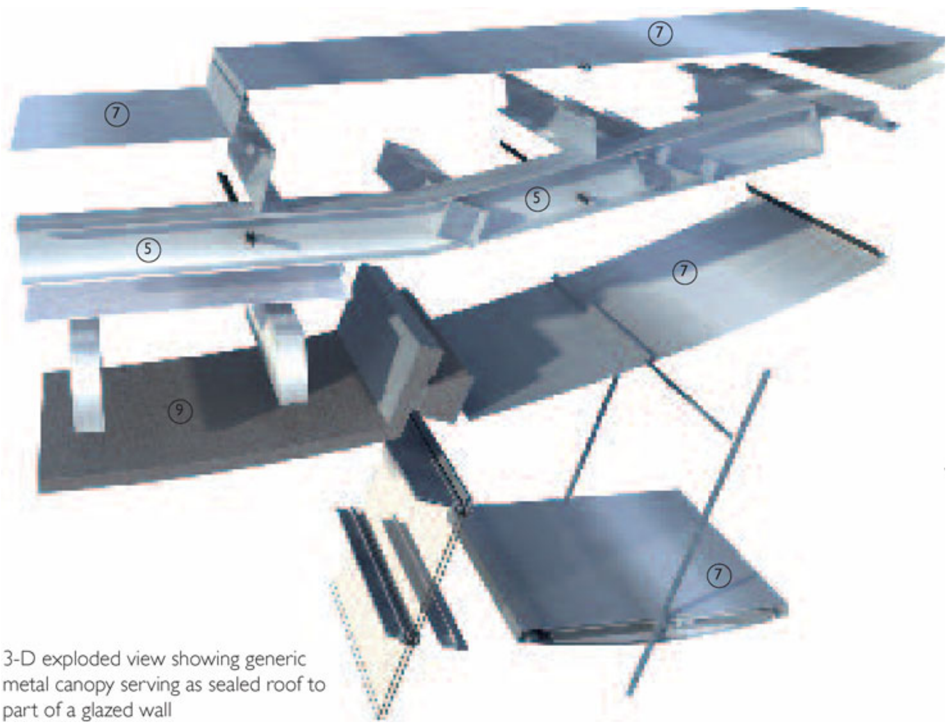
3-D exploded view showing metal louvres in front of glazed wall



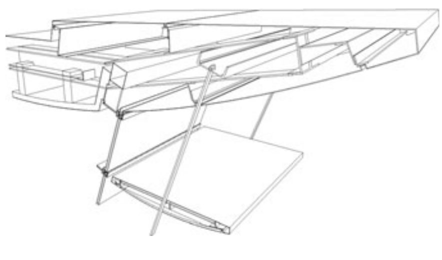
3-D exploded view showing electrically operated louvre panel mechanism



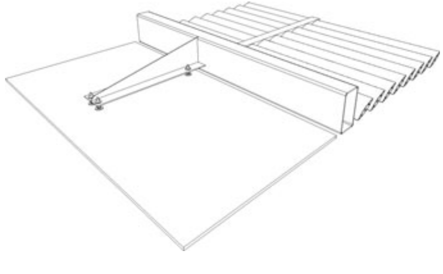
3-D exploded view showing metal canopy assembly



3-D exploded view showing generic metal canopy serving as sealed roof to part of a glazed wall



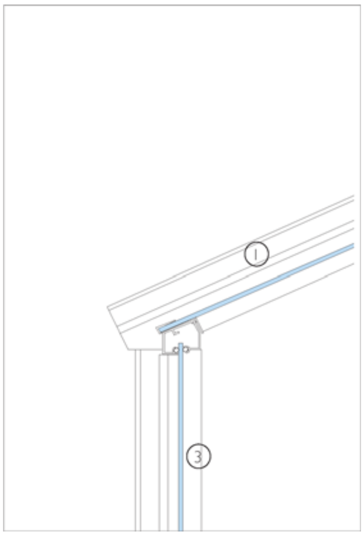
3-D exploded view showing generic metal canopy serving as sealed roof to part of a glazed wall



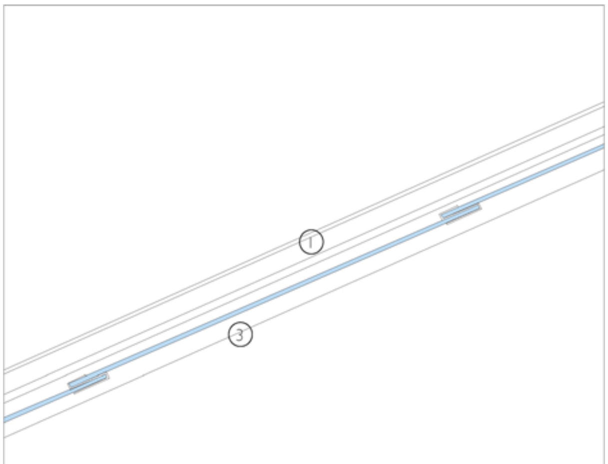
3-D exploded view showing canopy fixing method

8

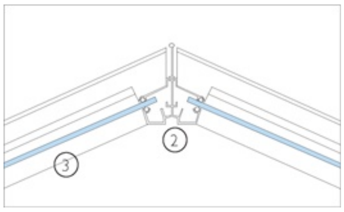
GLASS ROOFS



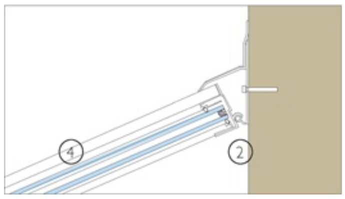
Vertical sections 1:25. Greenhouse glazing. Typical cross section.



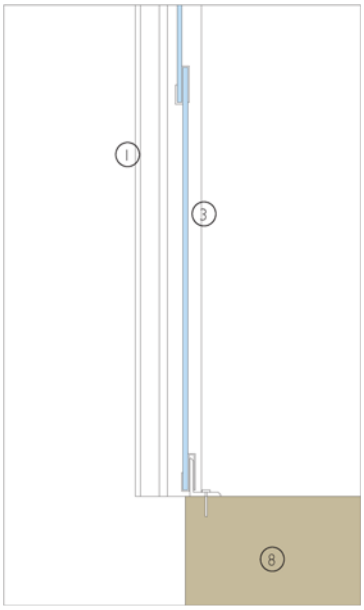
Vertical section 1:25. Typical section through greenhouse glazing

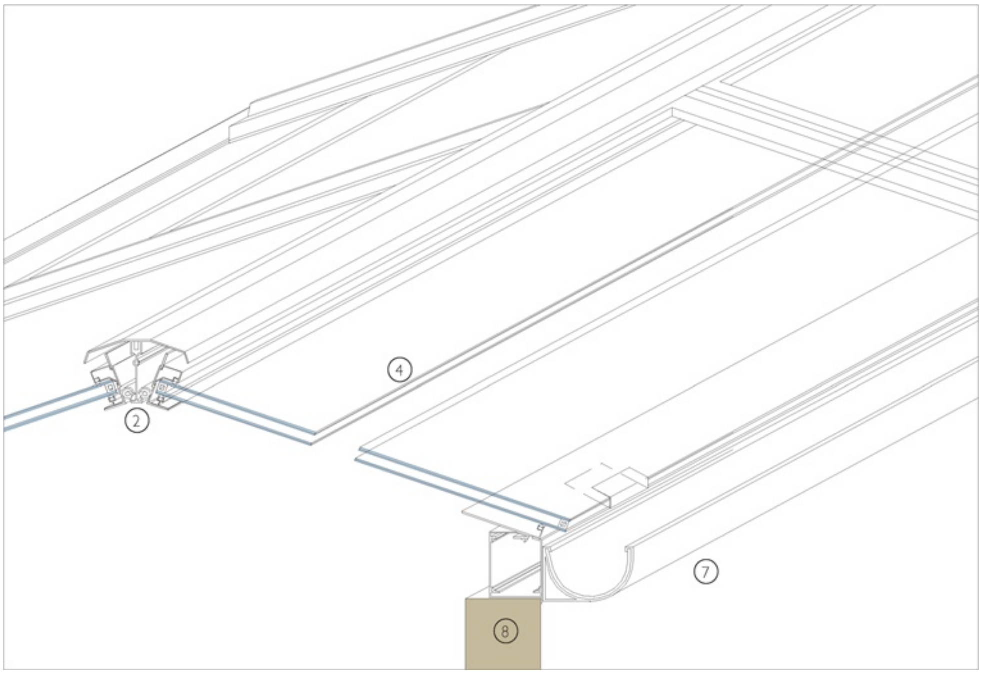


Vertical section 1:25. Greenhouse glazing. Typical ridge section.

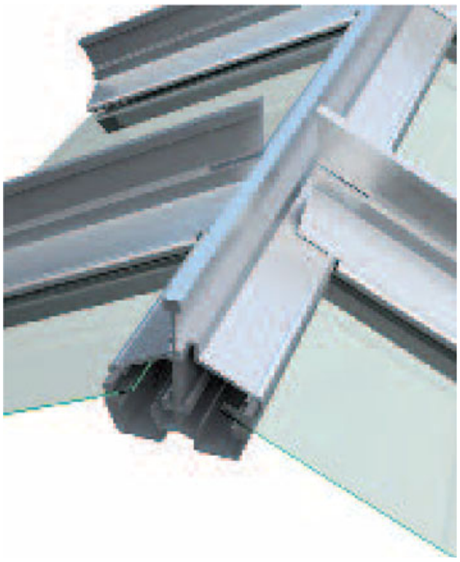


Vertical section 1:25. Greenhouse glazing. Abutment.





Isometric view of roof assembly



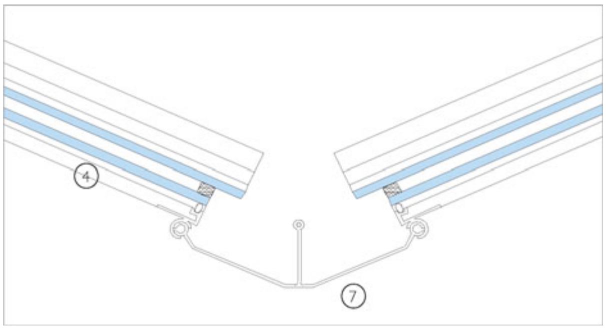
3-D view of green house glazing ridge detail

Greenhouse glazing

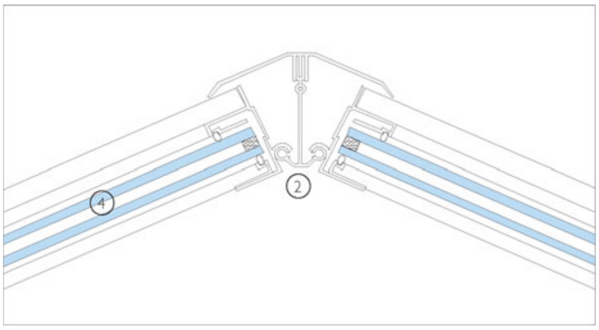
Curtain walling principles used in external walls have been adopted, over the last 20 years, as a reliable method of constructing glazed roofs to replace earlier systems developed from greenhouse glazing. Traditional greenhouse glazing used thin steel or cast iron sections to support glass sheets on 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. Traditionally, the glass is lapped with no seal, with glazing bars set at around 600mm (2ft) 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, which 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.

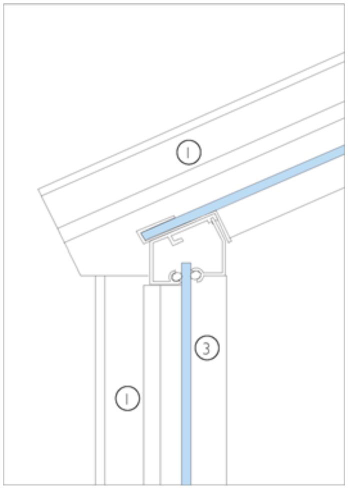
This glazing system is still used in greenhouses for agricultural activities, but has poor

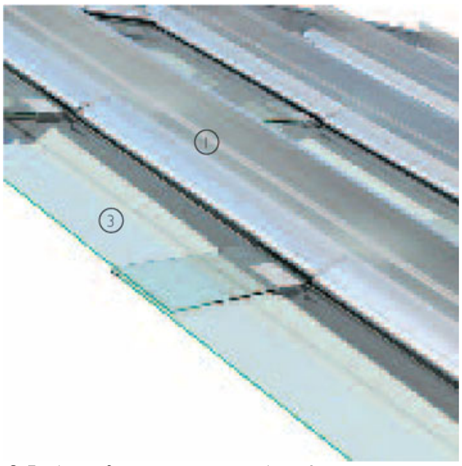


Vertical section 1:10. Valley detail

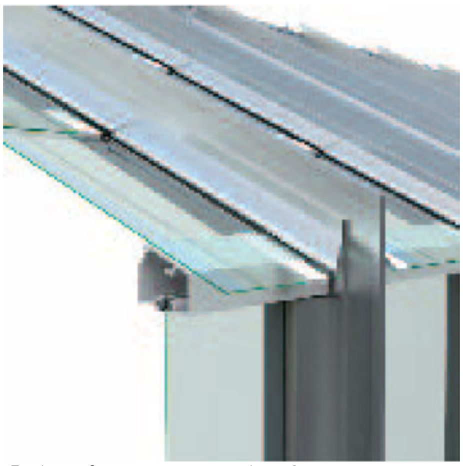


Vertical section 1:10. Ridge detail

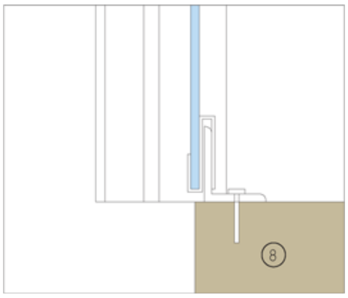




3-D view of greenhouse glazed roof



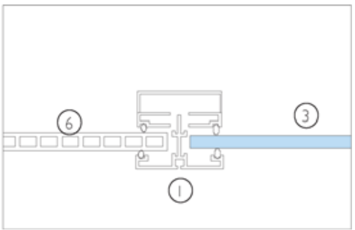
3-D view of greenhouse glazed roof



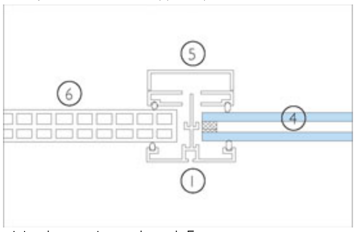
Vertical sections 1:10. Eaves detail

Greenhouse details

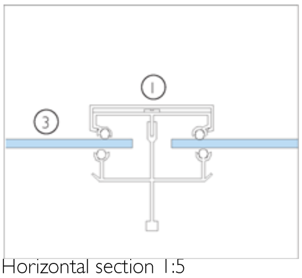
1. Extruded aluminium glazing bar
2. Extruded aluminium sections
3. Single glazed sheet
4. Double glazed unit
5. Aluminium clip-on capping
6. Polycarbonate sheet
7. Aluminium gutter
8. Concrete base



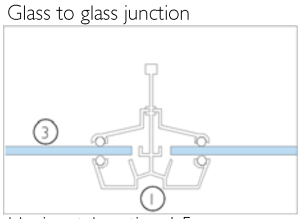
Horizontal section 1:5.
Polycarbonate to glass junction



Horizontal section 1:5.
Polycarbonate to glass junction



Horizontal section 1:5
Glass to glass junction



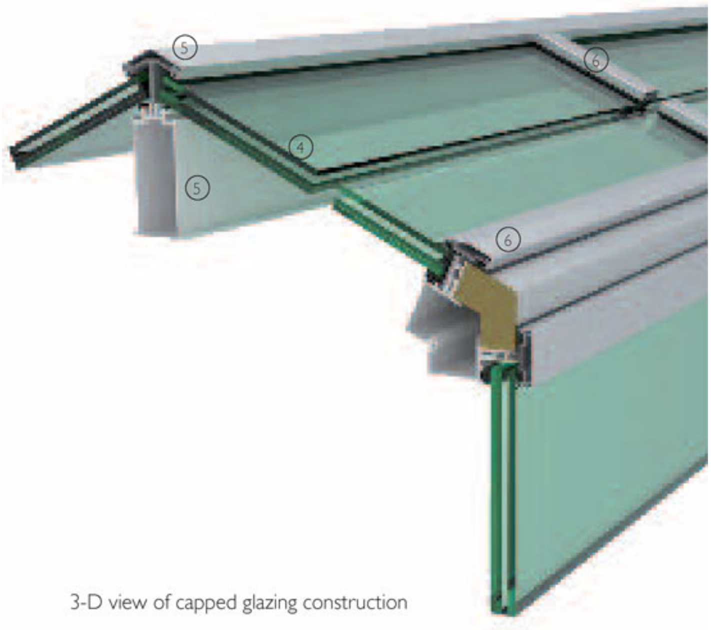
Horizontal section 1:5.
Greenhouse glazing.

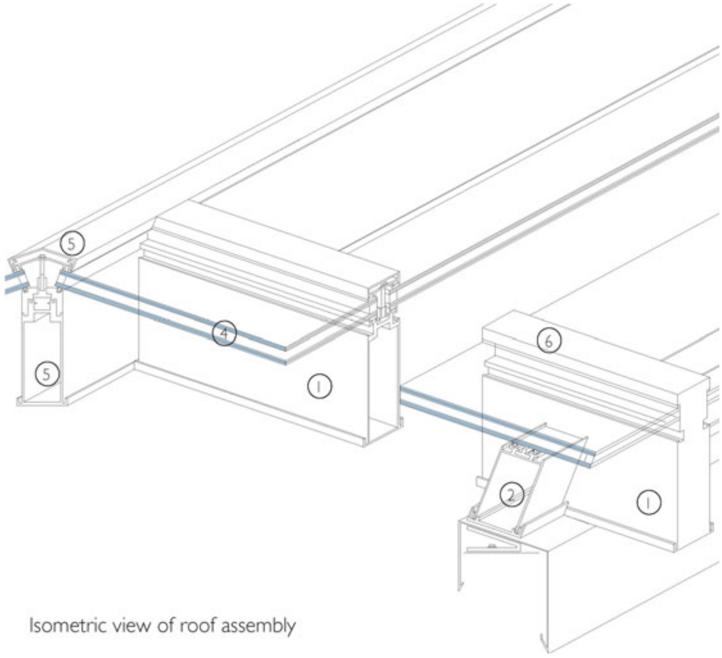
thermal insulation, since its purpose is to absorb the heat from the sun rather than excluding it. The use of single glazing, with no thermal breaks and high air infiltration rates (by curtain walling standards), make it ideal for agricultural use, but very poor for the use in general building construction.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

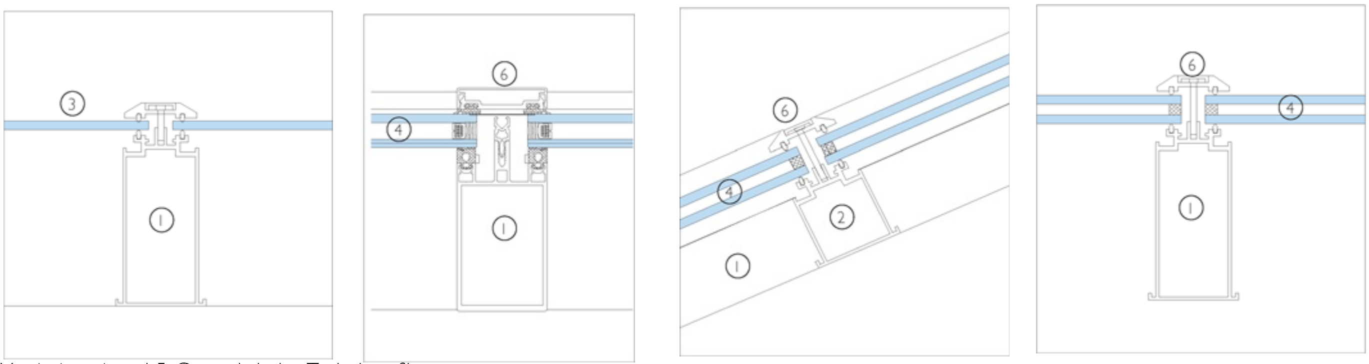
An essential component of greenhouse glazing that has been retained in modern glazed roofs is the glazing bar, which corresponds to a mullion in glazed walls. The greenhouse glazing bar has a condensation channel beneath the glass to drain away water that passes through the outer seal during rain. The 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, or are enclosed. 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


3-D view of capped glazing construction

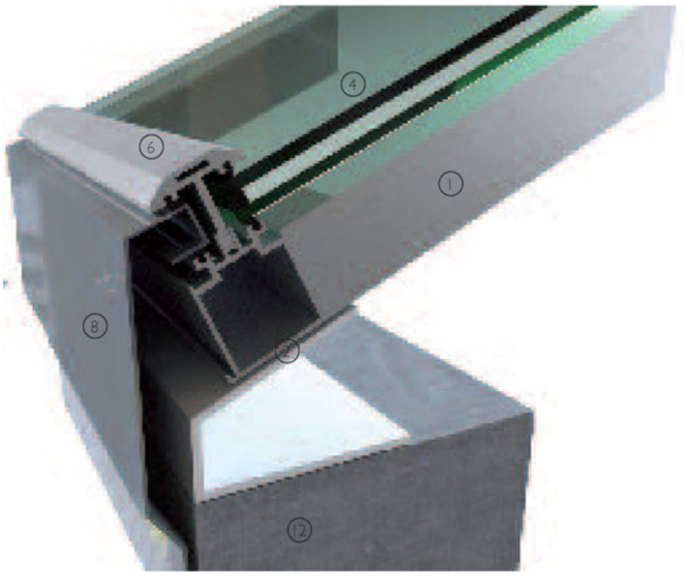

Isometric view of roof assembly


Vertical sections 1:5. Capped glazing. Typical profiles

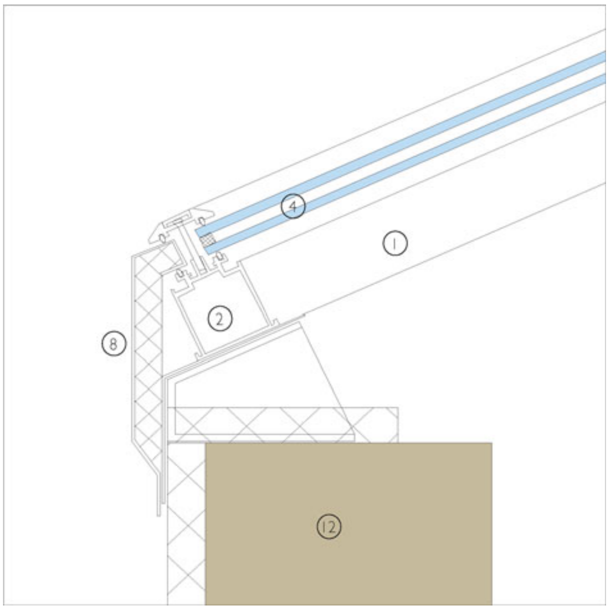
Capped glazing details

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

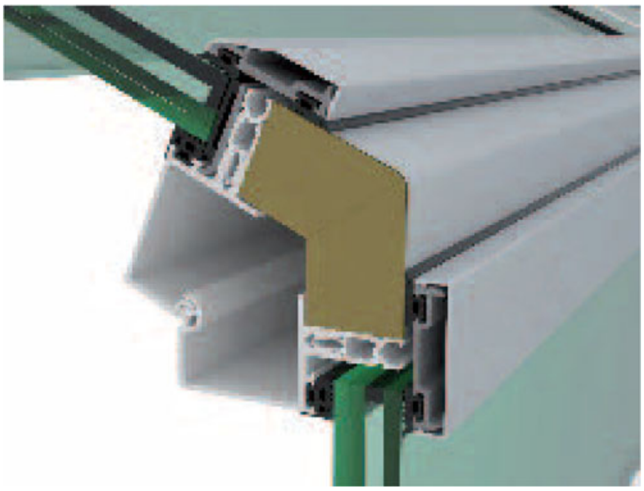
opening lights are used for more closely controlled ventilation. Single glazed sheets are held in place on their sides by supporting them on the glazing bars and securing them in place with continuous aluminium clips that snap onto the glazing bar. The aluminium sections are separated from the glass 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 horizontal joints. Greenhouse glazing can accommodate double glazing units. 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



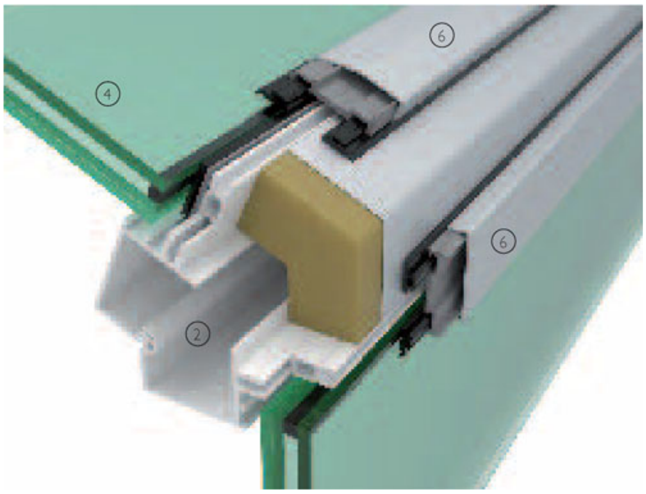
3-D view of capped glazing junction with parapet upstand



Vertical section 1:5. Capped glazing, parapet upstand detail



3-D view of capped glazing eaves detail

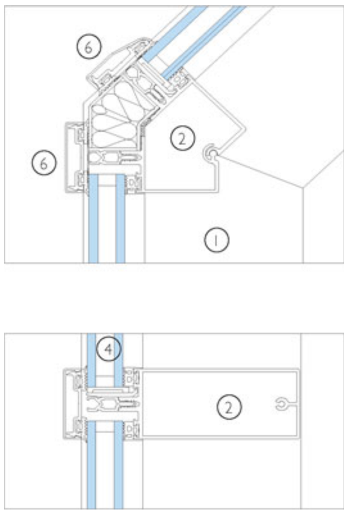


3-D cutaway view of capped glazing eaves detail

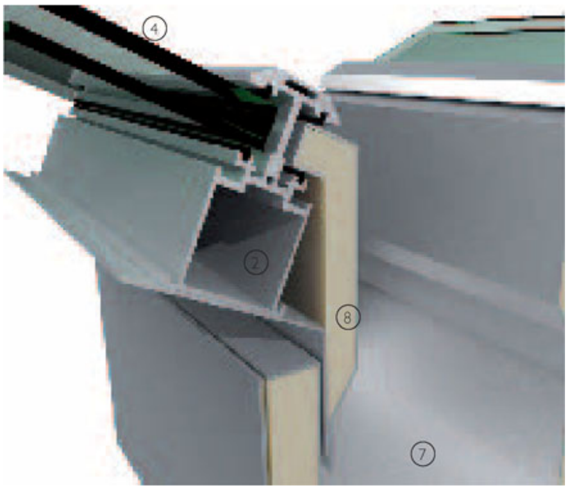
accommodate the increased glass depth, while short length aluminium clips are used along the horizontal joints to hold the lapped units in place. These horizontal joints are usually sealed with silicone to provide an air seal. Greenhouse systems can also accommodate both flat polycarbonate sheet and the multi-wall type. A twin wall sheet has thicknesses which 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.

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.

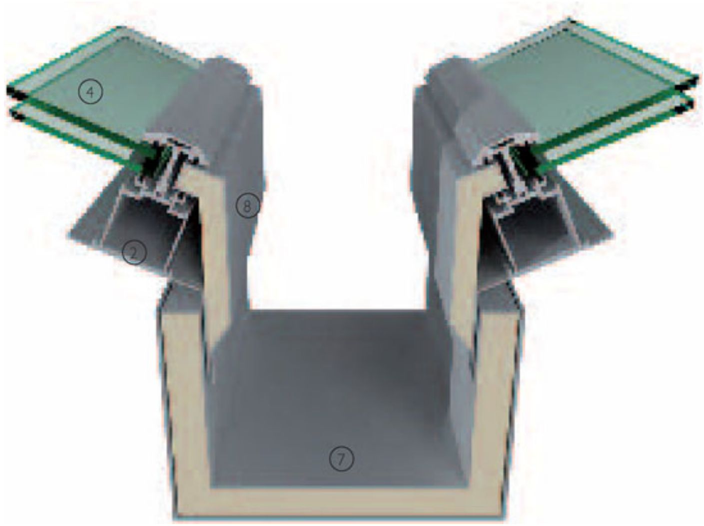
Gutters are formed by fixing gutter profiles to a box section used at junctions beneath it. The glass simply overhangs the edge of the roof to drain rainwater into the gutter. At ground level, the glass often overlaps the concrete ground slab, where a finished floor is provided. Where the greenhouse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



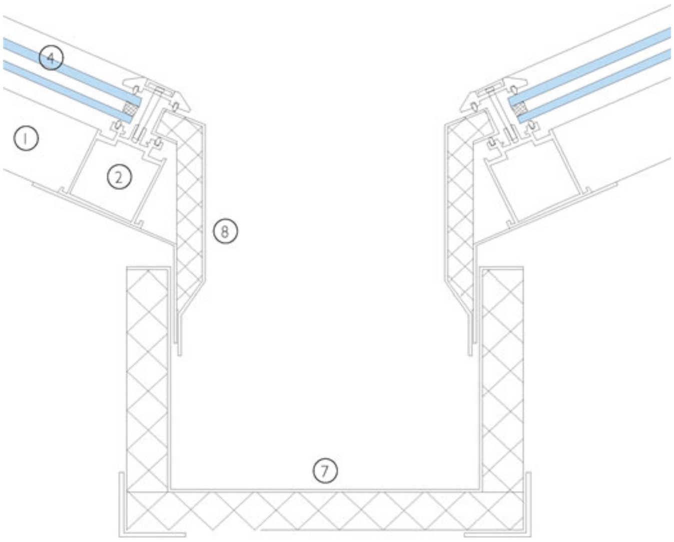
Vertical section 1:5. Capped glazing. Eaves with glass to glass fold



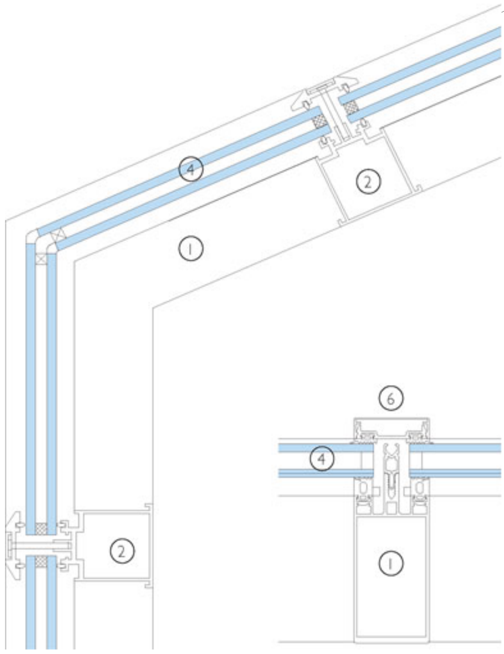
3-D view of capped glazing junction with valley gutter



3-D view of capped glazing junction with valley gutter



Vertical section 1:5. Capped glazing with valley gutter



Vertical section 1:5. Capped glazing. Eaves with profiles at fold

Capped glazing details

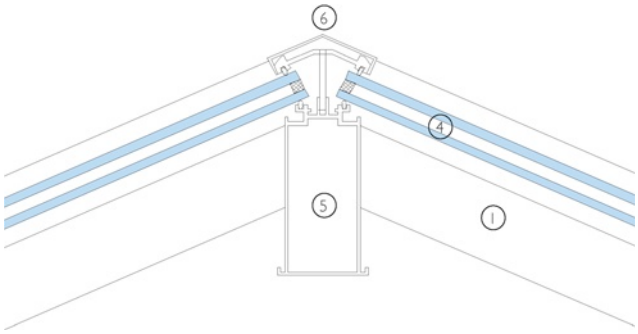
1. Extruded aluminium glazing bar
2. Transom
3. Single glazed unit
4. Double glazed unit
5. Ridge bar
6. Pressure plate and capping
7. Insulated gutter
8. Insulated flashing
9. Rooflight
10. Thermal insulation
11. Pressed metal flashing
12. Concrete base
13. Pressed metal trim

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. 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.

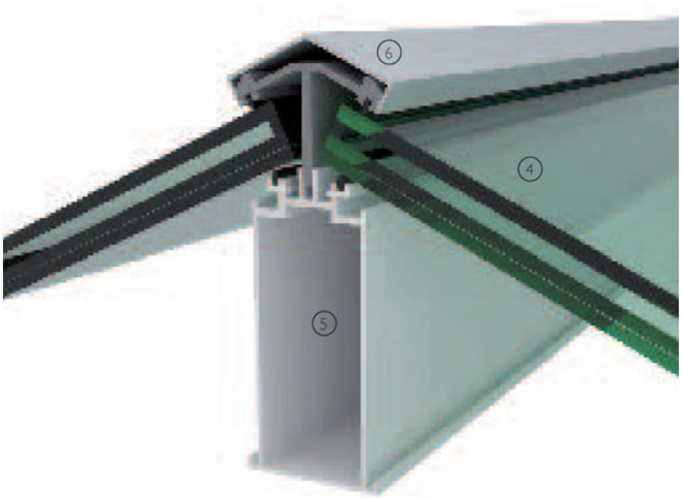
Although not useful for most applications in general building construction, greenhouse glazing is useful for the reader for two reasons: to understand how glazed roofs have evolved from a simple mass produced system, as well as for applications where a glazing system is required that is minimal in both 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

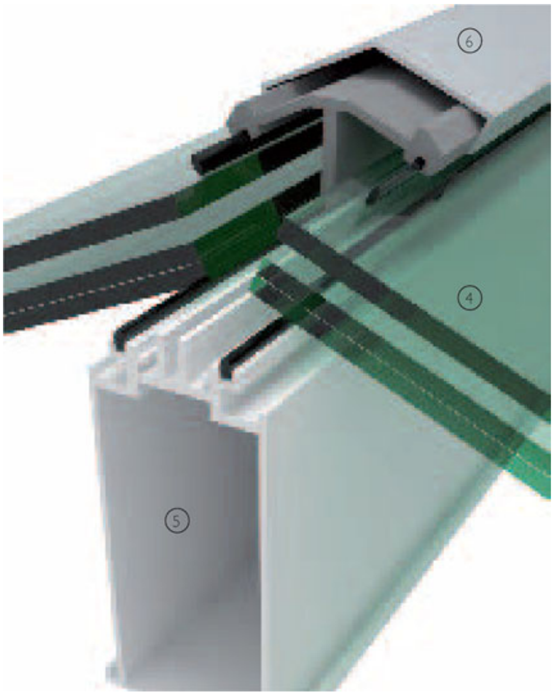
Systems for glass roofs use the principles of greenhouse glazing, but incorporate the principles of glazed curtain walling. Drained and ventilated systems are used, with thermal breaks and double glazed units. Pressure plates rather than clips are used to hold large glass units in place in capped systems, and toggle-type plates are used to provide flush



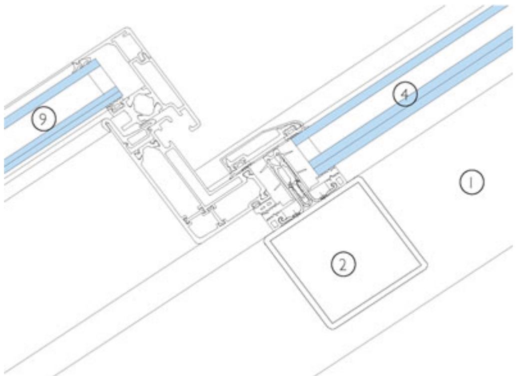
Vertical section 1:5. Capped glazing. Ridge



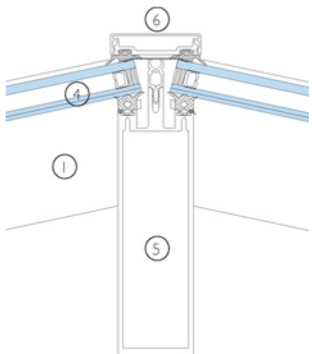
3-D view of capped glazing ridge detail



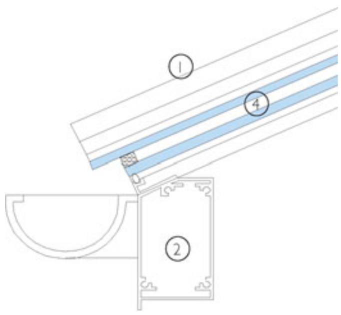
3-D cutaway view of capped glazing ridge detail



Vertical section 1:5. Capped glazing. Junction with rooflight



Vertical section 1:5. Capped glazing. Junction with rooflight



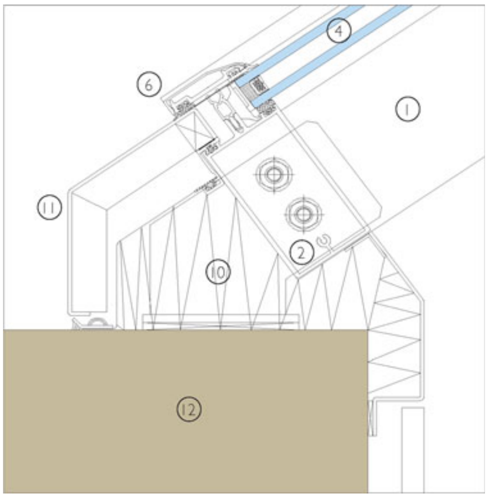
Vertical section 1:5. Capped glazing. Eaves gutter

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.

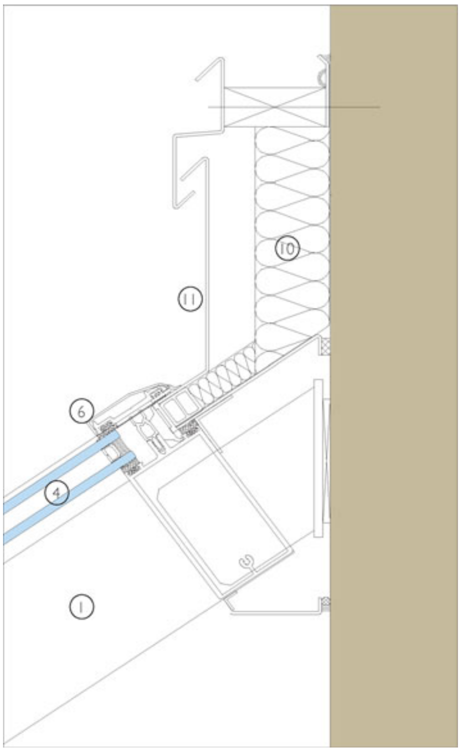
Capped systems

The capped system 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 of the extruded profile, may have an additional condensation channel. This provision can also be made by setting the condensation channels immediately beneath the glass. 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.

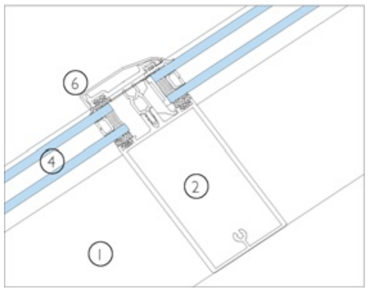
While glazing bars running down the roof project above the surface of the glass, those running along the roof, holding in place



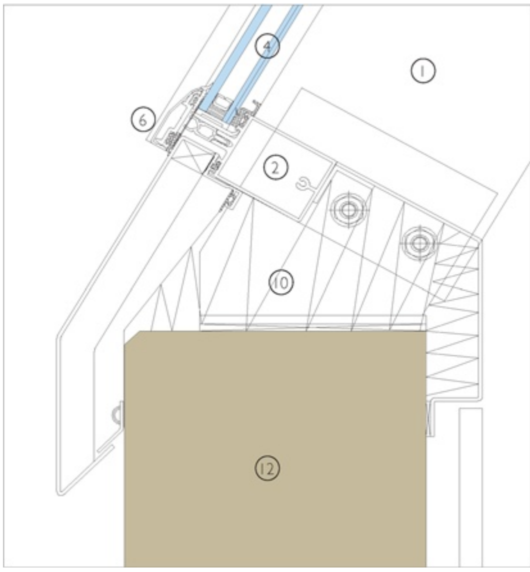
Vertical section 1:5. Capped glazing. Parapet upstand



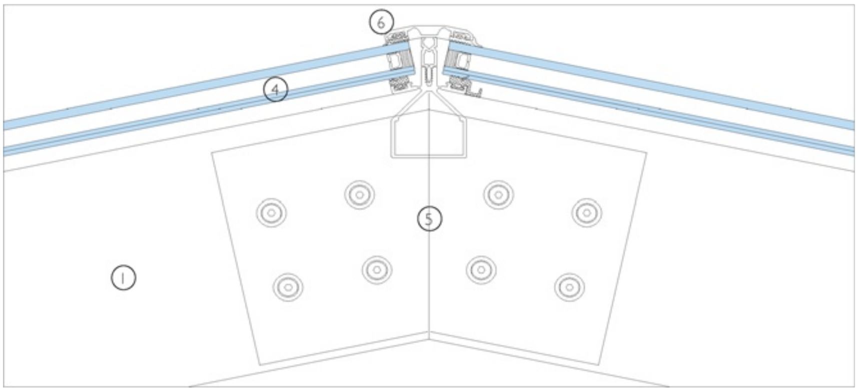
Vertical section 1:5. Capped glazing. Abutment



Vertical section 1:5. Capped glazing. Typical profiles



Vertical section 1:5. Capped glazing. Parapet upstand



Vertical section 1:5. Capped glazing. Ridge

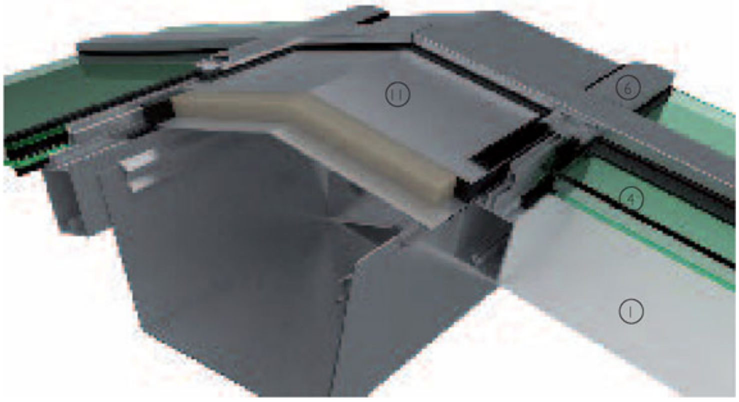
Capped glazing details

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

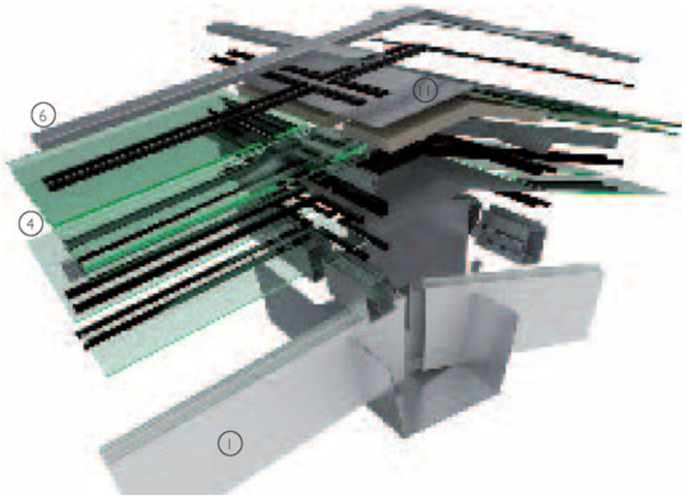
the top and bottom edges of the glass, require a method of allowing the water to run over the junction. Some systems use a step at this point, without a pressure plate on top that would otherwise impede the passage of water down the roof. Other systems use a pressure plate and cover capping with chamfered edges that allow 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 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.

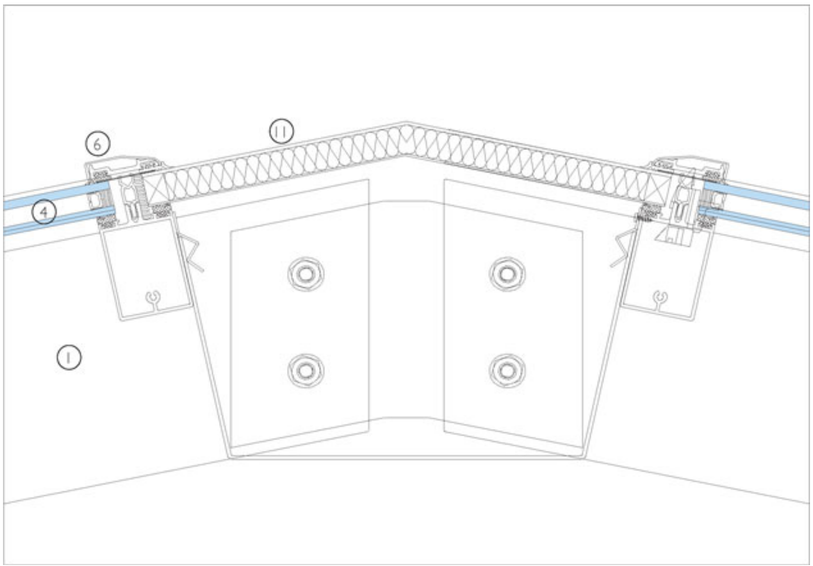
Gutters, at both valleys and eaves, are very different to greenhouse glazing. Instead



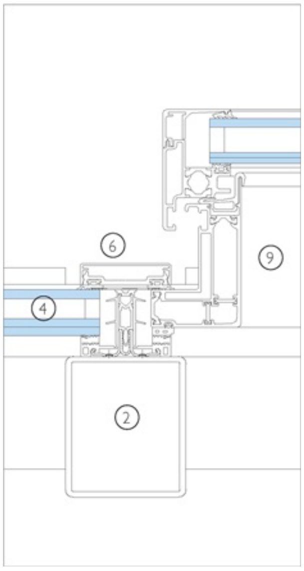
3-D view of capped glazing ridge detail



3-D exploded view of capped glazing ridge detail



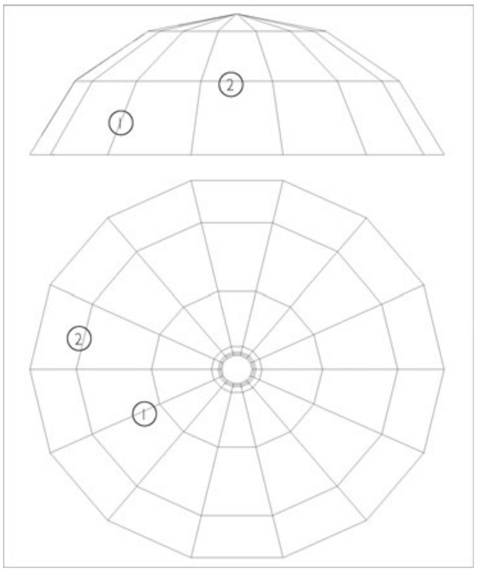
Vertical section 1:5. Capped glazing. Ridge



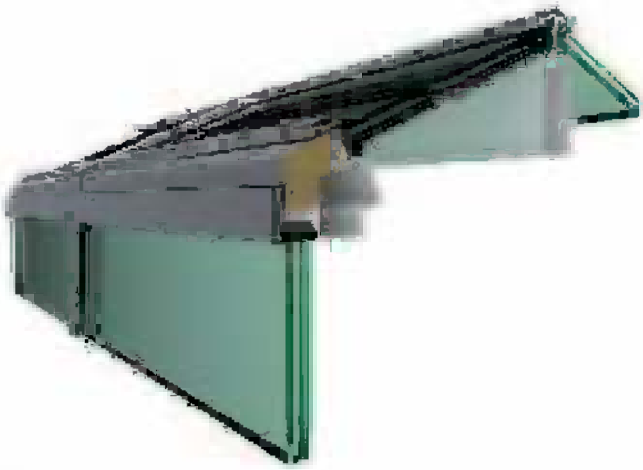
Vertical section 1:5. Capped glazing. Junction with rooflight

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. 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.

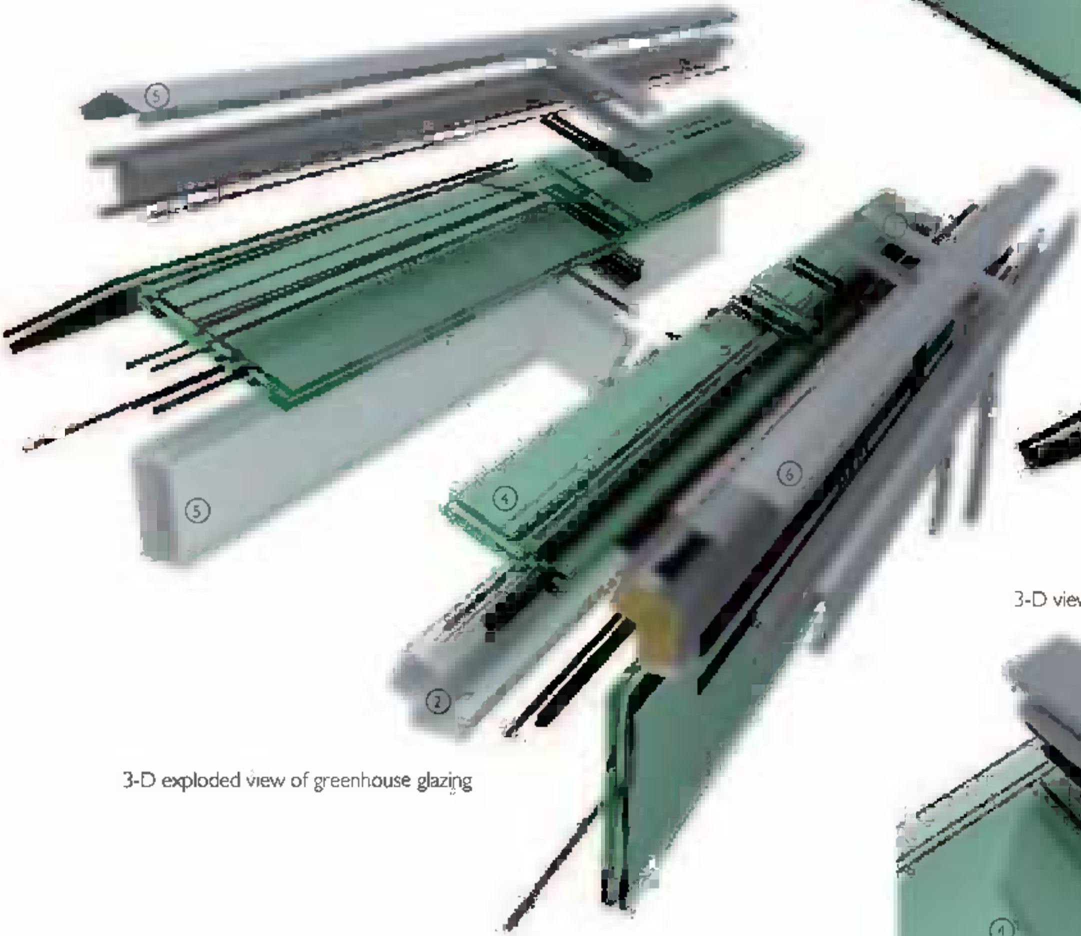
Regular downstand flashings are insulated in order to provide a continuity with the thermal insulation of the adjacent construction at the base of the roof in order to avoid a thermal bridge. Glazing bars that terminate at flashings and gutters allow the internal drain to release water at these points. Drops of water that find their way into the drainage chamber are drained out onto the outer (top) surface of the downstand flashing.



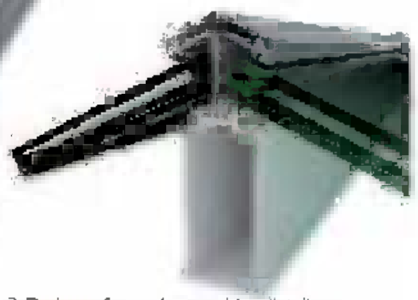
Vertical and horizontal sections 1:100. Capped glazing. General principle



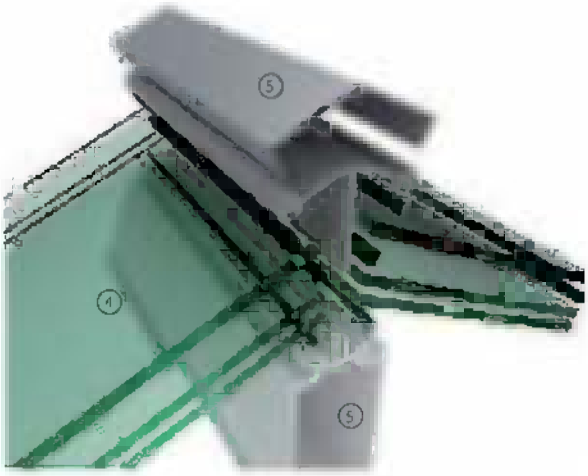
3-D view of greenhouse glazing



3-D exploded view of greenhouse glazing

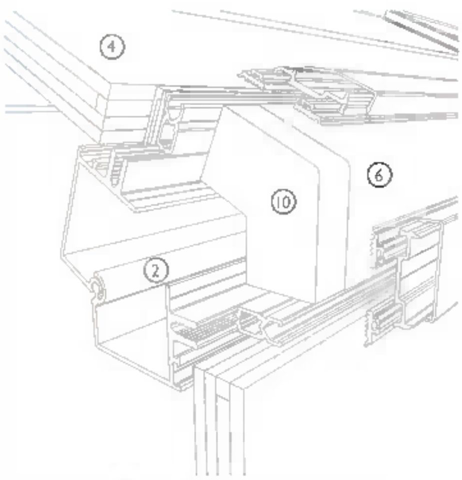


3-D view of greenhouse ridge detail



3-D exploded view of greenhouse ridge detail

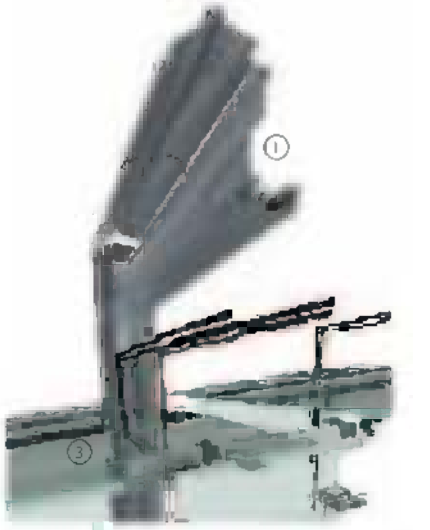
3-D exploded view of greenhouse eaves detail



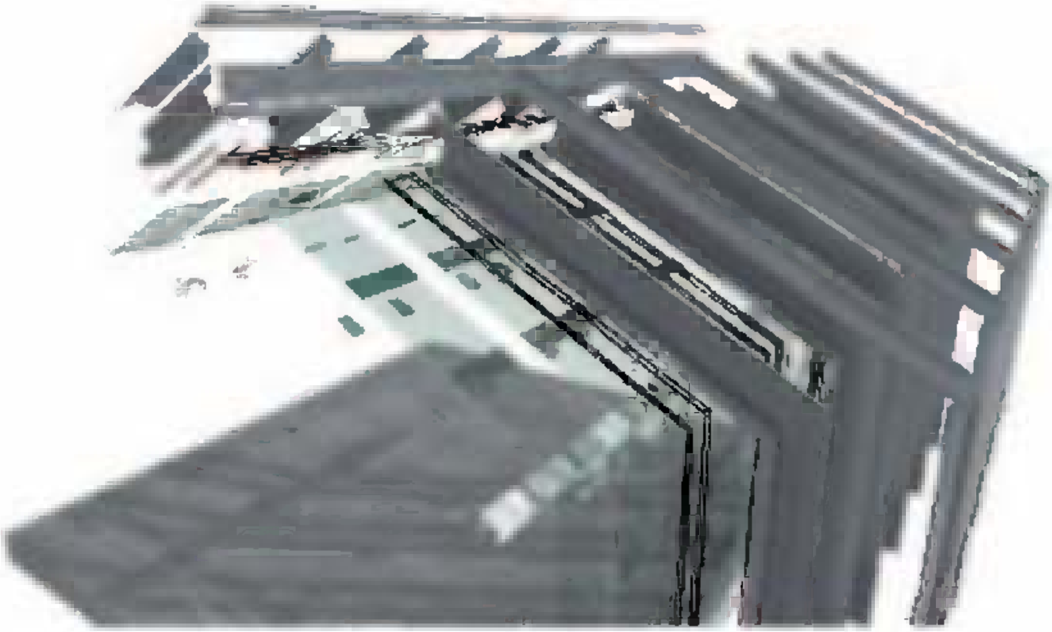
3-D line drawing of greenhouse eaves detail

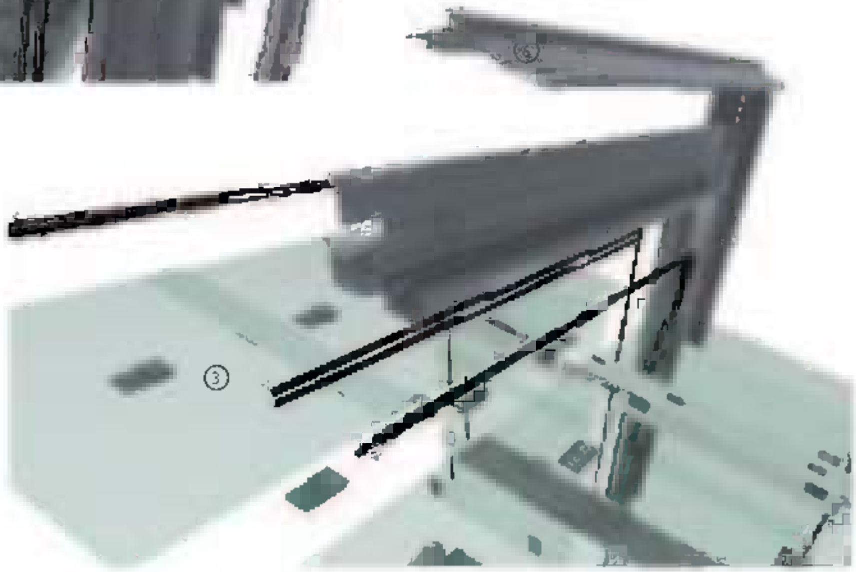
Capped glazing details

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

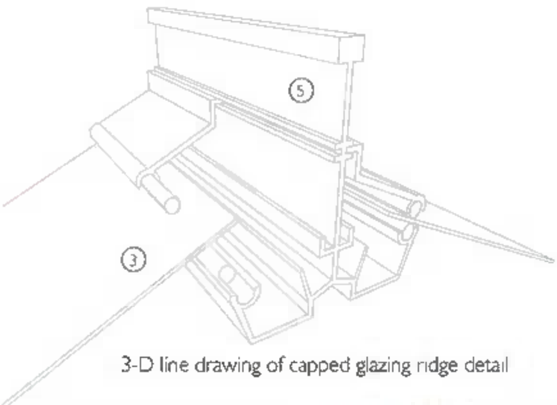


3-D exploded view of capped glazing construction

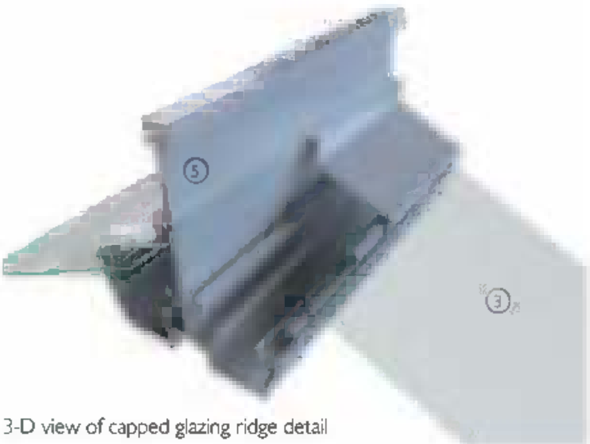

3-D exploded view of capped glazing construction



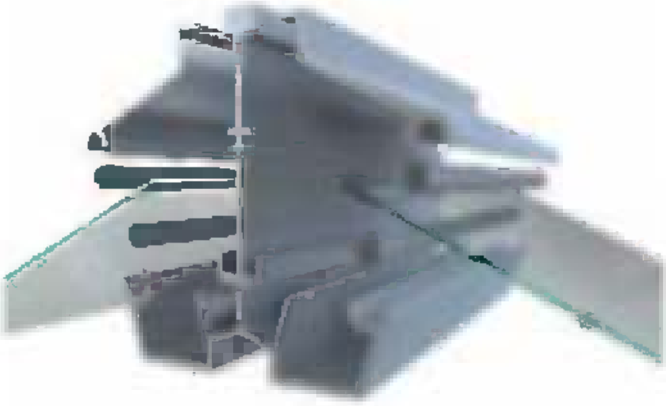
3-D exploded view of capped glazing construction

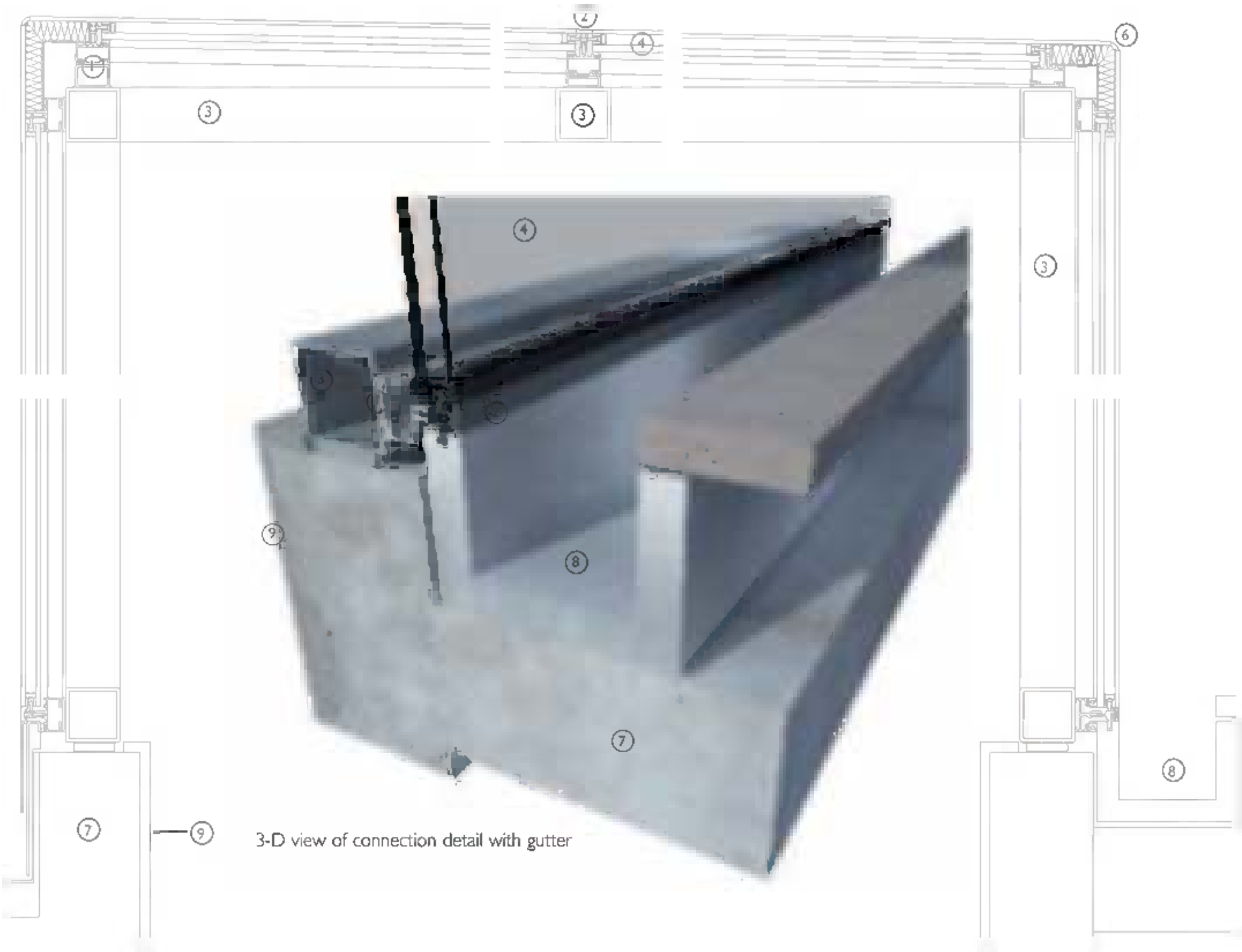


3-D line drawing of capped glazing ridge detail



3-D view of capped glazing ridge detail


3-D exploded view of capped glazing ridge detail



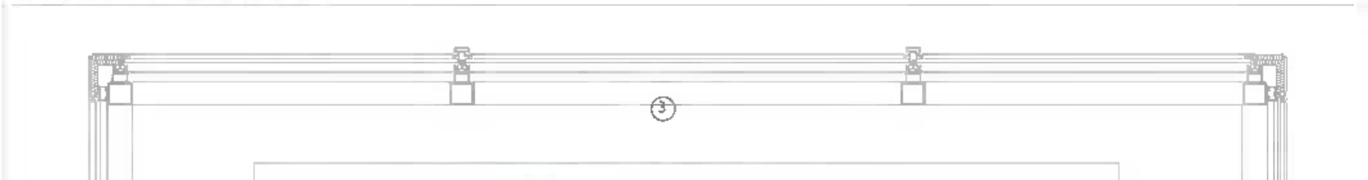
Vertical section 1:10 through rooflight showing typical details

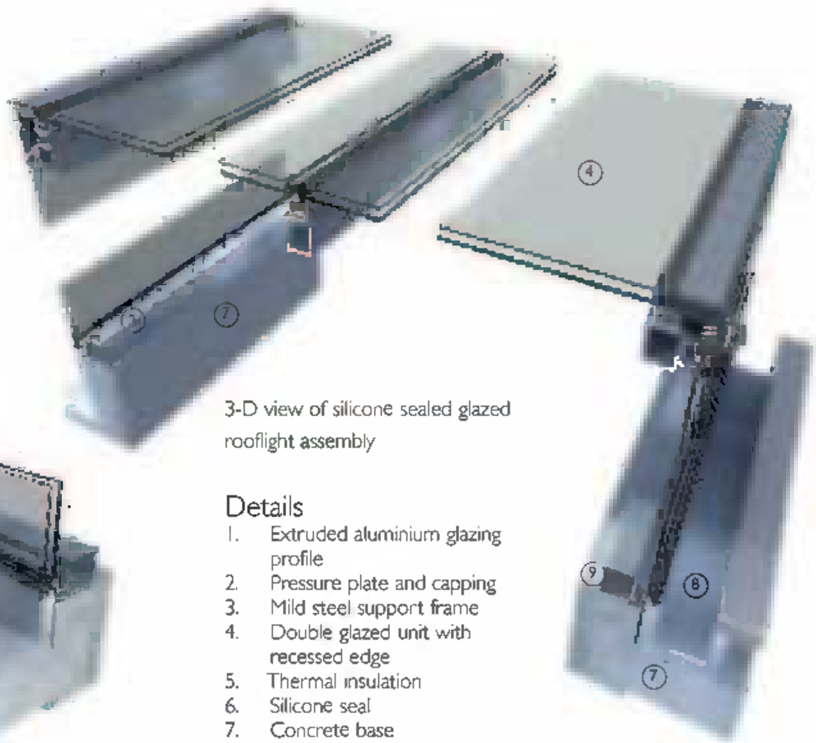
Silicone-sealed systems

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 behind the spacer. The adjacent spacer in 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.

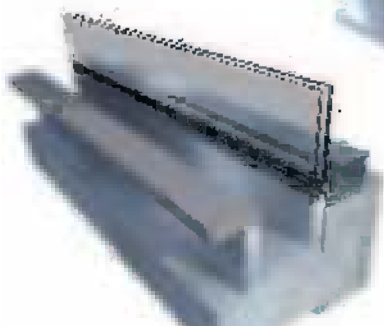
In some cases, the glazing bar has its structural box or fin removed in order to fix it directly to a steel support frame. Square hollow sections are shown here. Alternatively, an all-aluminium glazing bar can be used. As with capped systems, small amounts of rainwater that pass through the outer silicone 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 channel 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.

ical section 1:25 ypical assembly





3-D view of silicone sealed glazed rooflight assembly

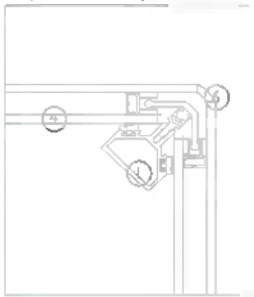


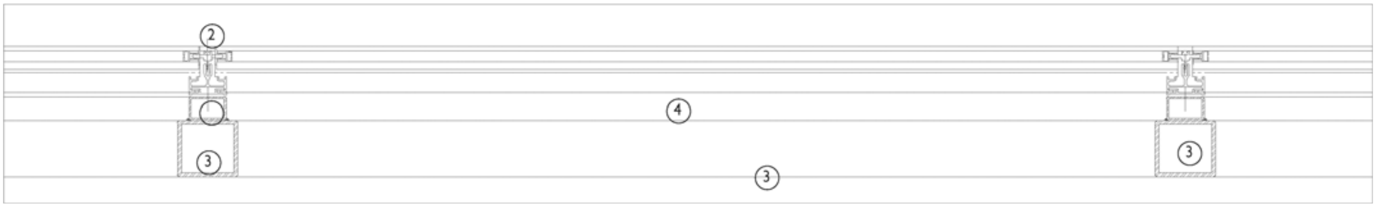
D view of conn ction detail ith gutt r

Details

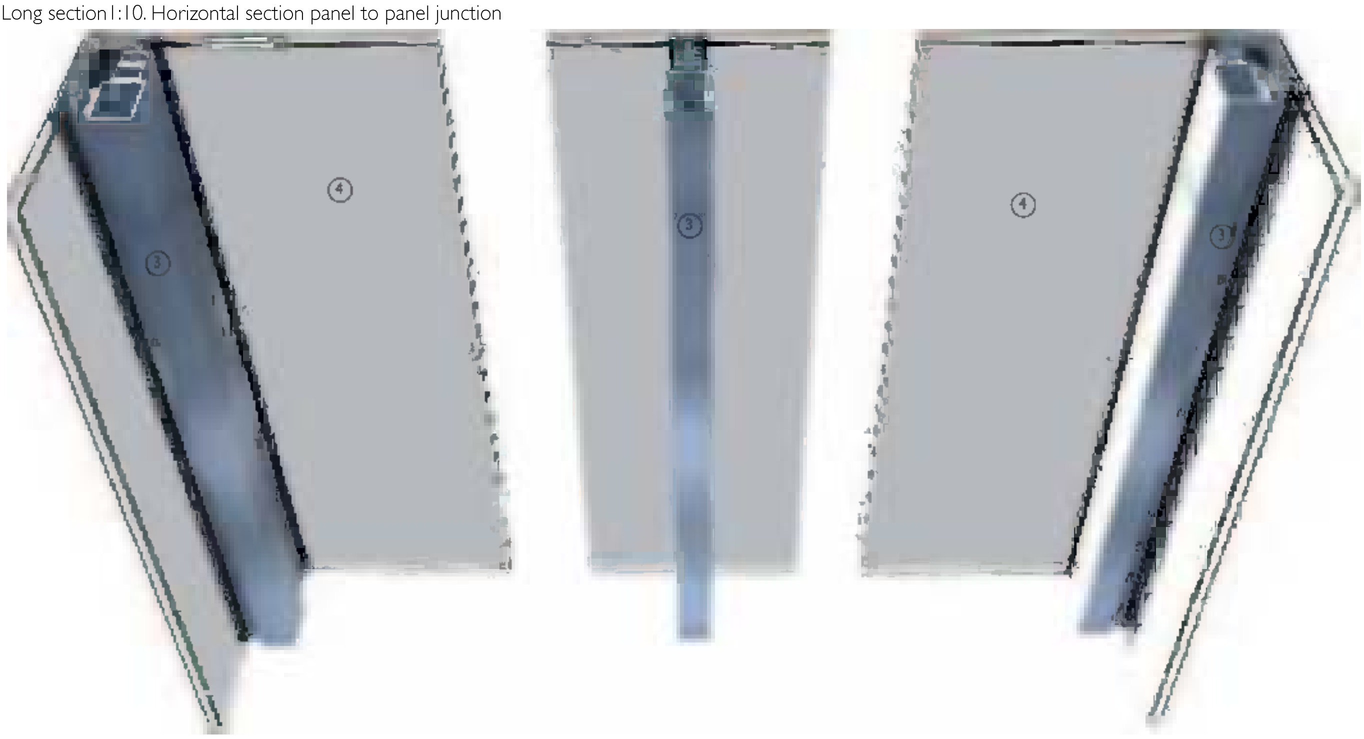
1. Extruded aluminium glazing profile
2. Pressure plate and capping
3. Mild steel support frame
4. Double glazed unit with recessed edge
5. Thermal insulation
6. Silicone seal
7. Concrete base
8. Gutter
9. Internal finish

Horizontal section 1:10. Pane to panel corner junction

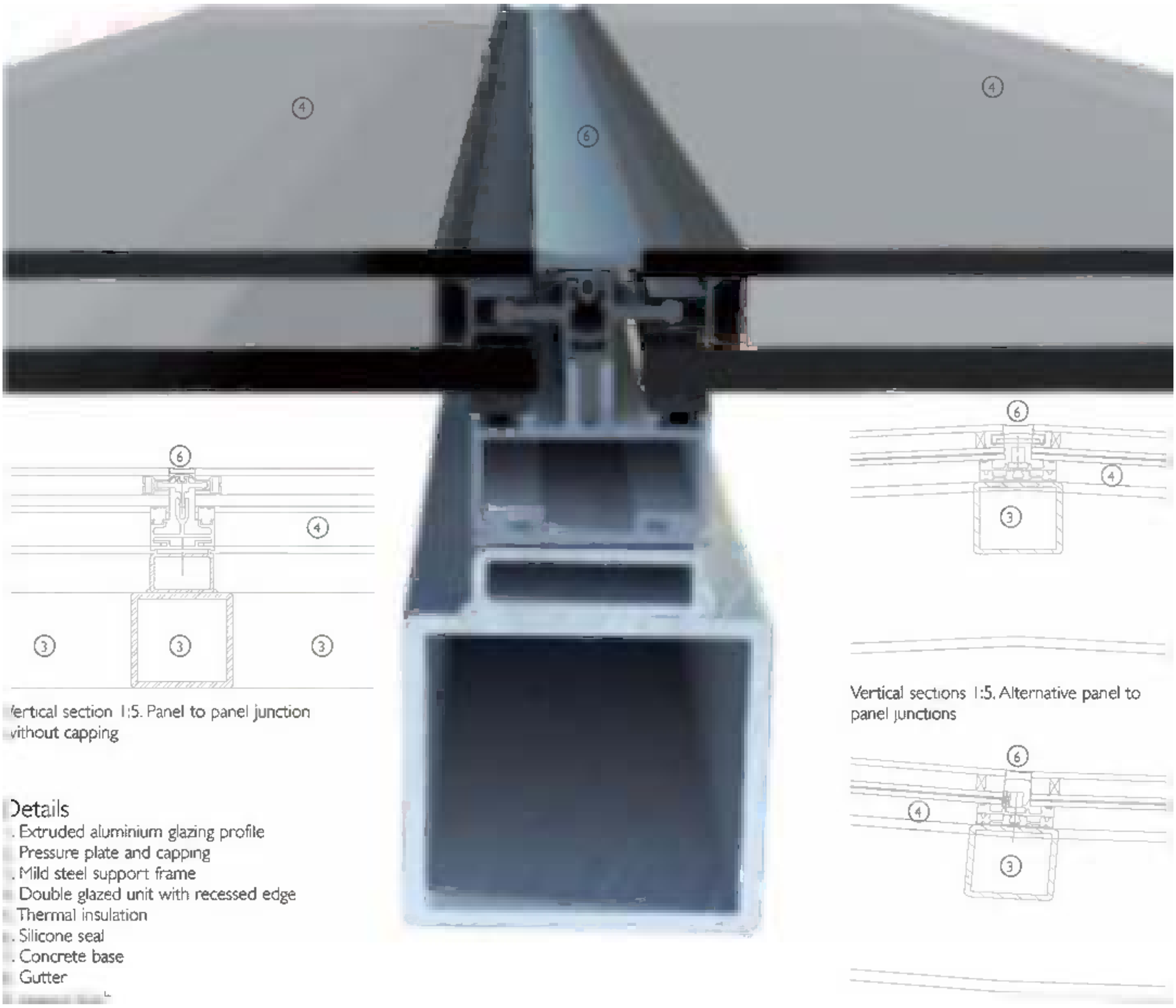




Long section1:10. Horizontal section panel to panel junction



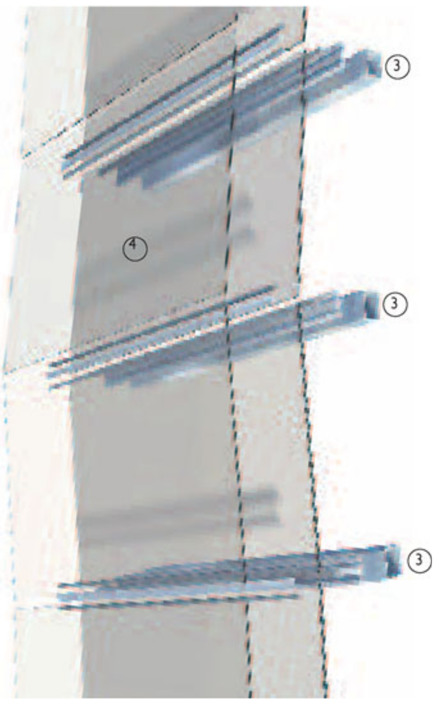
3-D view showing horizontal panel to panel junction



'ertical section 1:5. Panel to panel junction
vithout capping

Vertical sections 1:5. Alternative panel to panel junctions

Details
. Extruded aluminium glazing profile
Pressure plate and capping
. Mild steel support frame
Double glazed unit with recessed edge
Thermal insulation
. Silicone seal
. Concrete base
Gutter

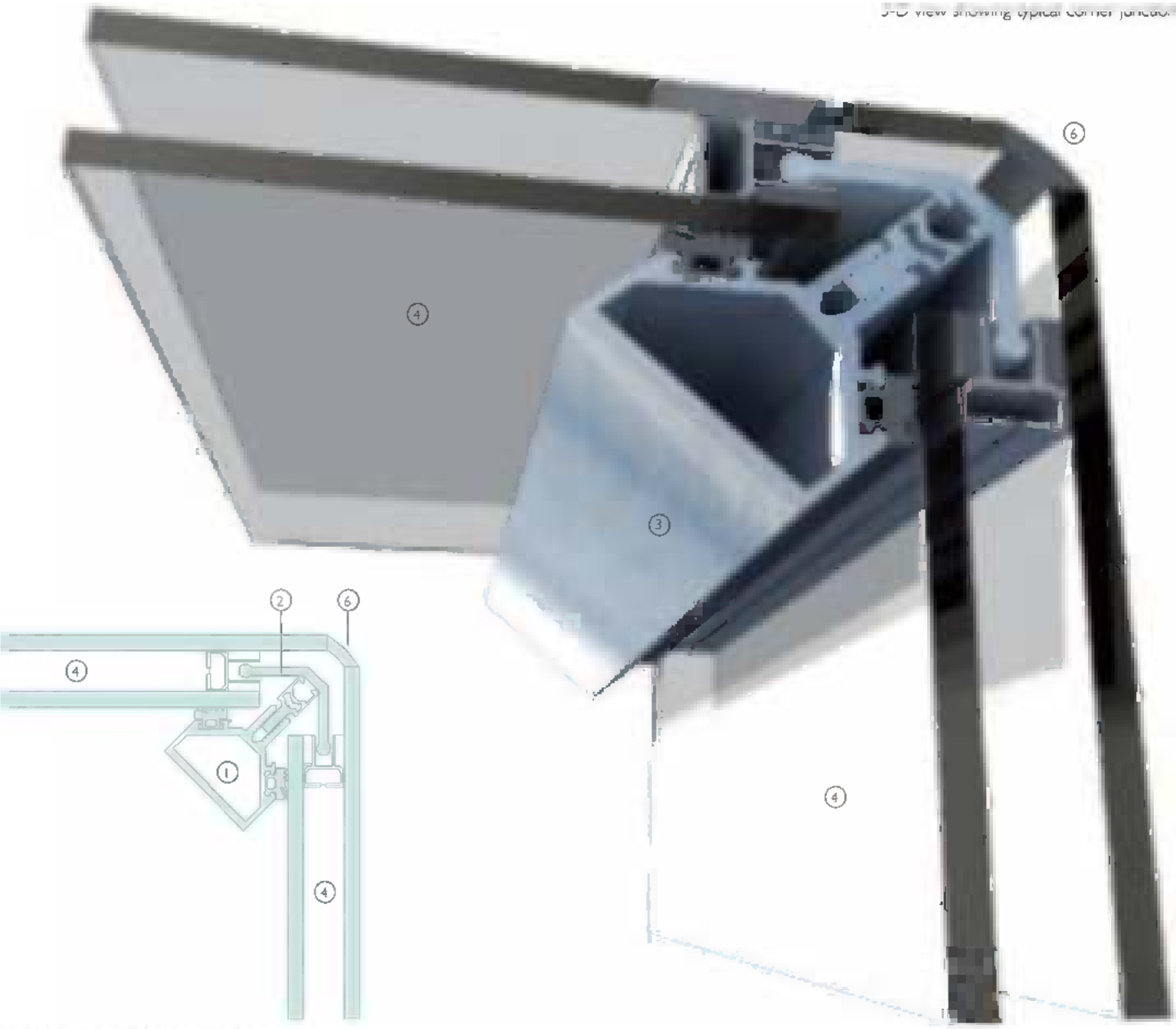


3-D exploded view showing panel to panel junction

Junctions

Since the advantage of silicone-sealed systems is of continuous glazed surfaces uninterrupted by visible glazing bars, ridges and valleys are treated as simple 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, or with two glazing bars meeting. 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

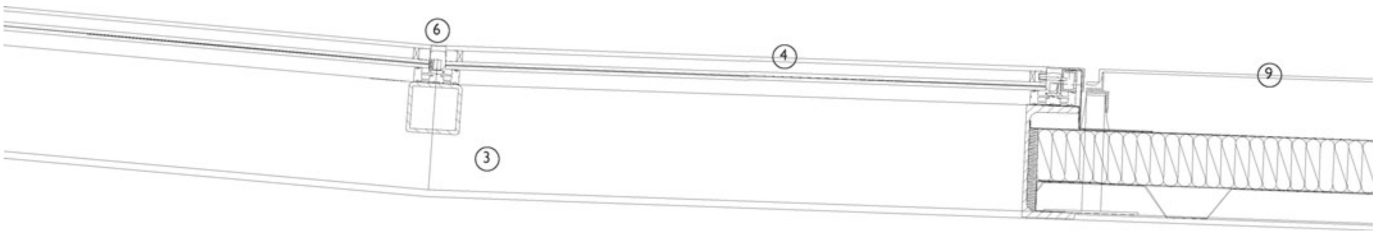


straight line without the assistance of an additional metal angle bedded into the silicone. The alternative method of forming a roof edge requires the edge of the double glazed unit to be coated or 'opacified' to avoid the frame behind being visible through the glass. This is often achieved by stepping 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. 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, a separate flashing can

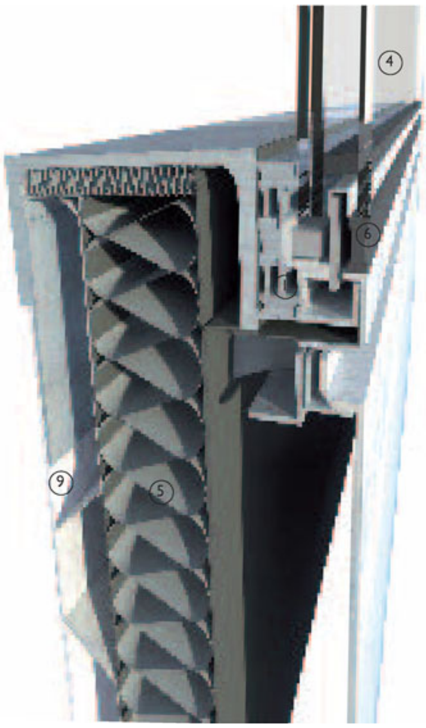
3-D view showing window-wall junction

Long section 1:10. Edge of rooflight



Cross section 1:10. Edge of rooflight.

Cross section 1:10. Junction of 2 rooflights with opaque roof

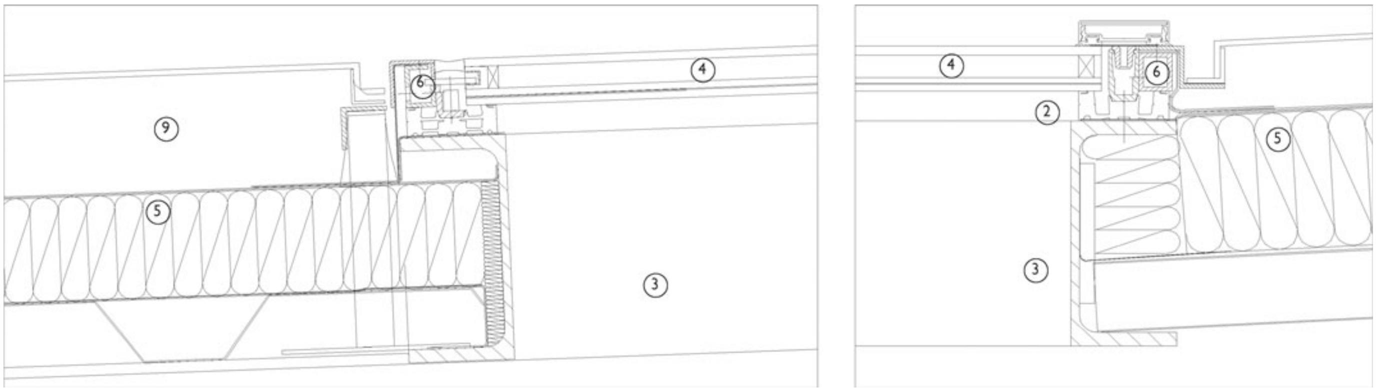


be used, fixed to the glazing bar but independent of the gutter. The gutter is still sealed to the glazing bar with a flexible EPDM gasket to provide a continuous seal.

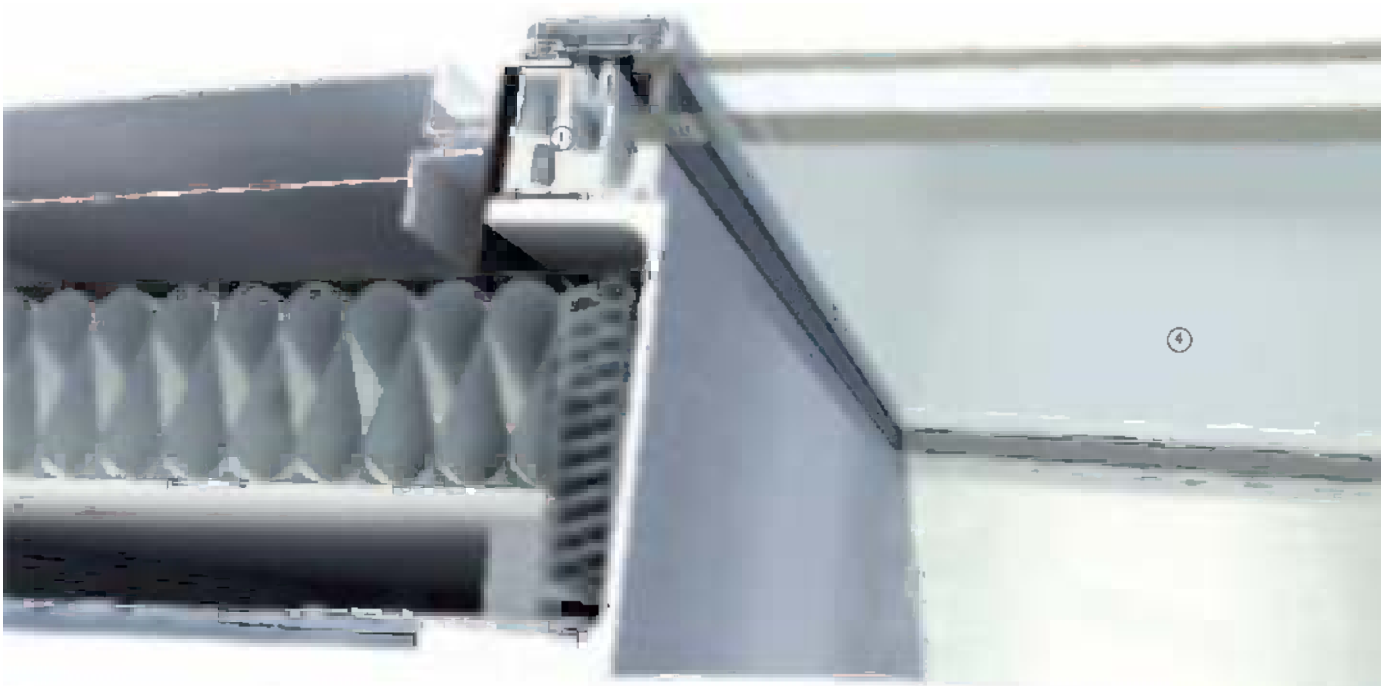
The base of the glazed roof that terminates in a glazed wall can meet an adjacent concrete roof slab with either a metal glazing channel, or in an upstand and flashing. Where a glazing channel is used, the double glazed unit sits in a profile formed from extruded aluminium, stainless steel or painted 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 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 can be used 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



Vertical section 1:5. Edge of rooflight

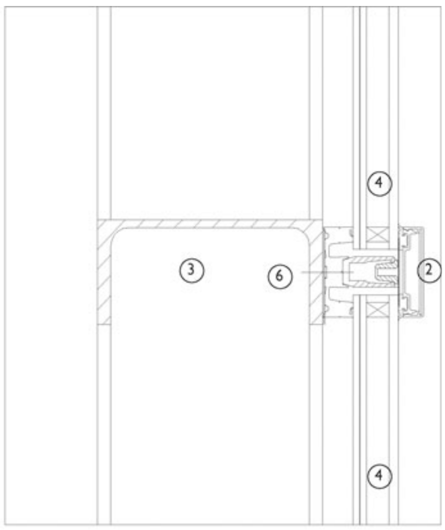


I-D view showing edge of rooflight

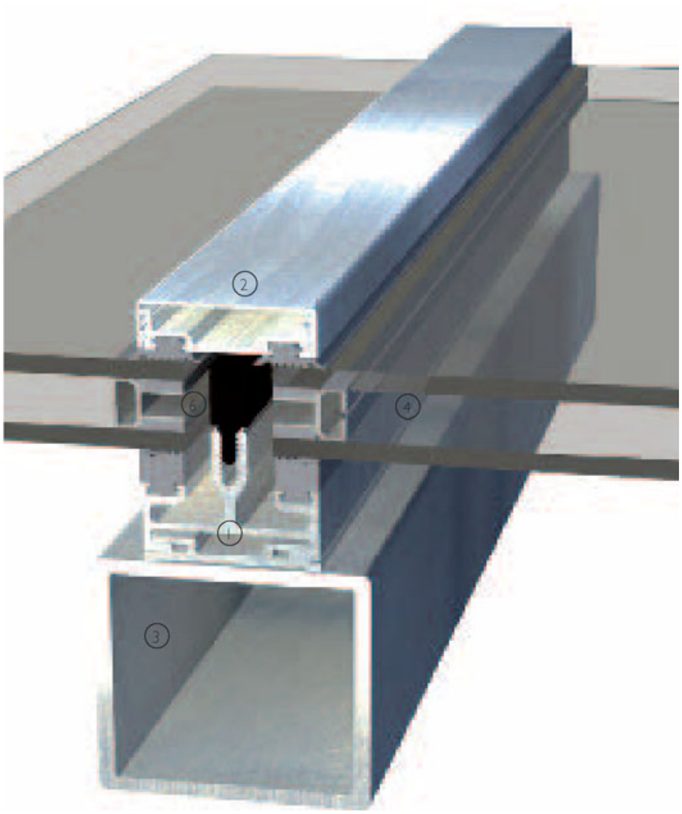
section) is its ability to be mixed with capped glazing. Since both systems are drained and ventilated (pressure equalised), the same glazing bar can be used in a mixed roof system of flush silicone joints and capped profiles. Although this mix is done often for visual reasons, it does allow for easily formed junctions with adjacent areas of roof in different materials, and for a mix of actual 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.

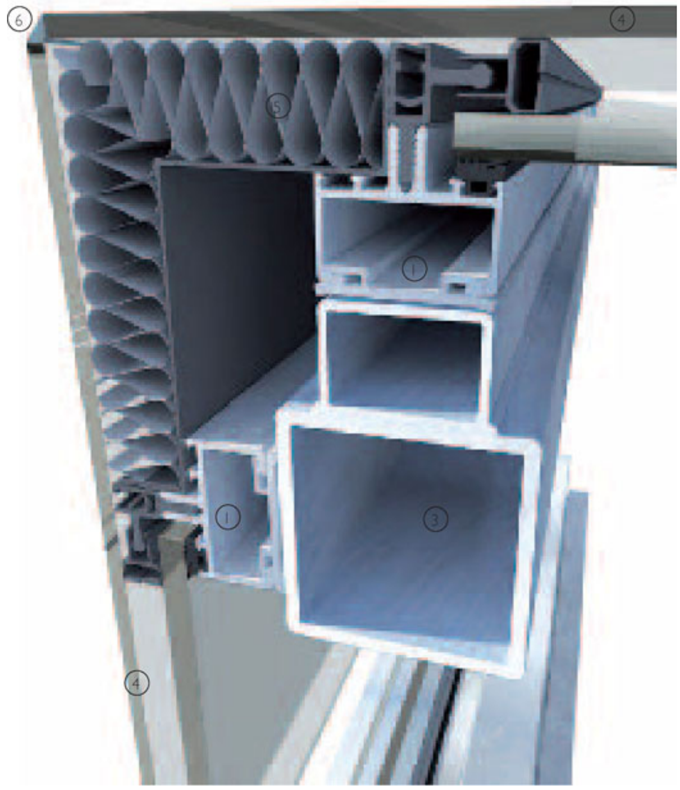
The internal drainage of the mixed glazing system works in the same way, with any water that penetrates the silicone sealed glazing being drained along the internal condensation channels before draining into the profiles of the capped system and onwards down to the base of the roof. The condensation channel and inner air seal can also be formed in a single EPDM extrusion without the use of any aluminium extrusion, but with a supporting structure behind. In this case,



Vertical section 1:5. Horizontal panel to panel junction with capping



3-D view of panel to panel junction detail with capping



3-D view of corner detail showing insulated corner covered by opaque glazing

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 can also be used. The EPDM gasket, combined with a steel supporting 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.

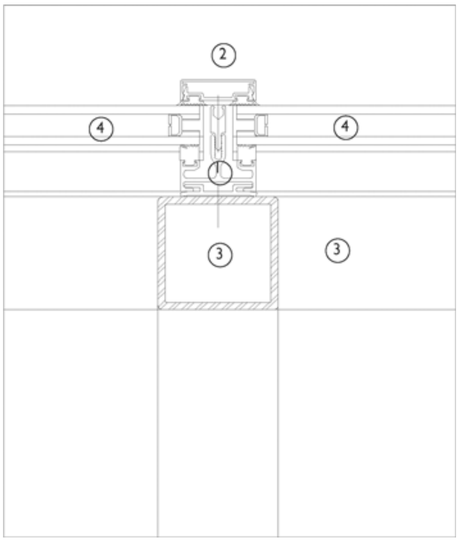
Rooflights

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 glazing to provide individual rooflights that are visually integrated into adjacent areas of opaque roof. A single layer membrane roof can be sealed into the edge of a capped glazed rooflight by clamping the membrane into the glazing system. A metal rainscreen can also be incorporated, sitting 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.

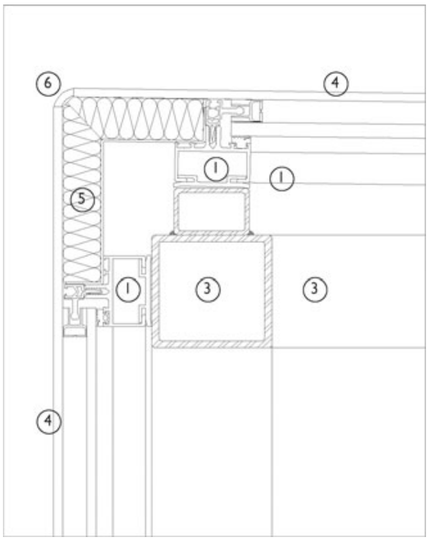
The edge of the rooflight is formed with a capped glazing profile, while the joints within the rooflight, running across it (at 90°), use a silicone-sealed profile to allow water to run down to the bottom edge of the rooflight. This lowest edge of the rooflight has a silicone sealed edge with a drip 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 its sides. 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

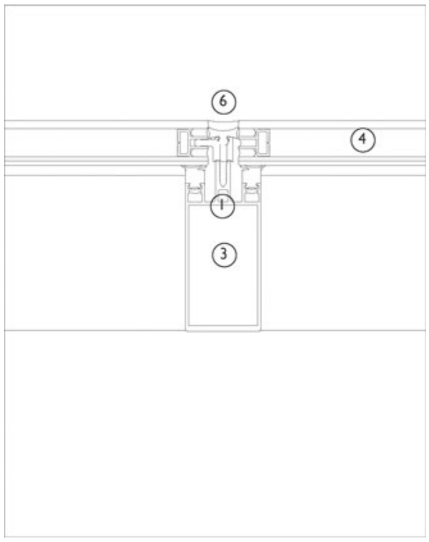
1. Extruded aluminium glazing profile
2. Pressure plate and capping
3. Mild steel support frame
4. Double glazed unit with recessed edge
5. Thermal insulation
6. Silicone seal
7. Concrete base
8. Gutter
9. Internal finish



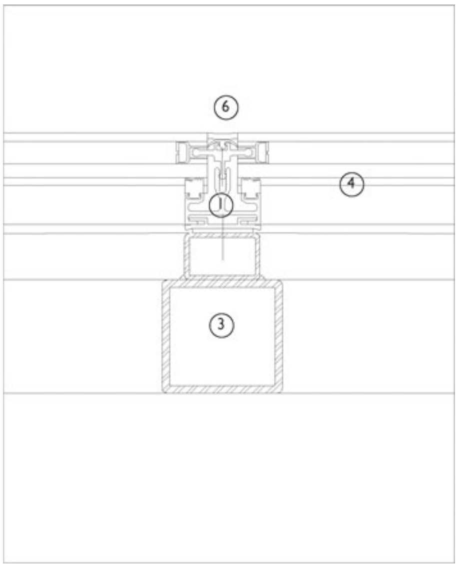
Vertical section 1:5. Horizontal panel to panel junction with capping



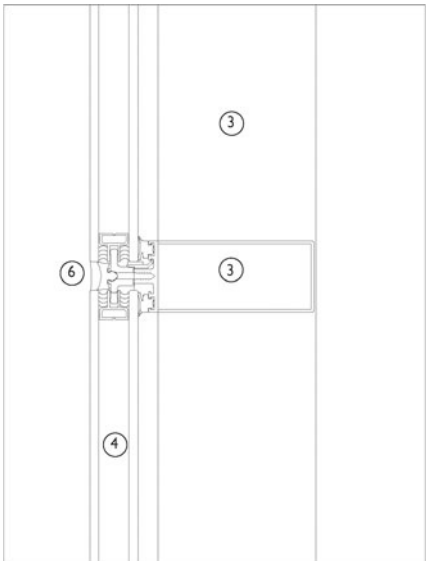
Cross section1:5. Corner



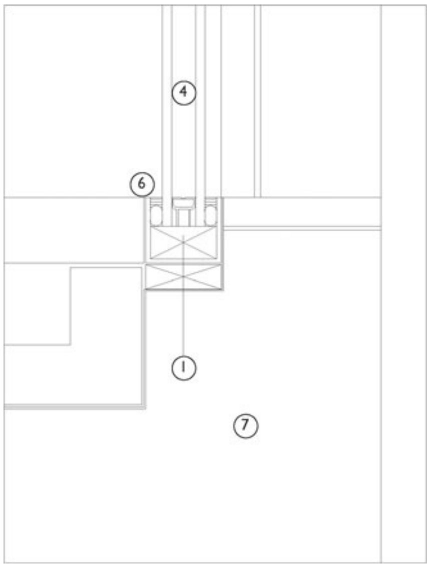
Vertical section 1:5. Horizontal panel to panel junction without capping



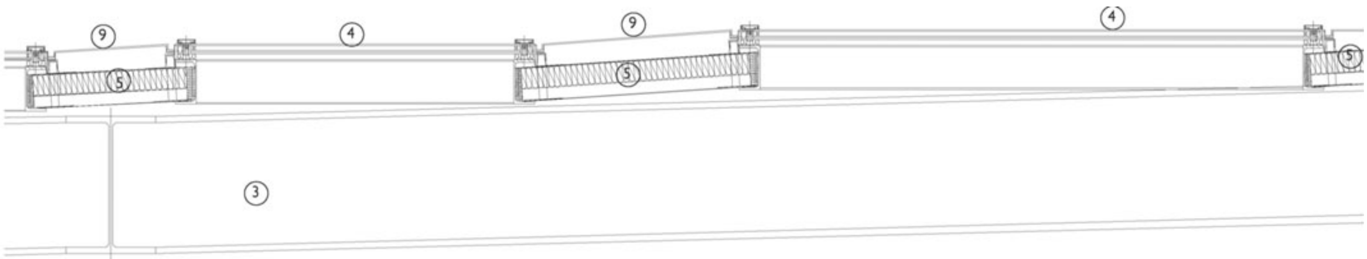
Vertical section 1:5. Horizontal panel to panel junction without capping



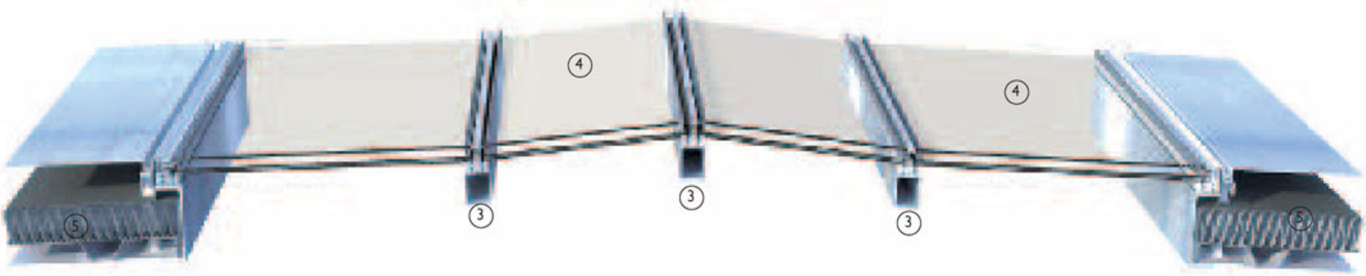
Vertical section 1:5.Vertical panel to panel junction with capping



Vertical section 1:5. Junction with adjacent roof
Detail G



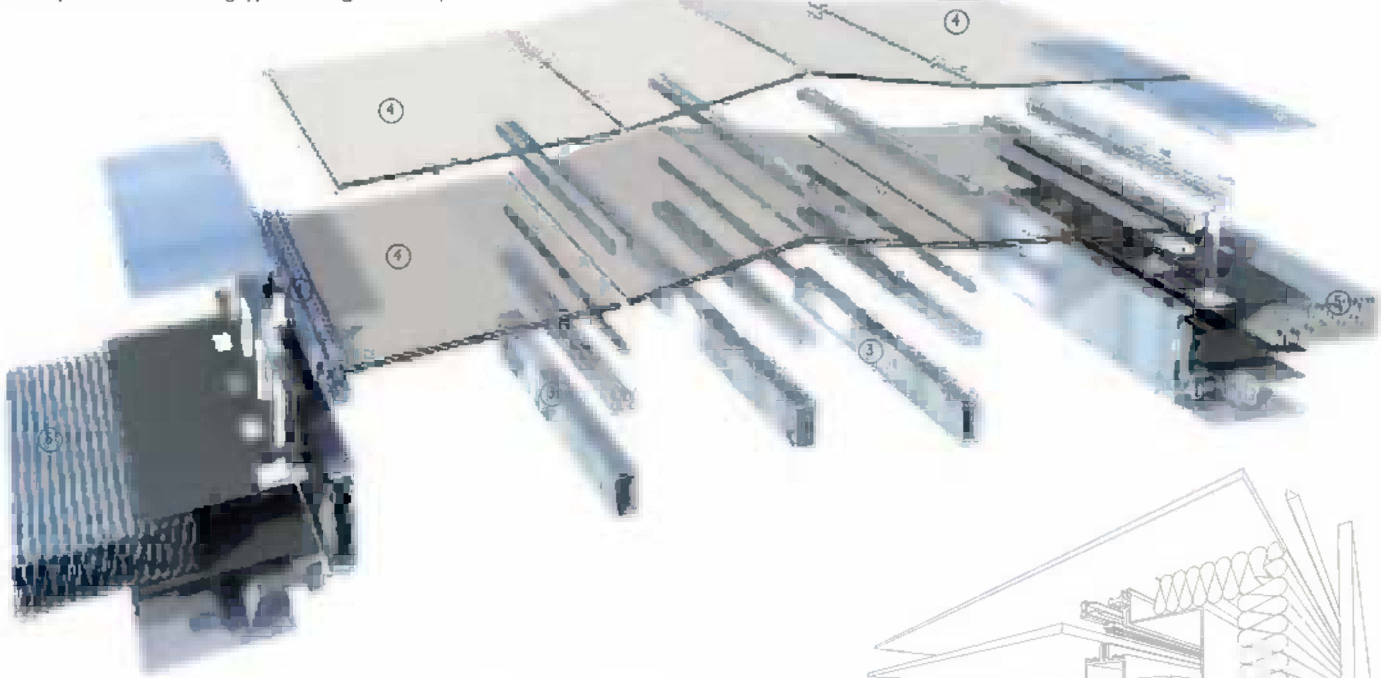
Typical cross section 1:25. Capped glazing.Typical profiles

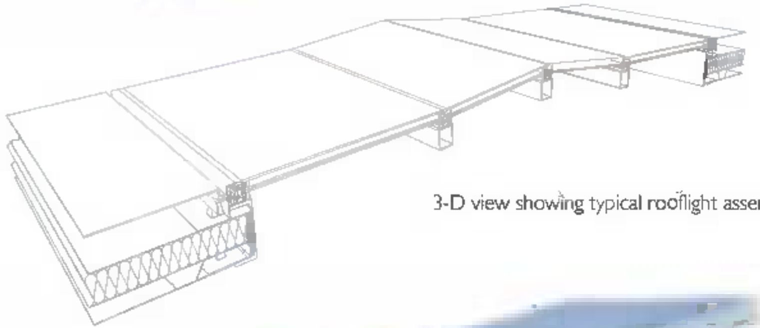


3-D view showing typical cross section with capped glazing

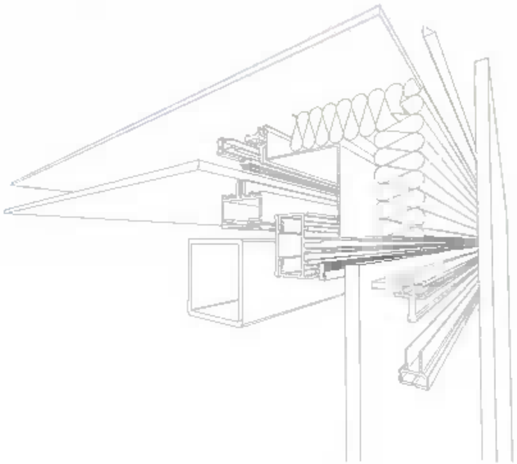
Silicone-sealed glazing and rooflights

3-D exploded view showing typical rooflight assembly

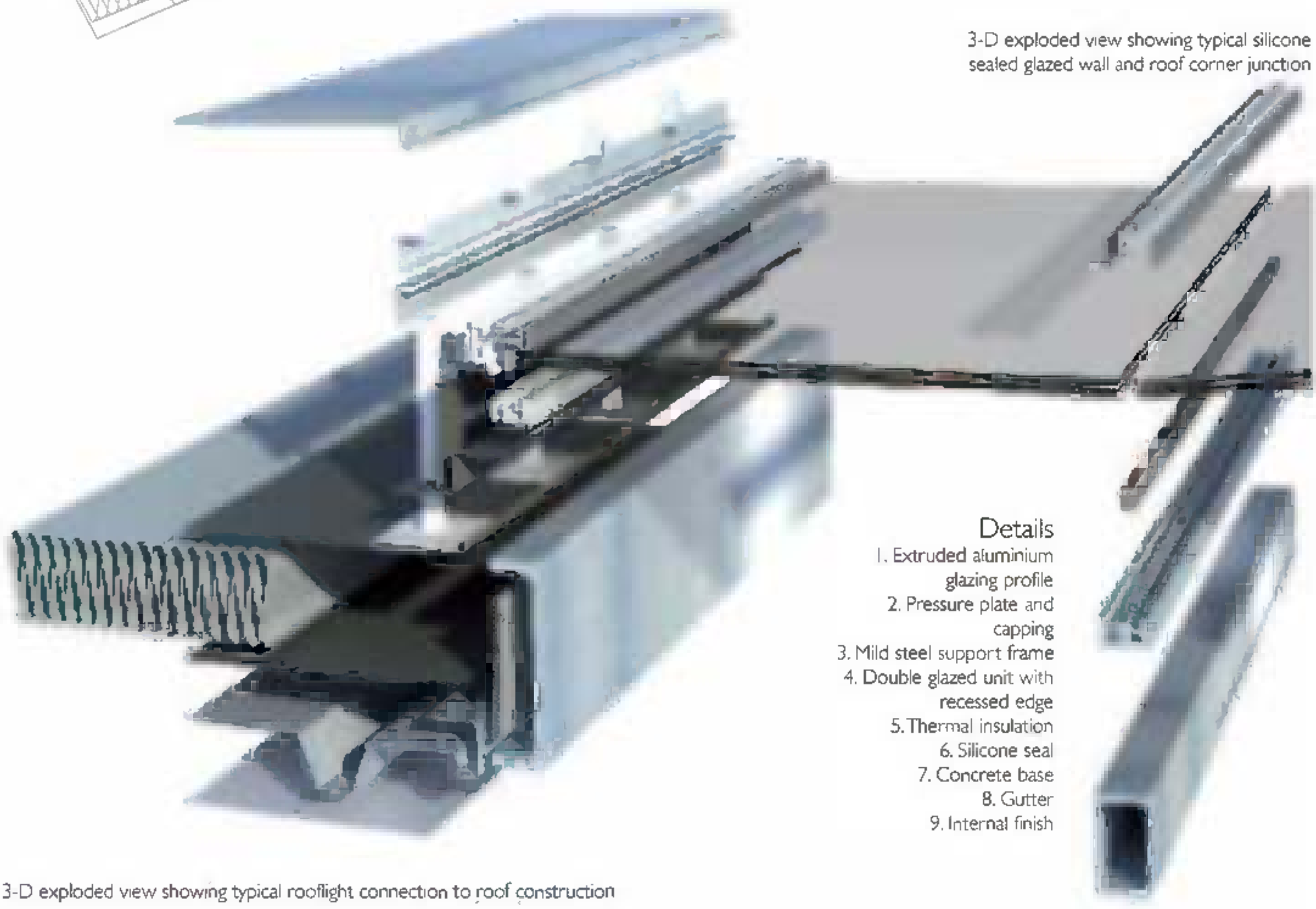




3-D view showing typical rooflight assembly



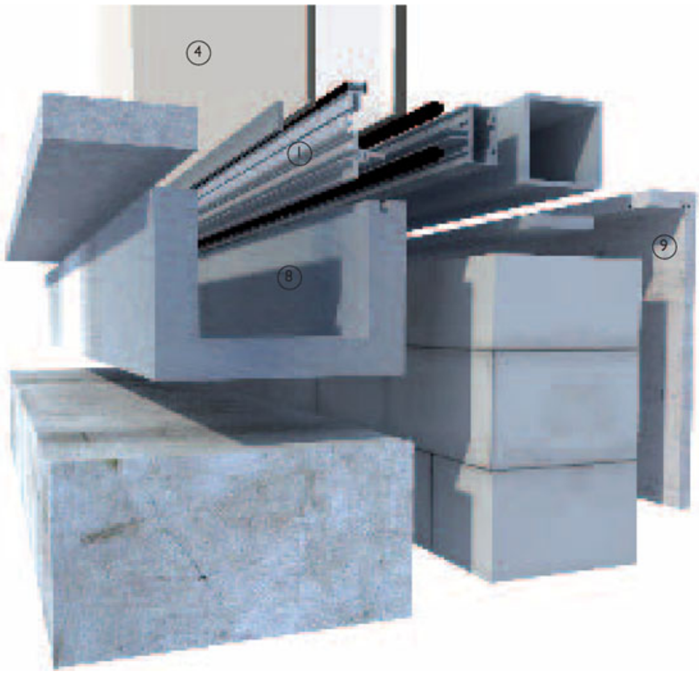
3-D exploded view showing typical silicone sealed glazed wall and roof corner junction



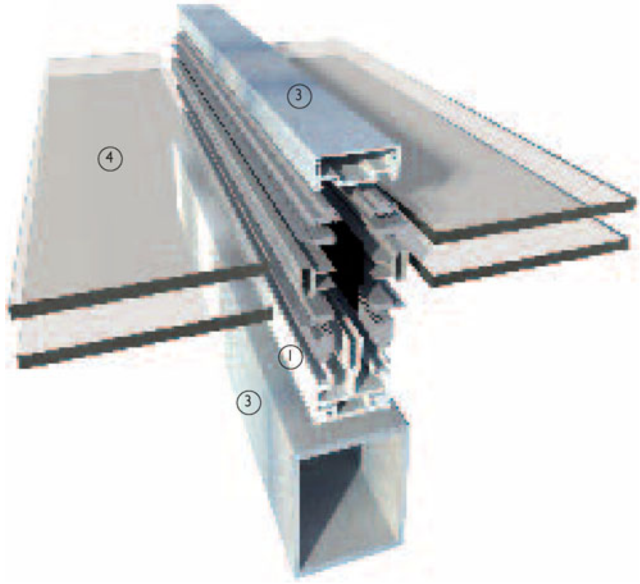
Details

1. Extruded aluminium glazing profile
2. Pressure plate and capping
3. Mild steel support frame
4. Double glazed unit with recessed edge
5. Thermal insulation
6. Silicone seal
7. Concrete base
8. Gutter
9. Internal finish

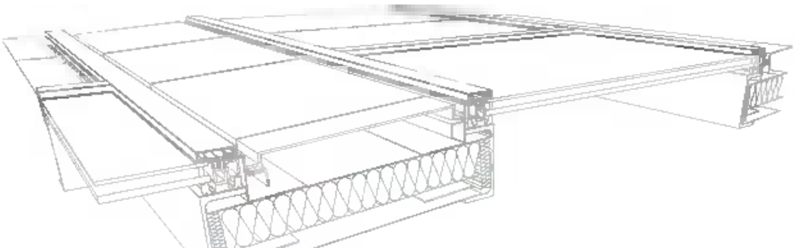
3-D exploded view showing typical rooflight connection to roof construction



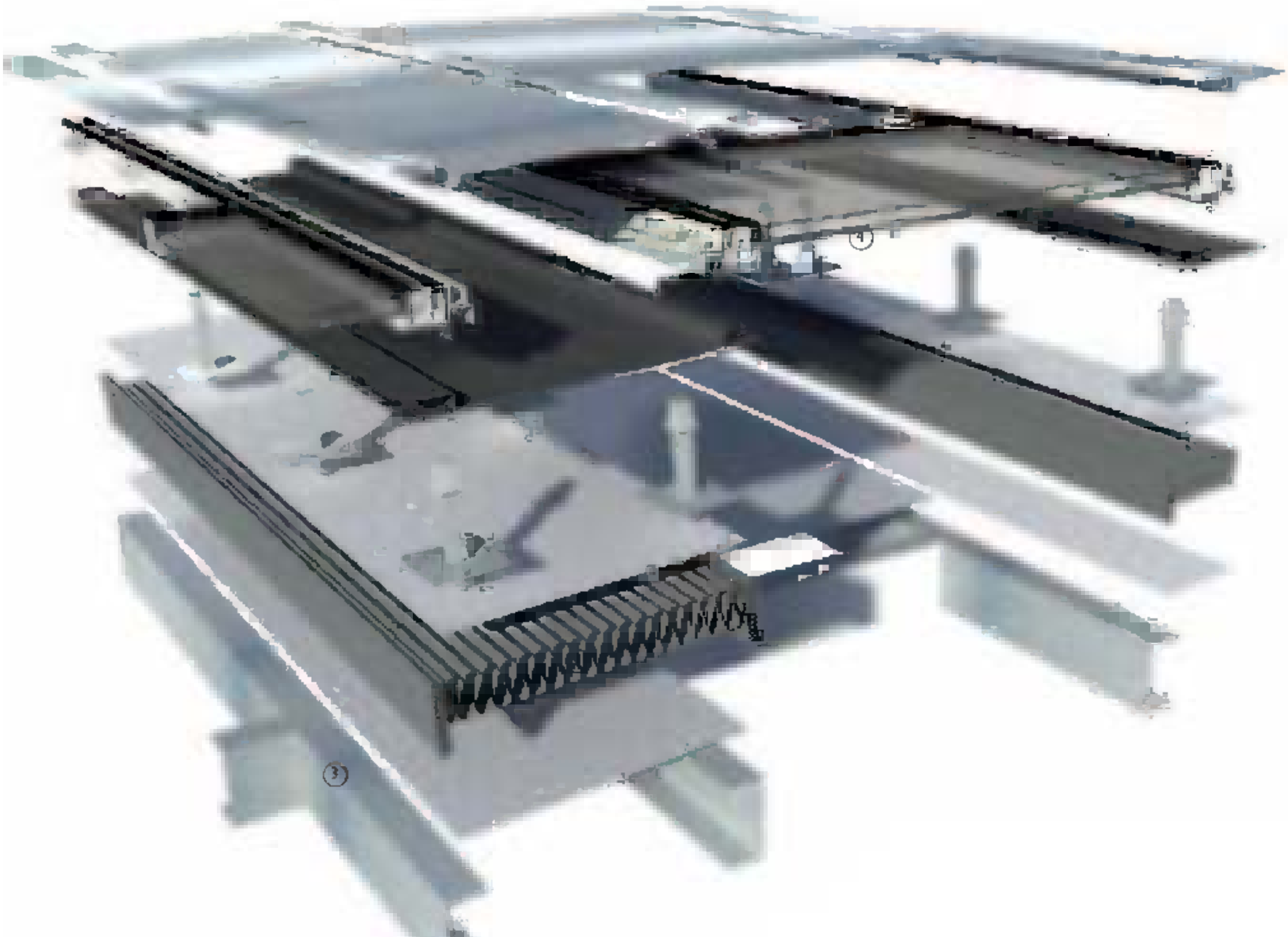
3-D exploded view showing gutter in silicone glazing



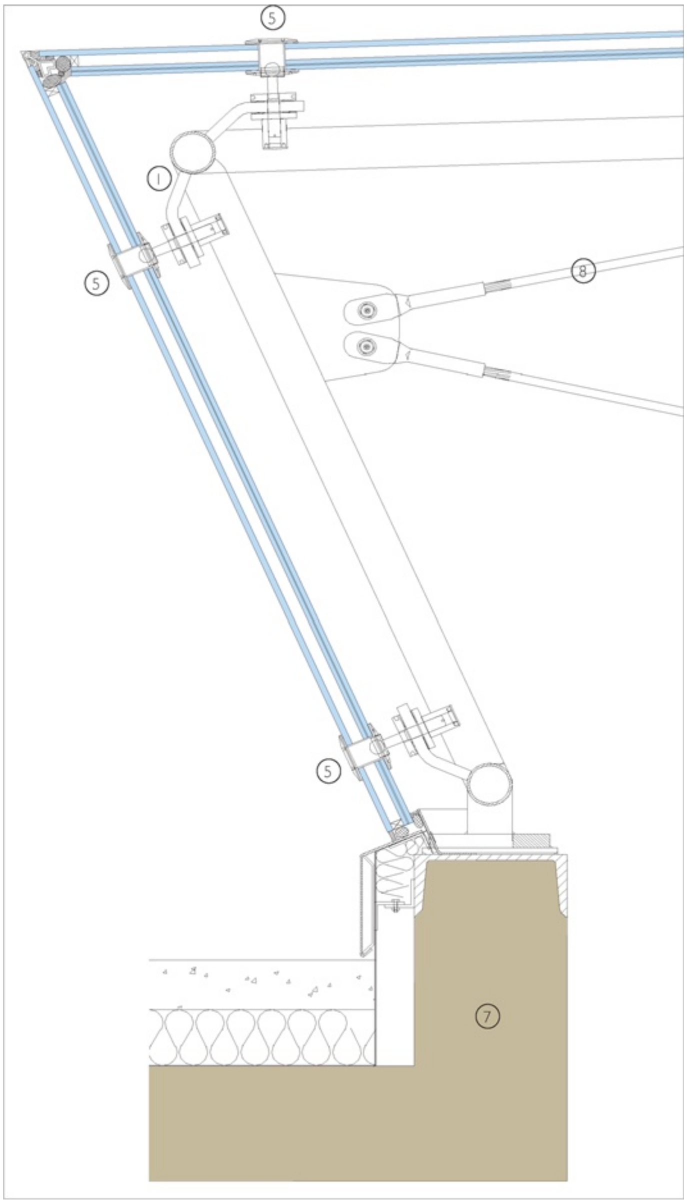
3-D exploded view showing panel to panel junction with capped glazing



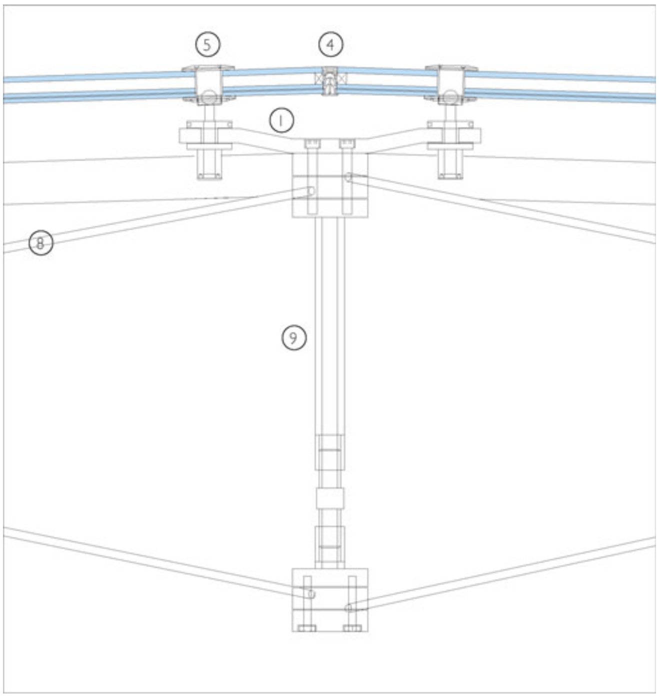
3-D view showing typical rooflight assembly in opaque roof



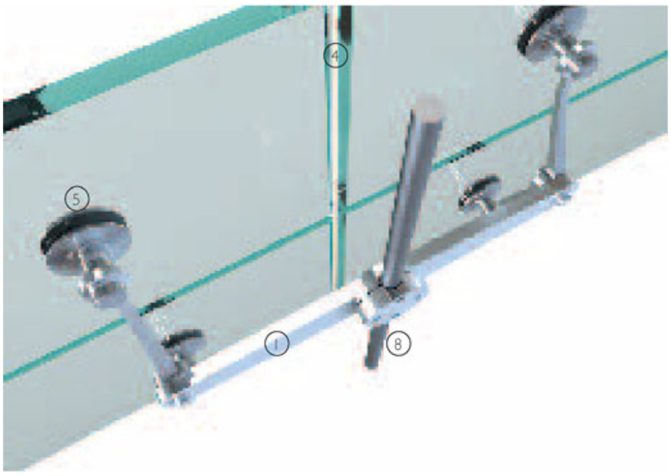
3-D exploded view showing typical rooflight assembly in opaque roof



Vertical section 1:10. Corner

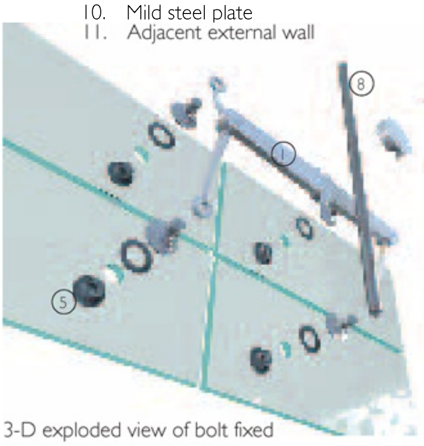


Cross section. 1:10. Horizontal panel to panel junction



3-D view of bolt fixed glazing with two point fixing

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

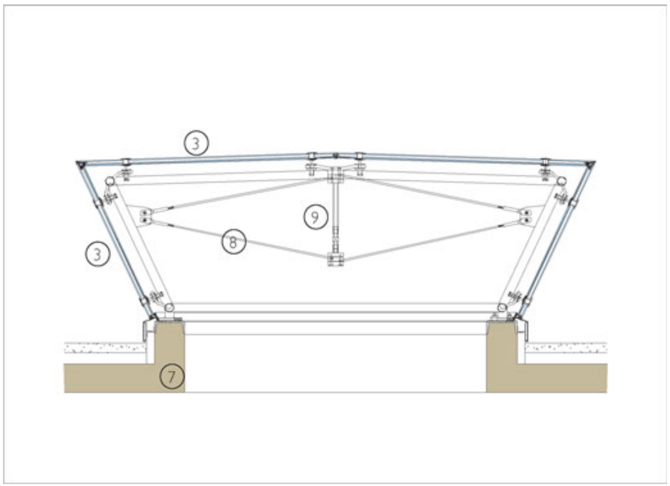


3-D exploded view of bolt fixed glazing with two point fixing

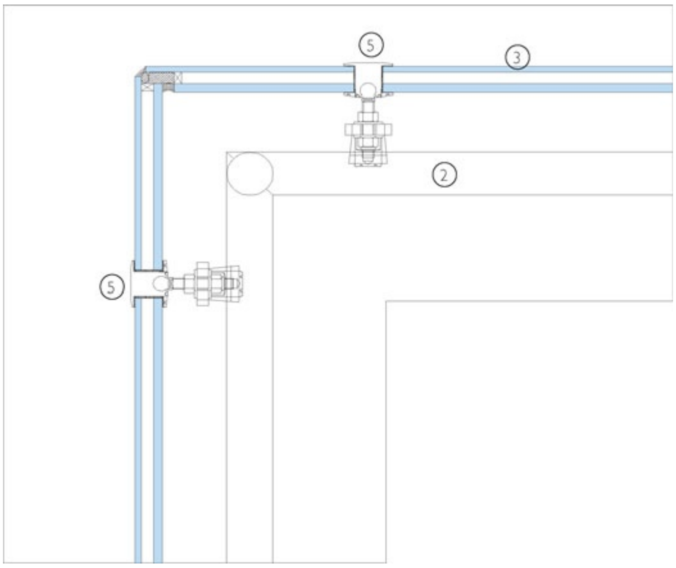
This method of glazing for roofs has been adapted from the technique used for glazed walls, where glass is fixed at points with specially designed bolts rather than with a frame supporting the perimeter of the glass. Bolt fixed glazing for facade construction developed from patch plate glazing in the 1960s, where single glazed sheets of glass are bolted together with mild steel brackets. In the contempoary version, 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.

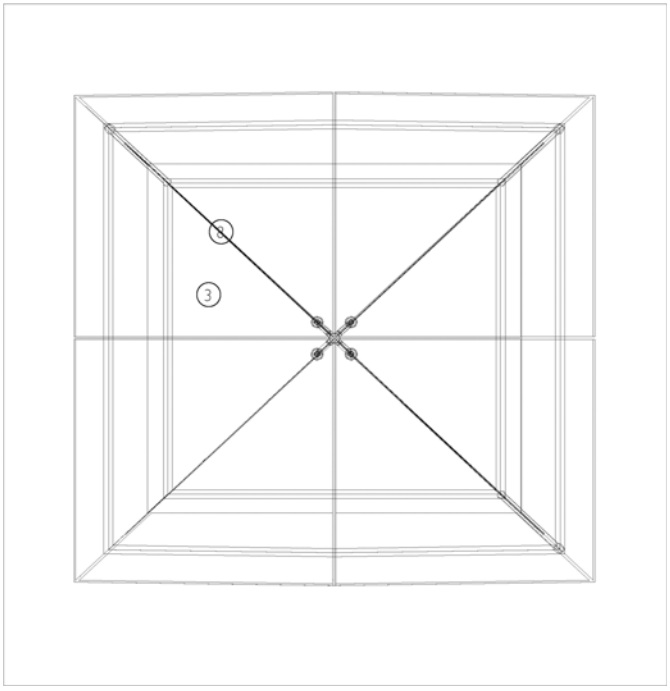
During the early 1990s doubts were raised over the reliability of the waterproof



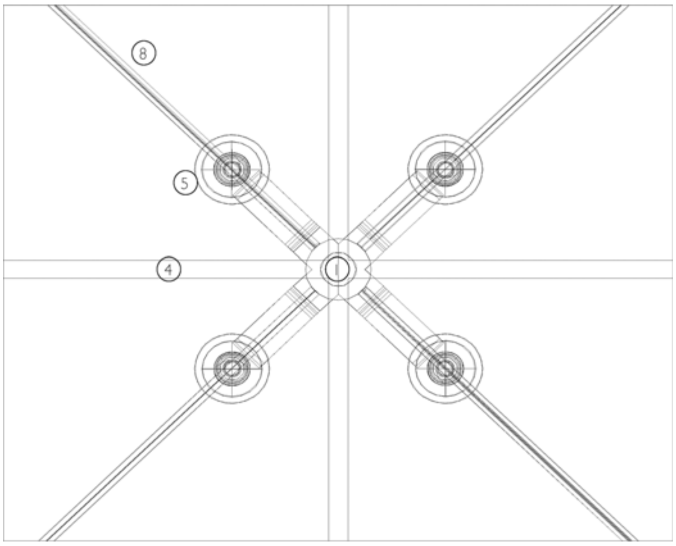
Vertical section1:50.Typical assembly



Horizontal section. 1:10.Vertical panel to panel junction



Horizontal section 1:50.Typical assembly



Horizontal section. 1:10. Bolt fixing

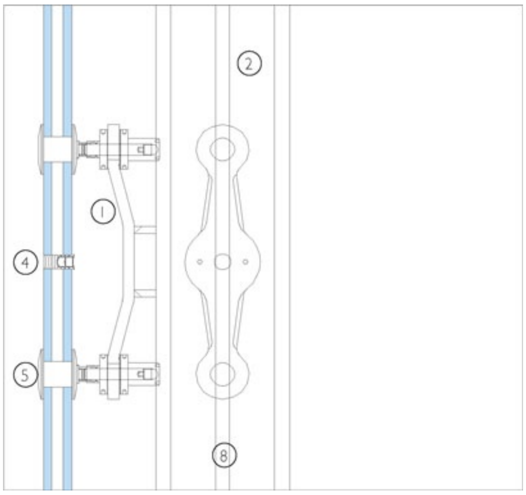
silicone seals between glazed units, but these were soon overcome with a mixture of laboratory testing and a better understanding of the workmanship required with silicone jointing. While manufactures offer proprietary systems for walls, which can include a supporting structural system such as cable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

Generic structural support methods

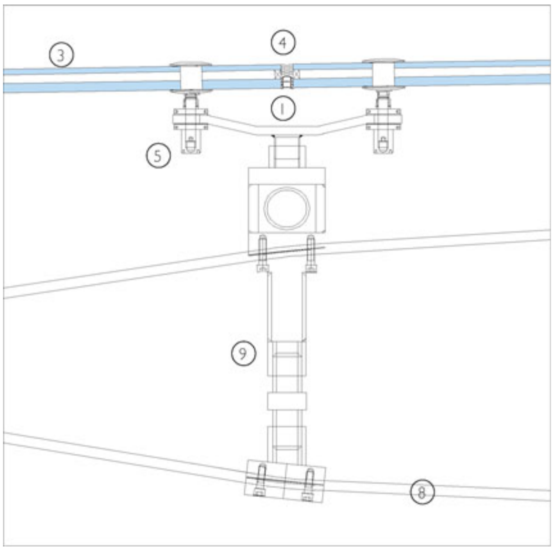
Whereas glazed walls are usually structurally supported by either top hung or bottom supported methods, the support of glazed roofs is by trusses, steel sections or purlins that span across the roof opening. For (nominally) flat roofs, there are two common arrangements of supporting beams. A supporting beam can be set under each glass joint, so that bolts are supported on each side of the beam by a short bracket. Alternatively, by setting the beam in the middle of alternate glass panels, only half the number of beams are required to support the same three panels of glass. Brackets are cantilevered 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 the first option, 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

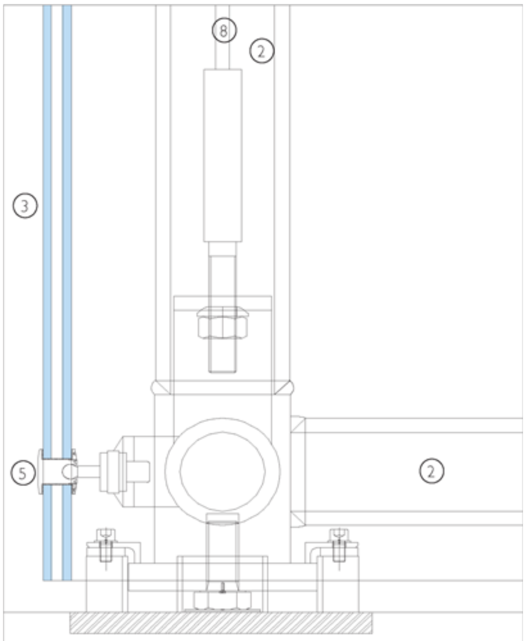

3-D view of bolt fixed glazing with two point fixing



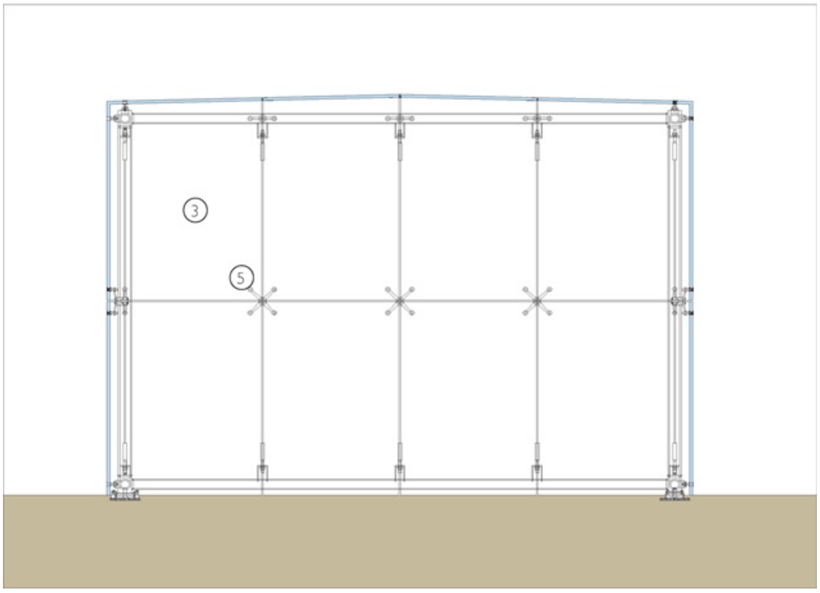
Vertical section 1:10. Vertical panel to panel junction



Vertical section 1:10. Horizontal panel to panel junction



Vertical section 1:10. Junction with adjacent roof



Elevation 1:100. Typical assembly

Details

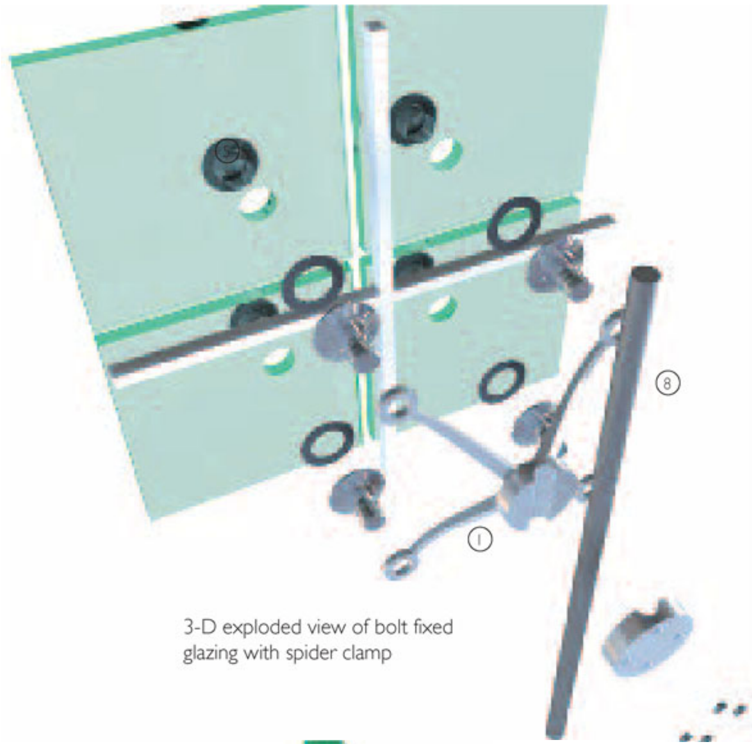
1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall

at oblique viewing angles. Triangulated trusses provide both structure and support for the glass, but tend to be visually heavy. Cable trusses 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.

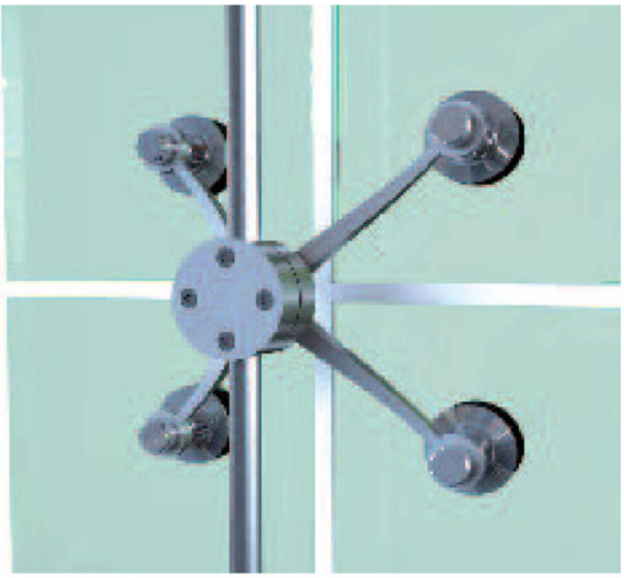
Supporting brackets

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. 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 at 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. Where 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 oversize 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. The flat bracket can be replaced by a casting, usually in either mild steel or aluminium.

3-D view of bolt fixed glazing with spider clamp



3-D exploded view of bolt fixed glazing with spider clamp

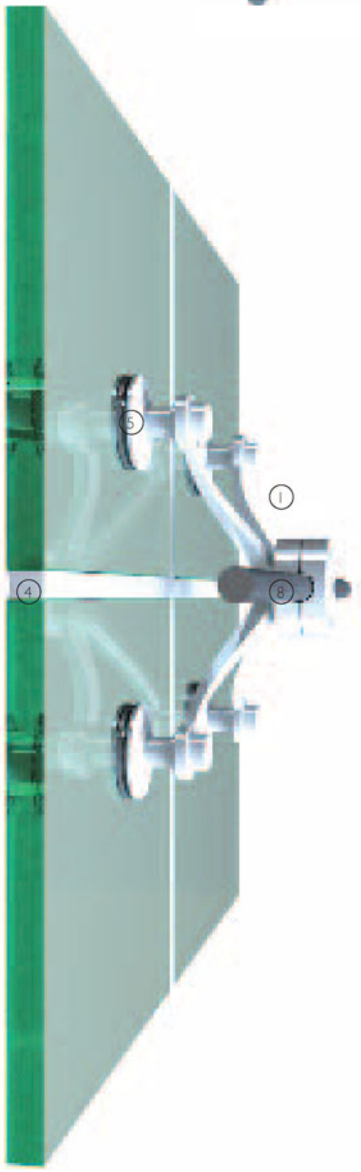


3-D view of bolt fixed glazing with spider clamp

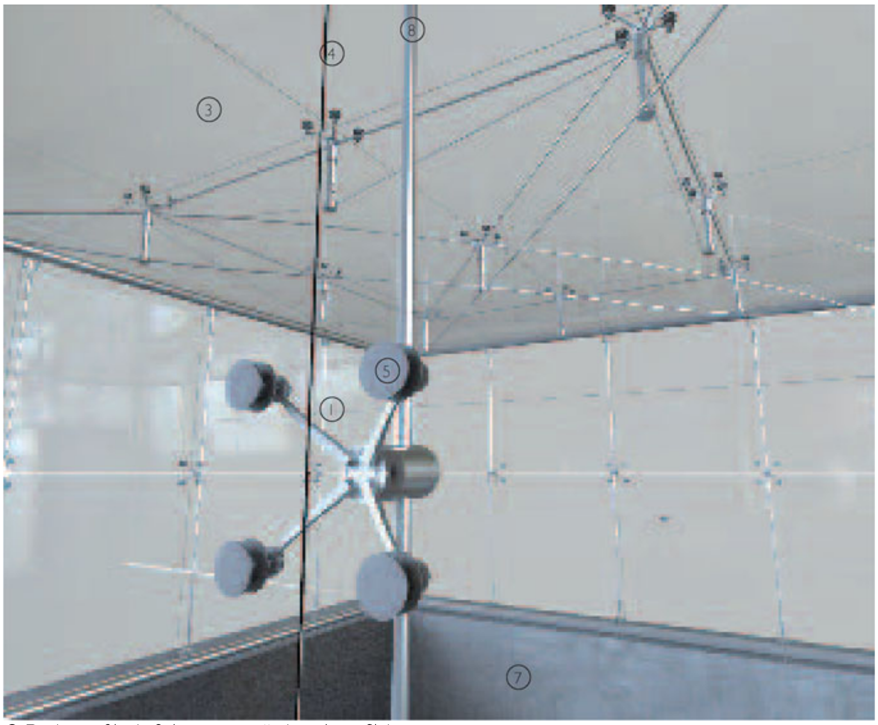
The casting for this application would be made from a steel mould which is expensive to manufacture, so a large quantity of cast brackets are needed to make this method economic. Adjustment is made in the same way as the channel bracket example. The beam can become a cable truss, where a supporting bracket 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

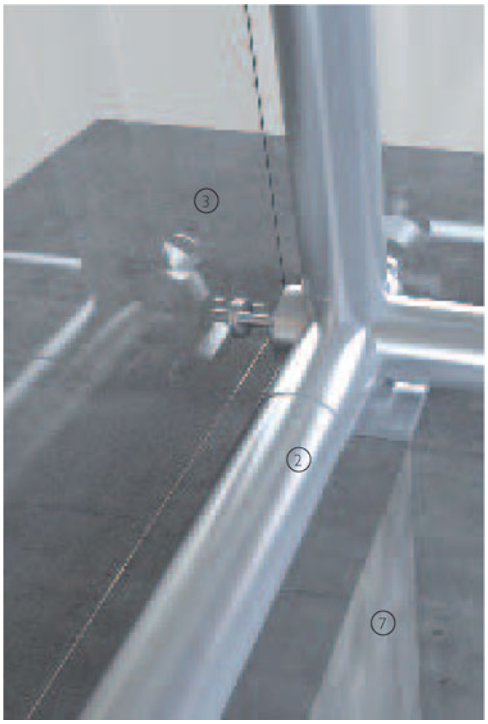
The essential component in this glazing method, the bolt fixing, is made typically in stainless steel, and consists of several components that form the complete assembly. The part that passes through the glass has either a disc on each side of the glass to clamp the glass or double glazed unit together, 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 commonly used fixing, the inner disc screws over the threaded shank that forms part of the outer disc



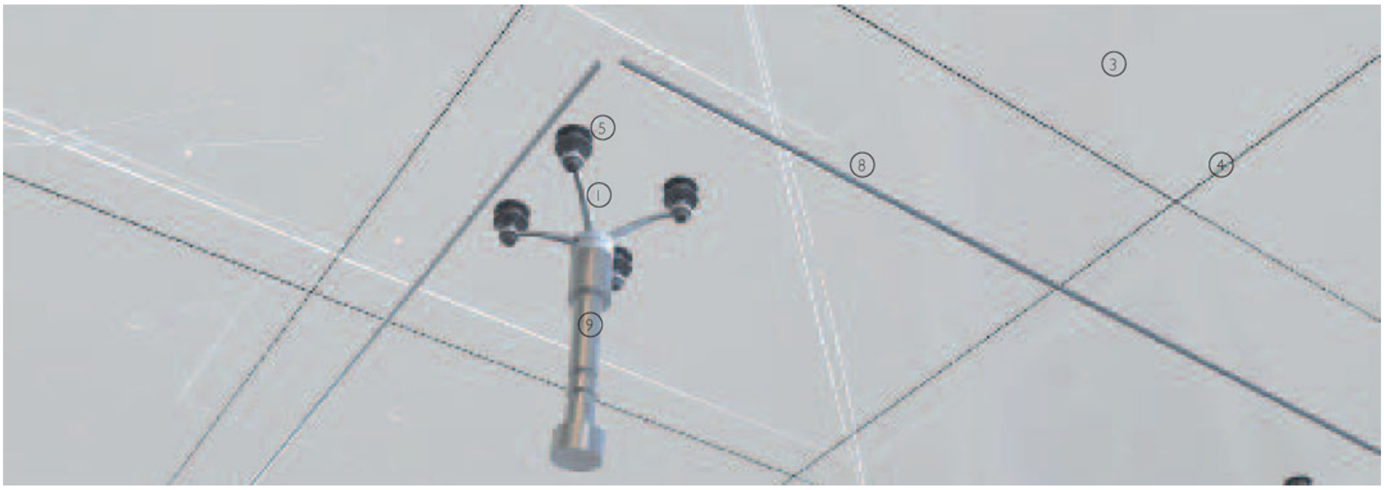
3-D view of bolt fixed glazing with spider clamp



3-D view of bolt-fixing on small glazed rooflight



3-D view of mild steel support frame for bolt fixed rooflight



3-D exploded view of bolt-fixing on small glazed rooflight

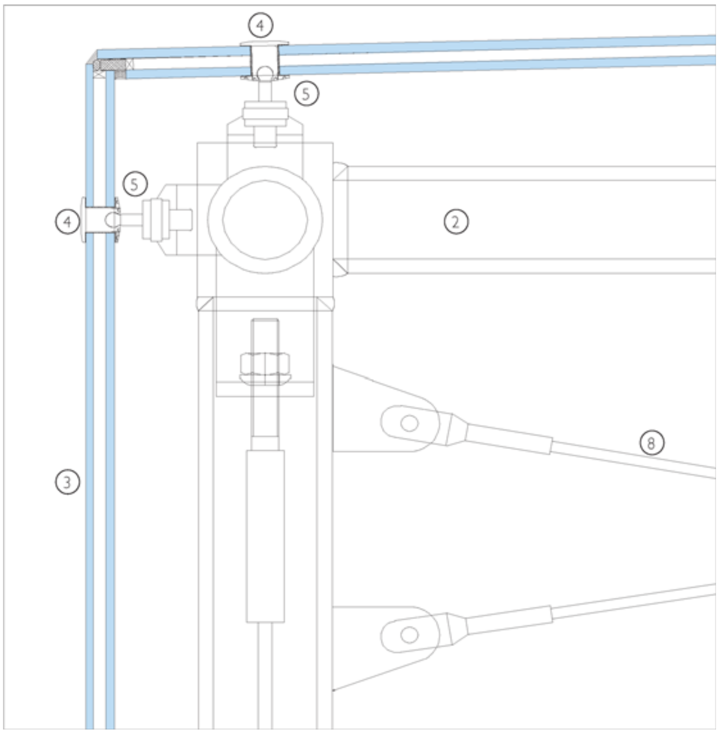
3-D view of mild steel support frame for bolt fixed rooflight

until it is tight up to the inner face of the glass. The threaded shank projecting into the building and 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. The visible thread in the shank can be either left exposed, or be covered with threaded sleeves and stop ends. This bolt type is used regardless of the orientation of the roof, whether flat or pitched.

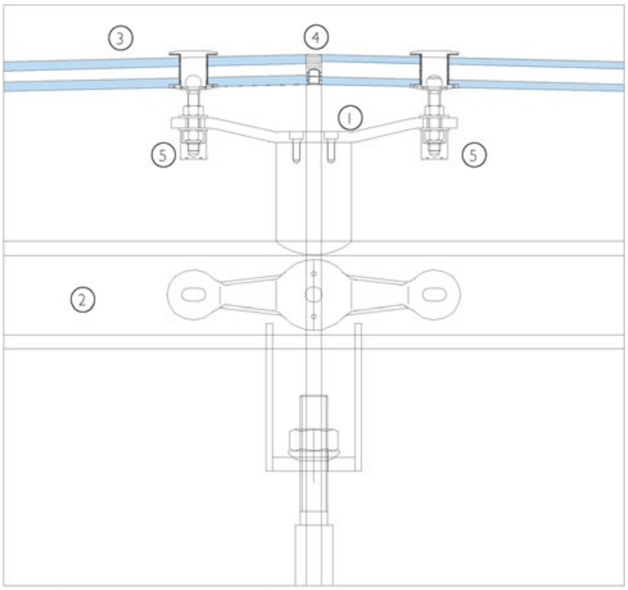
Arrangement of bolt fixings

The arrangement of brackets for bolt fixed roofs is dependent upon the position of the fixing bolts. Rectangular shaped double glazed units can be 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). Flat plates can be used, subject to structural requirements.

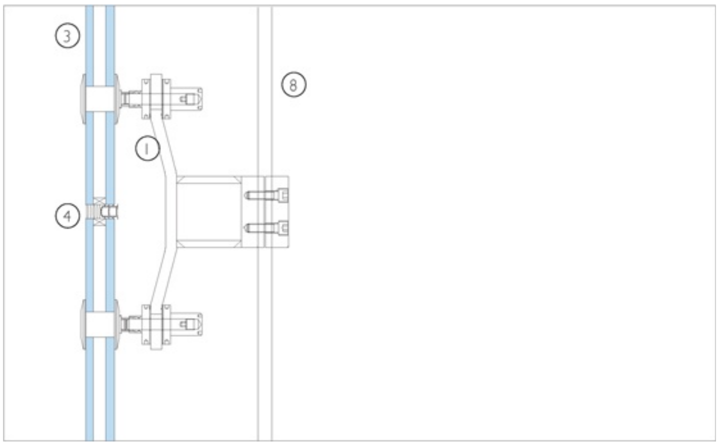
Where the glass fixing bolts are equidistant from the edges of the glass, a cross-



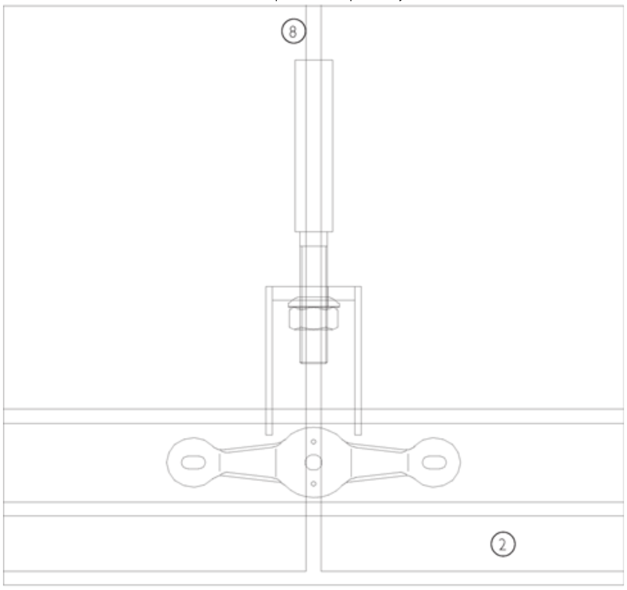
Vertical section 1:10. Corner



Vertical section 1:10. Horizontal panel to panel junction



Vertical section 1:10. Vertical panel to panel junction



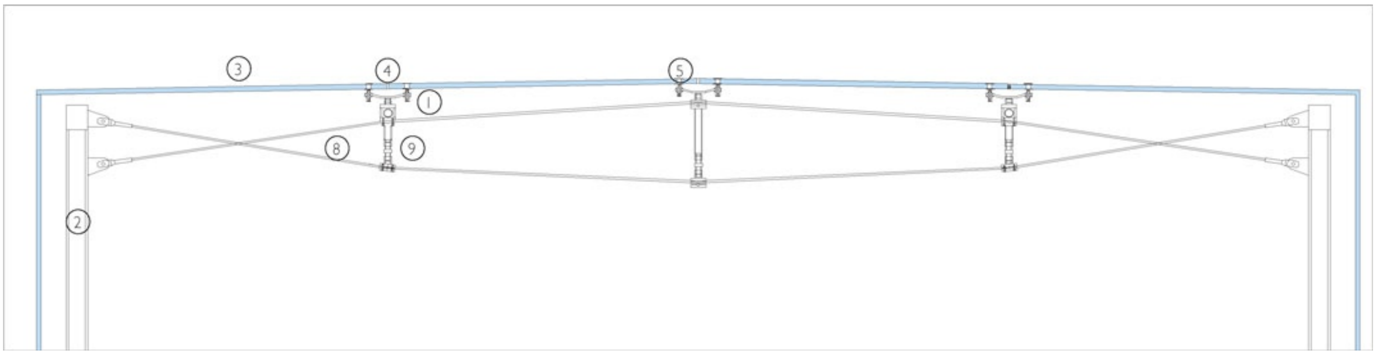
Horizontal section 1:10. Horizontal panel to panel junction at edge

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 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.

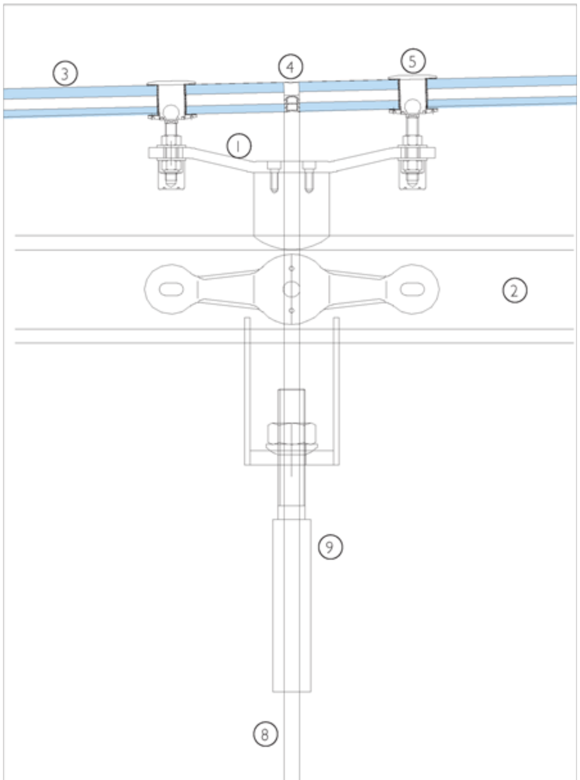
Glazed units

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, 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

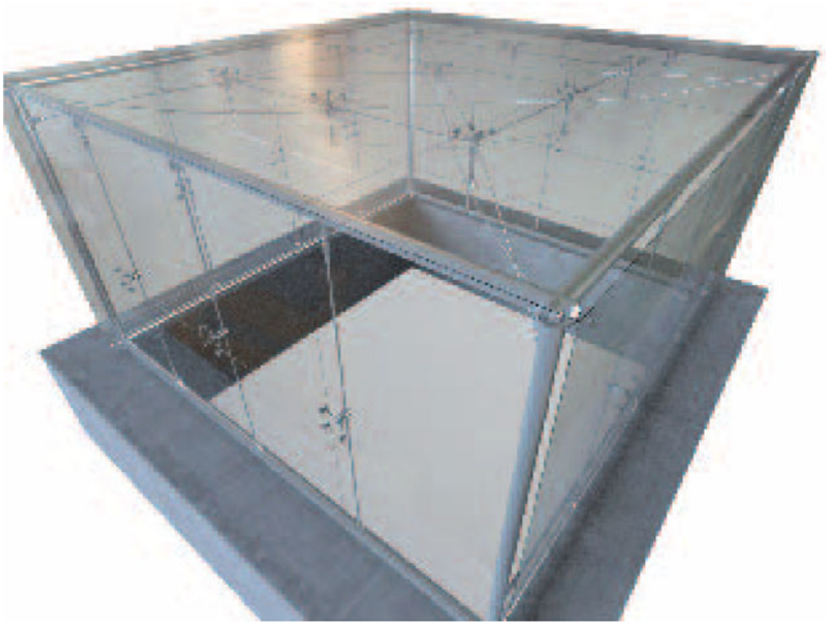
Details
1. Mild steel connector
2. Mild steel support frame
3. Double glazed unit
4. Silicone seal
5. Bolt fixing
6. Support bracket
7. Concrete base
8. Stainless steel cable
9. Mild steel tension rod
10. Mild steel plate
11. Adjacent external wall



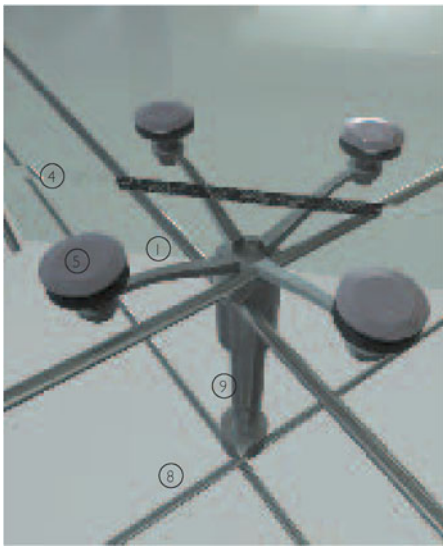
Vertical section 1:50. Typical assembly



Vertical section 1:10. Vertical panel to panel junction



3-D view of small rooflight roof assembly

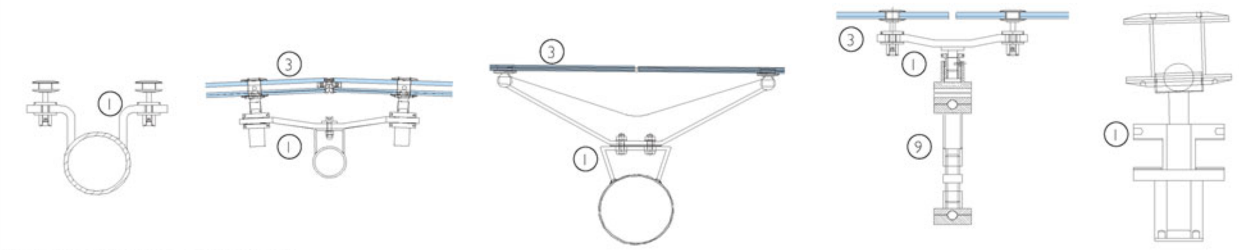


3-D detail view of typical roof assembly

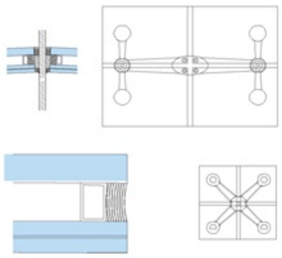
width for the adhesion of silicone sealant in a regular double glazed unit, are used where brackets penetrate the outer seal from inside the roof to outside. If required, these brackets are used to support external sun shading and maintenance equipment. These brackets are usually in the form of flat plates that are welded to the internal supporting structure, and project through the joint. 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 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.

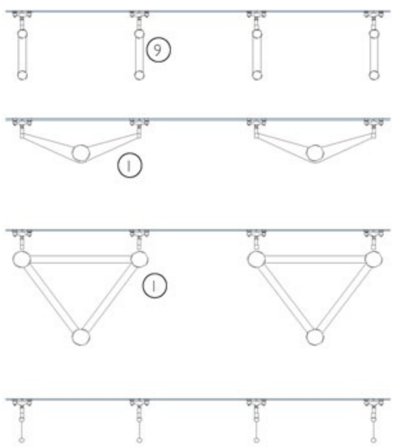
In the manufacturing of double glazed units, the butyl seal between the spacer and the glass creates a slightly wavy line, visible to the eye when it spreads beyond the face of the spacer. This slightly uneven appearance of the edge of the glazed unit can be concealed by the use of edge 'fritting', or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



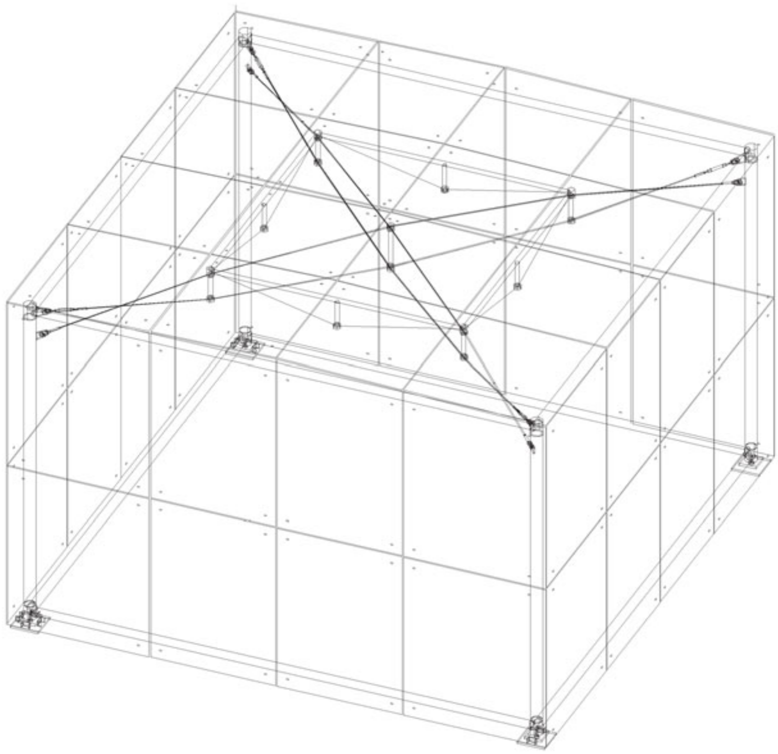
Vertical sections. Varying glass fixings



Horizontal sections. Bolt fixed arrangements



Vertical sections. Bolt fixed arrangements



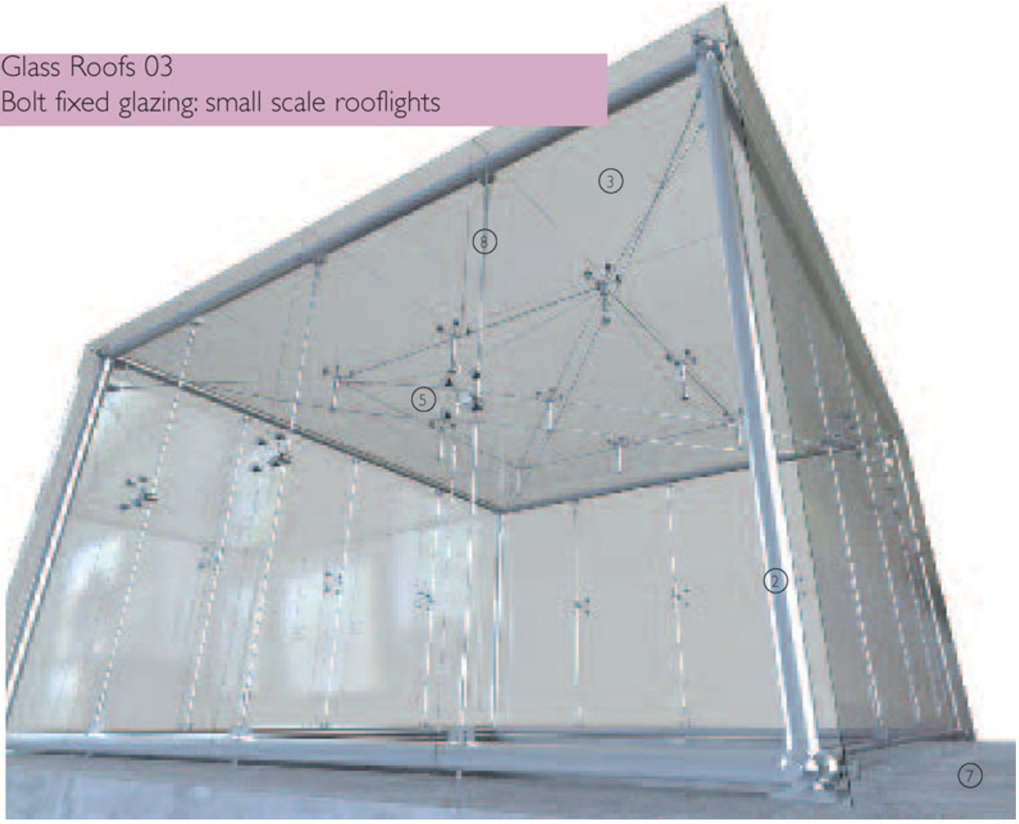
Isometric view of roof assembly

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.

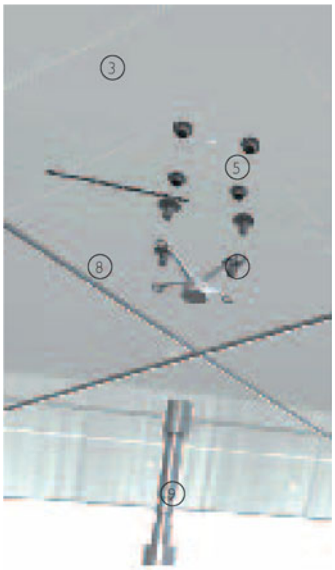
The drilling of the glass itself is now well established in glass manufacturing, with both float glass and laminated glass being drilled before any heat treatment to make them either heat strengthened or fully toughened. Where coated glasses are used, such as solar control coatings or low emissivity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

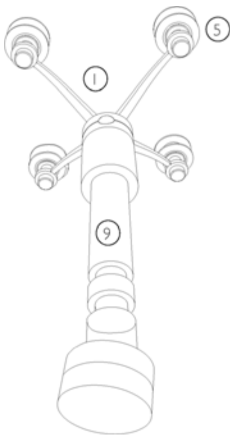
3-D detail view of typical roof assembly



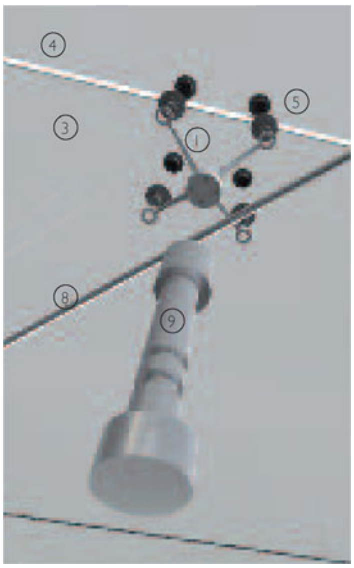
3-D view of small rooflight roof assembly



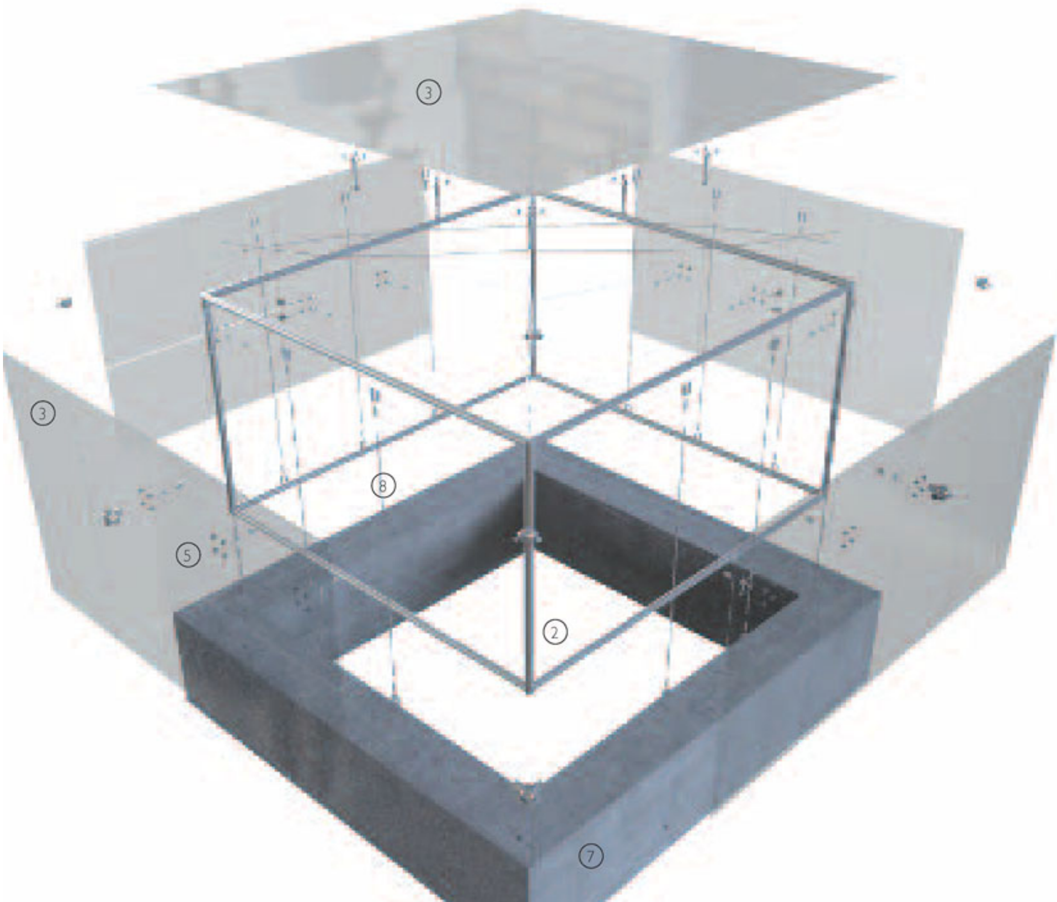
3-D exploded detail view of bolt fixed glazing junction



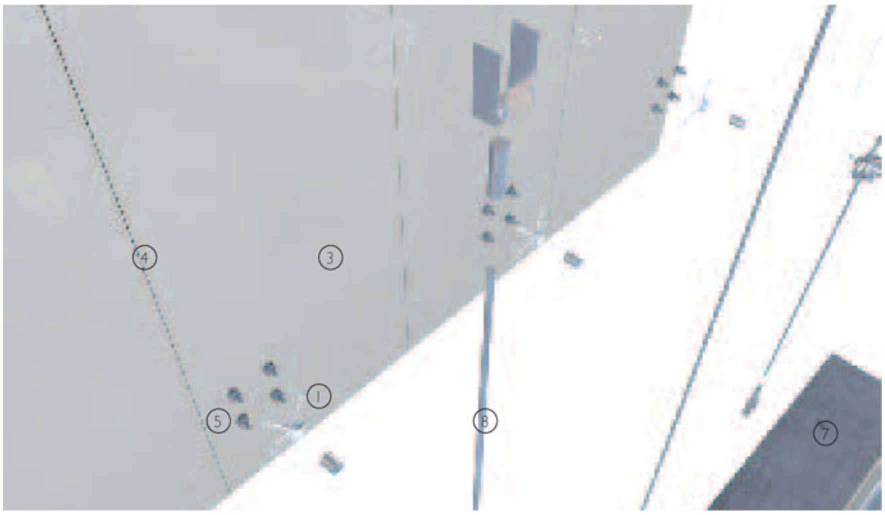
3-D line drawing of bolt fixing



3-D exploded detail view of bolt fixed glazing junction

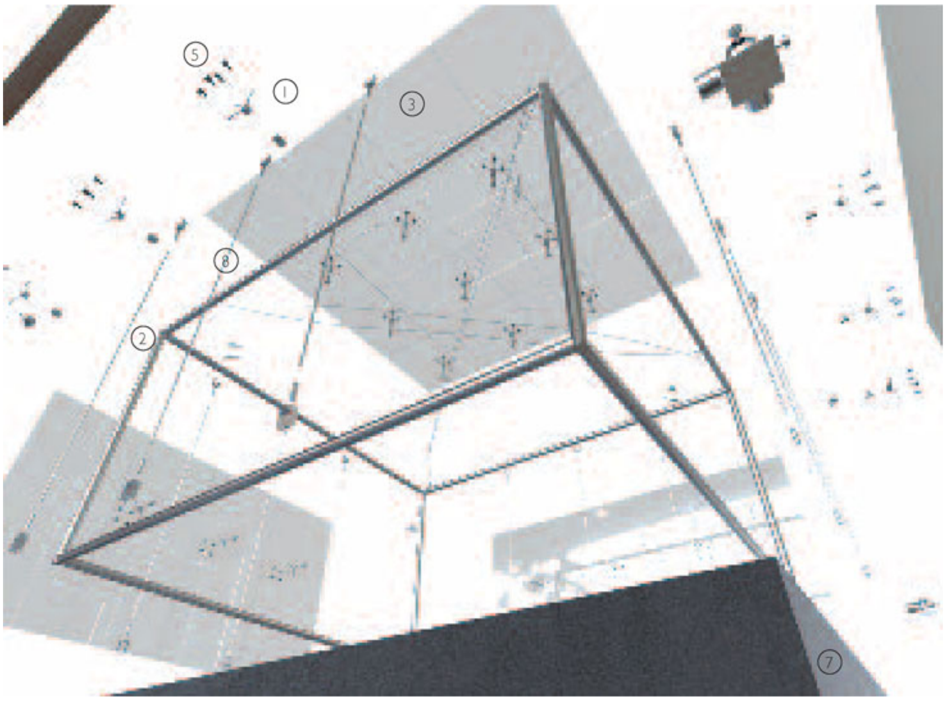


3-D exploded view of small rooflight roof assembly

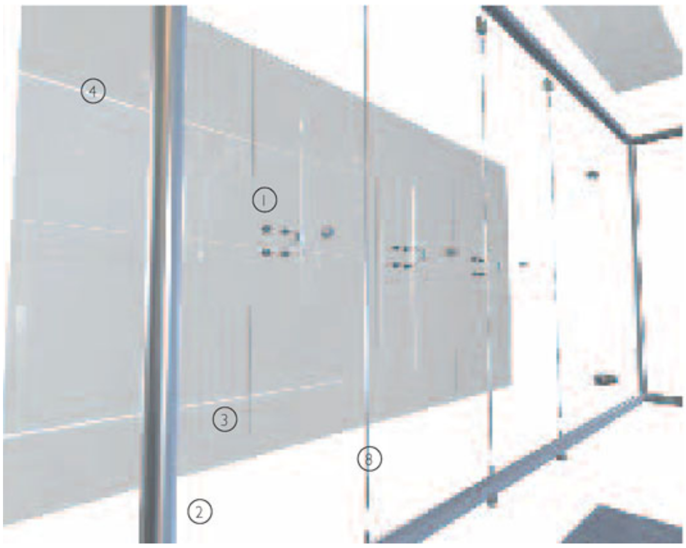


3-D exploded view of bolt fixed glazing rooflight wall assembly

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

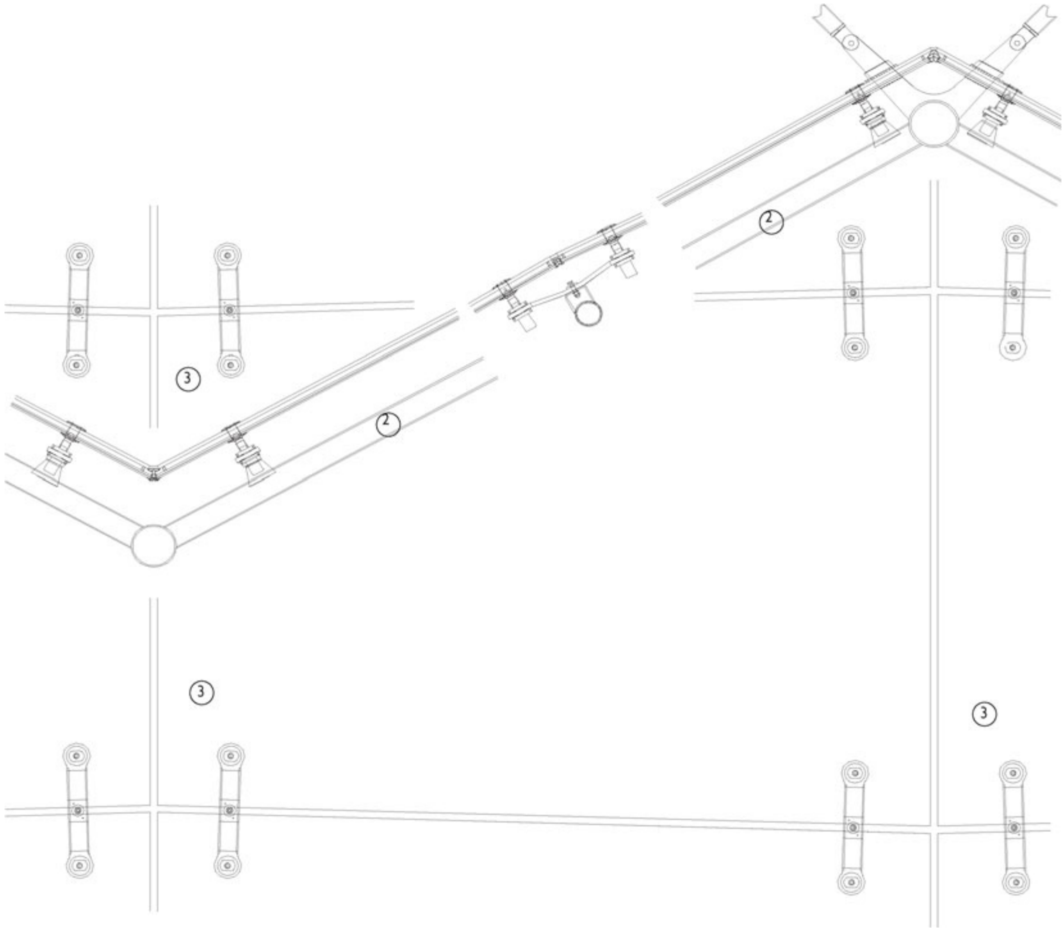


3-D exploded view of small rooflight roof assembly

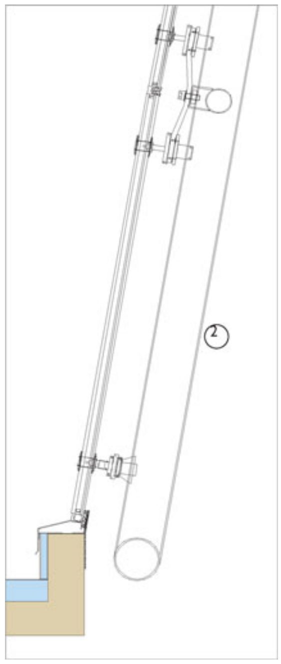


3-D exploded view of bolt fixed glazing rooflight wall assembly

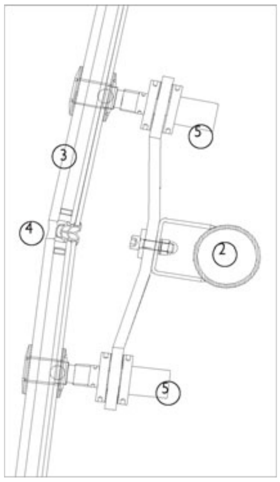
3-D exploded view of bolt fixed glazing rooflight wall assembly



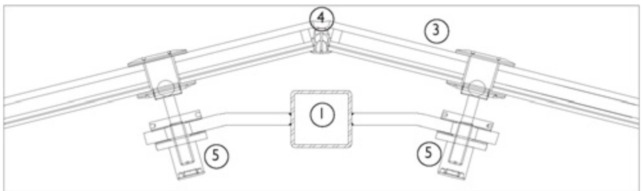
Vertical section 1:25. Typical assembly



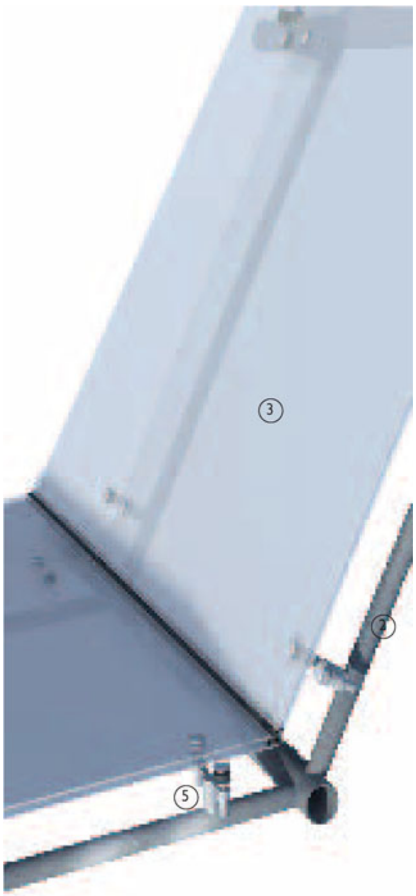
Vertical section 1:25. Panel to panel junction



Horizontal section 1:10. Panel to panel junction



Vertical section 1:10. Typical assembly



3-D view showing internal fold of glazed pitched roof assembly

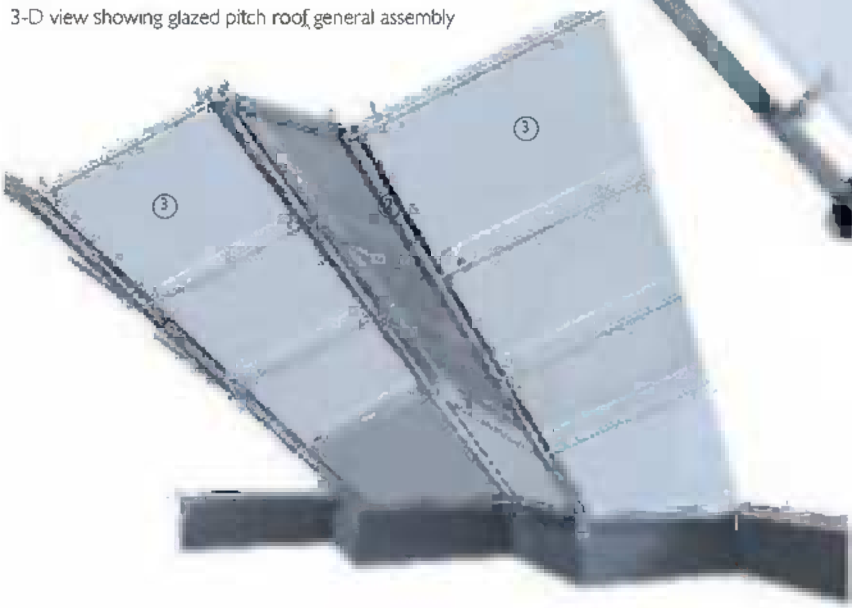
The generic support structures described in the previous section suit a range of roofs in a single plane, whether pitched or (nominally) flat. Supporting structures which are facetted or curved to form complex geometries require a slightly different approach. These supporting structures are dictated 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. 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 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 of the structure. 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

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
12. Single glazed solar shading glass

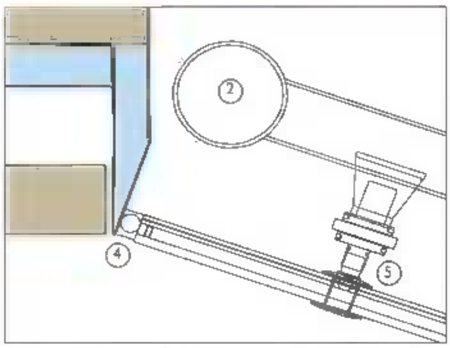
3-D detail view showing bolt fixed pitched roof comprising double glazed units supported by metal structural frame



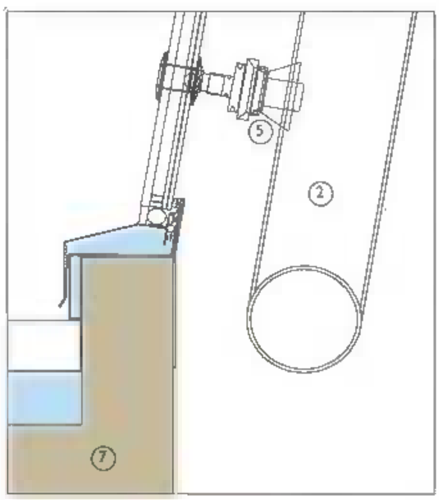
3-D view showing glazed pitch roof general assembly

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 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.

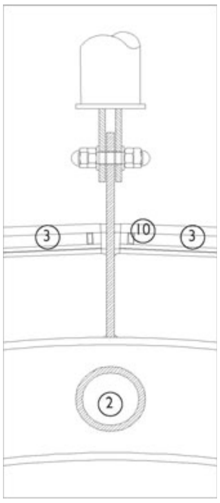
The structural form of the 'ladder' usually corresponds to the layout of the glass panels, since the corners of panels are fixed back to the supporting structure, which is preferably as close to the glass joints (in elevation) as possible. In other examples the structure is set in line with the joints in the glass. In some cases the bolt fixings for the glass are 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 fixings in relation to the edge of the glass are optimised to reduce the glass to an economic thickness. Bolt fixings can be 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



Horizontal section 1:10. Junction with adjacent wall



Vertical section 1:10. Base upstand

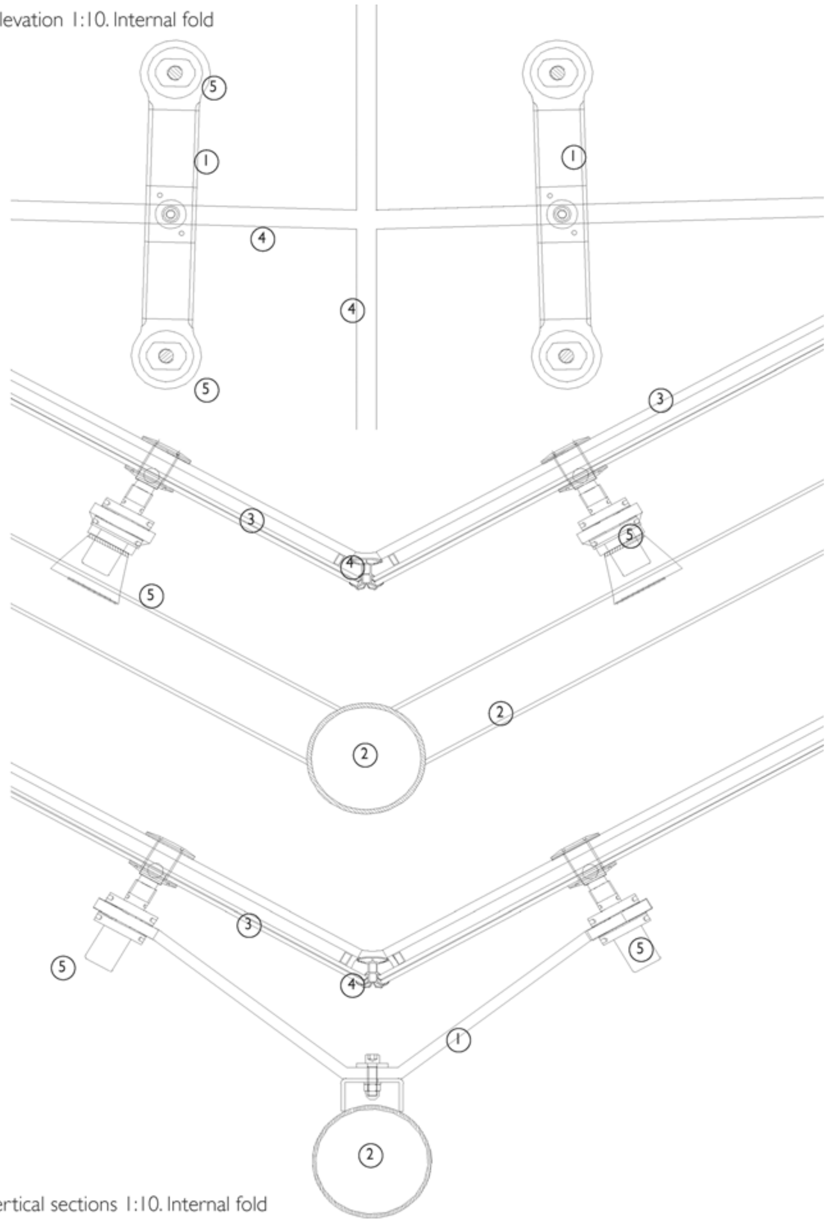


Horizontal section 1:10. Penetration of plate through glass joint

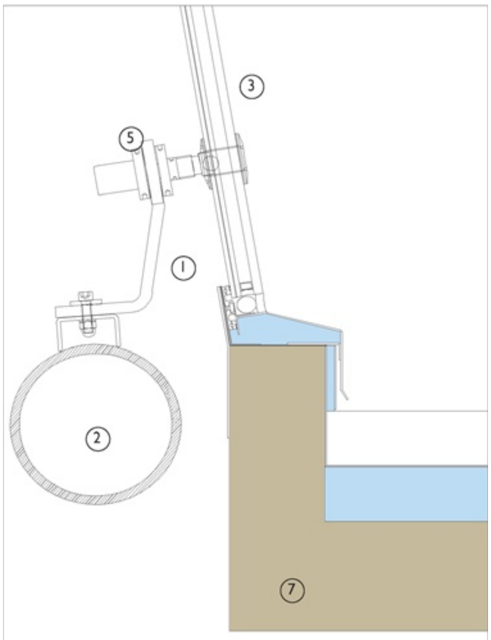
Details

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



Vertical sections 1:10. Internal fold



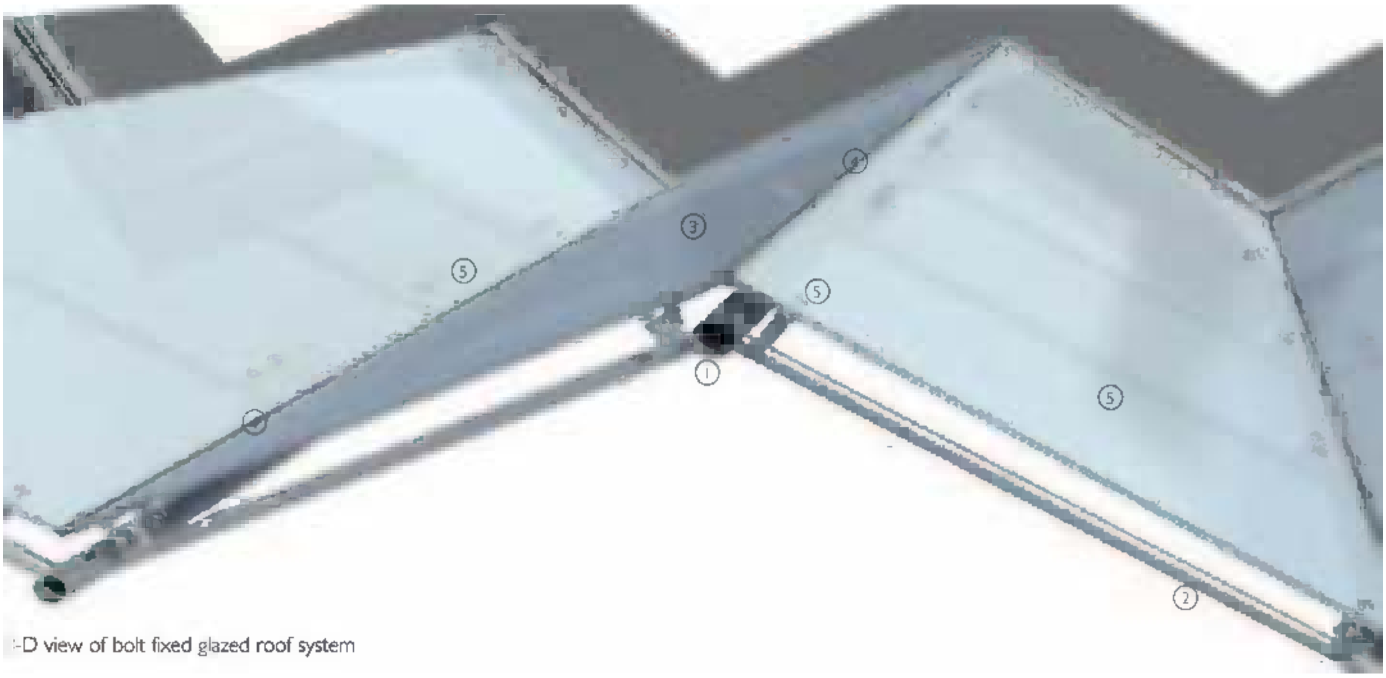
Vertical section 1:10. Base upstand

3-D view showing underside of bolt fixed glazed roof system

the brackets. The stainless steel bolts are aligned in elevation with adjacent brackets.

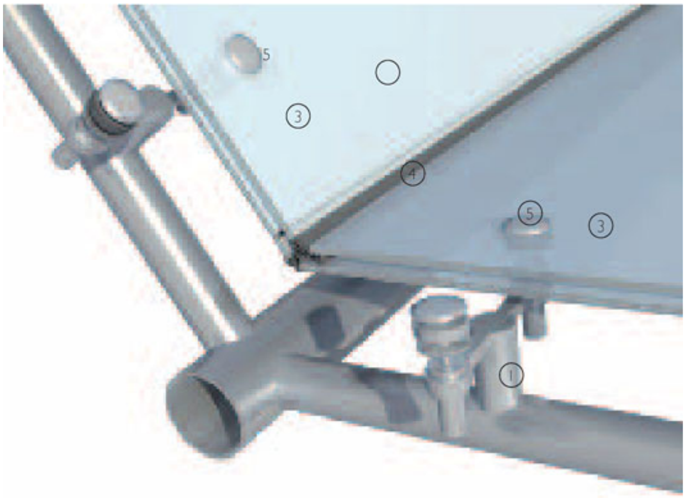
Base of glazed roof

Bolt fixed glazed roofs are often fixed to a surrounding reinforced concrete slab. 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 some cases, a low pitched roof meets a reinforced concrete upstand 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



-D view of bolt fixed glazed roof system

3-D view of of external fold



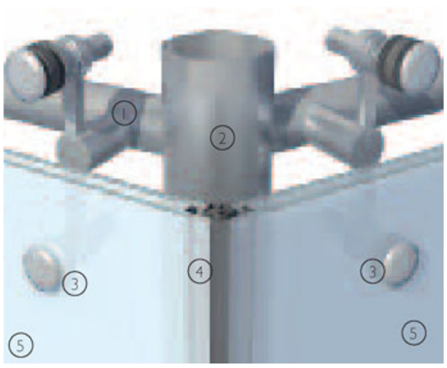
3-D view of internal fold

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. In some instances, an all-metal upstand flashing can be used, while in others the upstand is concealed by an accessible timber deck.

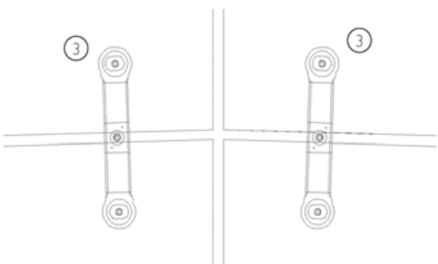
External and internal folds

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. 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. The internal fold, on the other hand, can have the inner laminated glass extending 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.

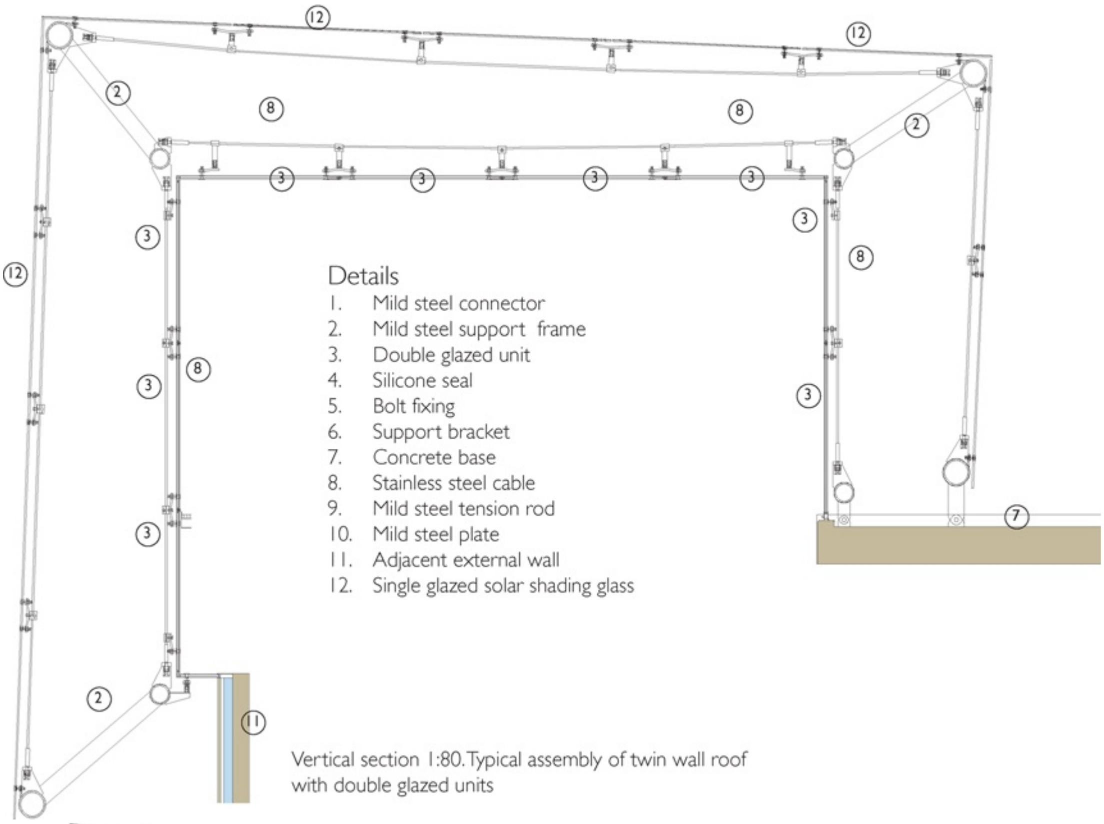
Junctions of the edge of the roof with external walls in other materials are similar to flashings at the base of the roofs, with



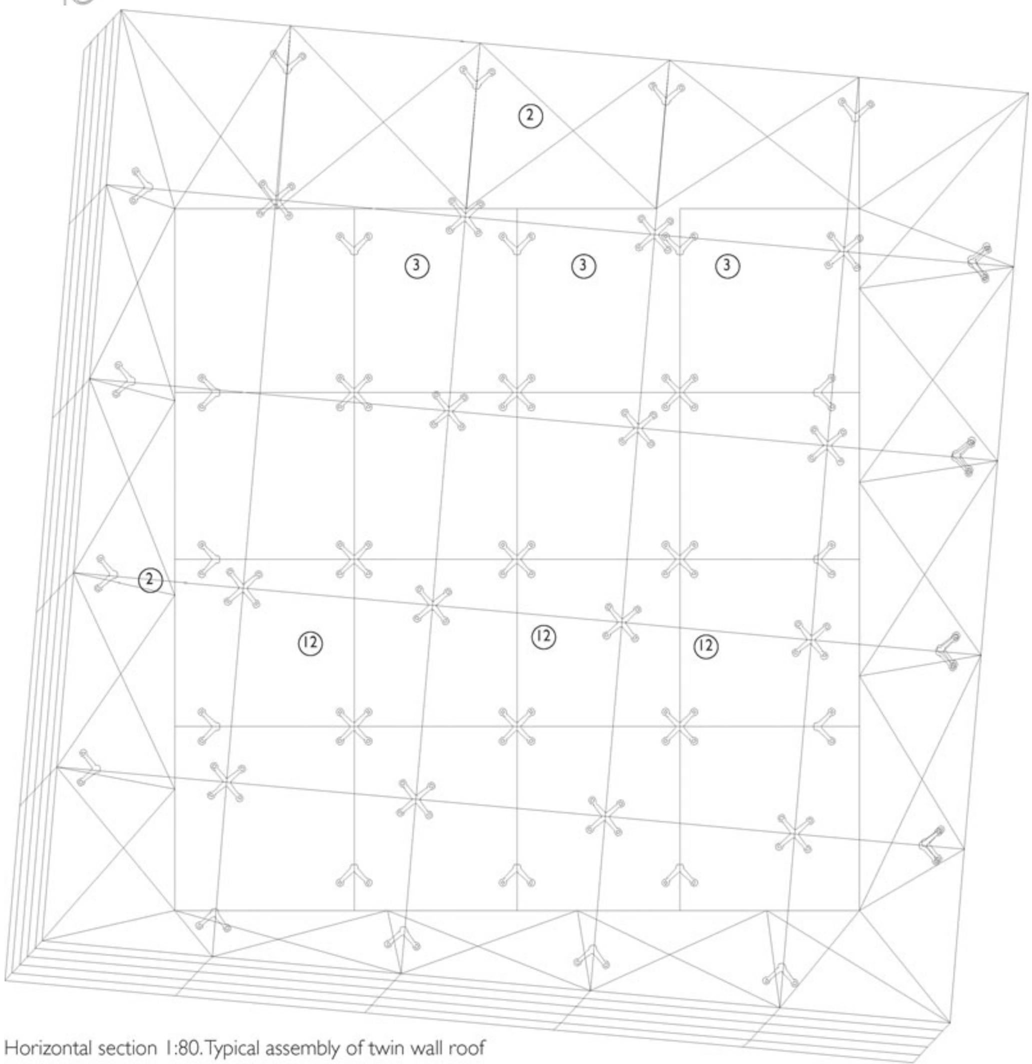
3-D view of bolt fixed system



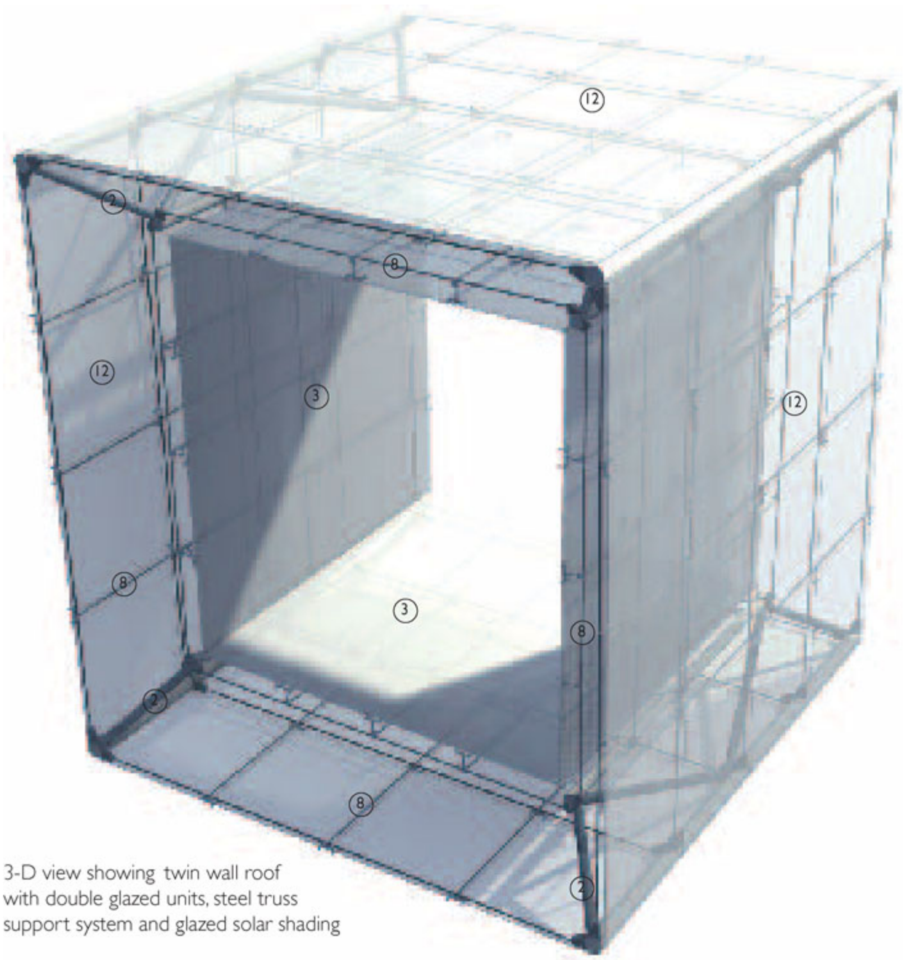
Horizontal section 1:25. Typical clamp assembly



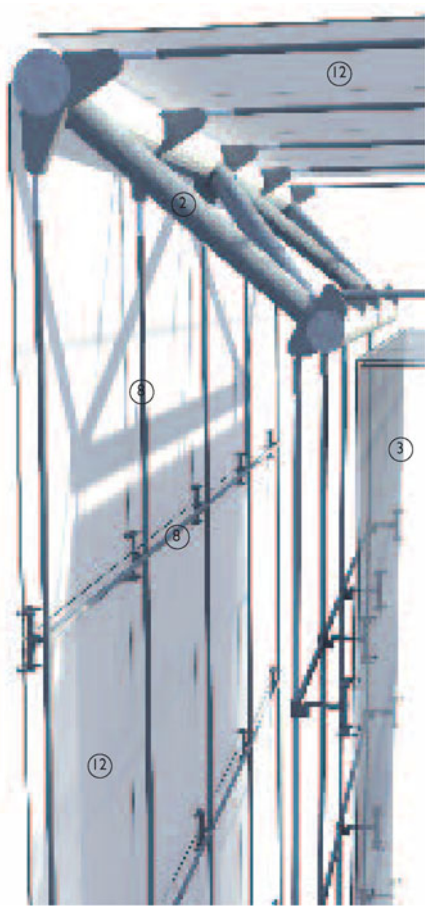
Vertical section 1:80. Typical assembly of twin wall roof with double glazed units



Horizontal section 1:80. Typical assembly of twin wall roof with double glazed units



3-D view showing twin wall roof with double glazed units, steel truss support system and glazed solar shading



3-D view showing twin wall roof system detail

which these joints can be continuous as the roof perimeter turns from roof to external wall. In some cases, an insulated aluminium closer is bonded to the edge of the double glazed unit and is sealed against the adjacent wall construction. The bolt fixed roof could meet, for example, a metal rainscreen wall, or an external wall clad in a range of panels.

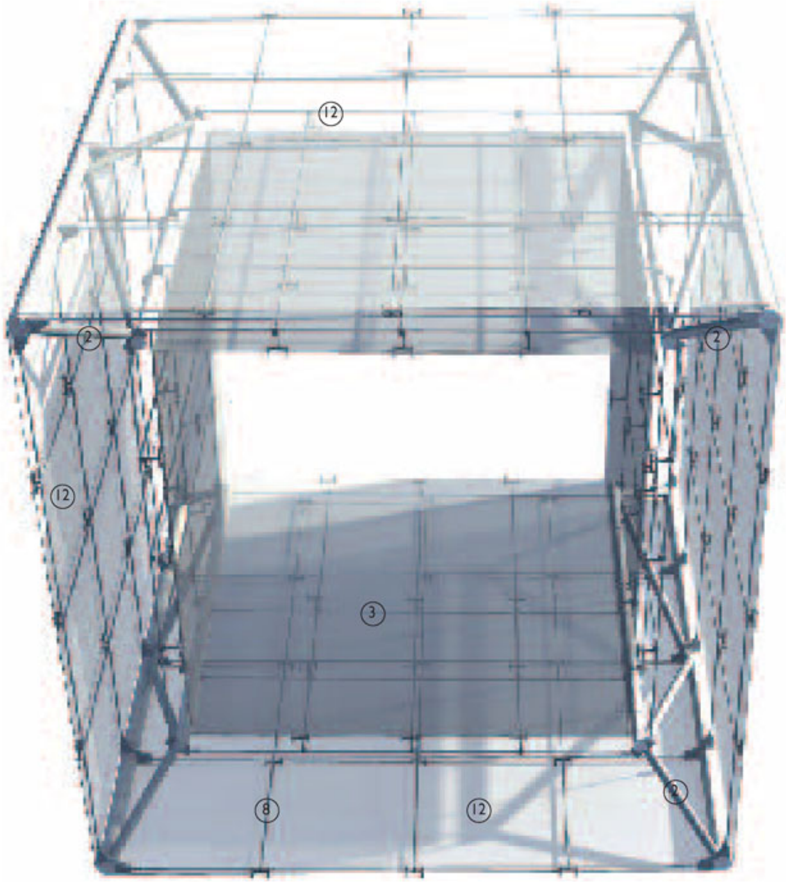
Support brackets for external shading and for rope fixing points for abseil-based cleaning are sometimes designed to penetrate through the joints between the glass joints. This method is described in the previous section. Where these brackets occur at external and internal folds, the brackets are usually 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, the glazing is sealed against the adjacent construction. In some instances, 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 fixed glazing to move independently of the other materials making the junction. In this case 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 generic examples, 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. 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 do not rquire bolt fixings, increasing the sense of transparency. In plan, external corners can be 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 corners of meeting double glazed units in

3-D view showing fixing method of twin wall roof with double glazed units, steel truss support system and glazed solar shading

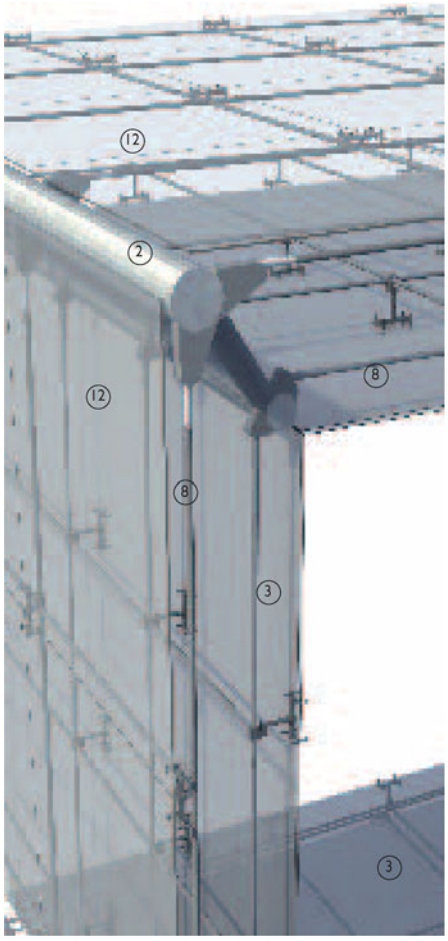


3-D view showing overview of twin wall roof with double glazed units, steel truss support system and glazed solar shading

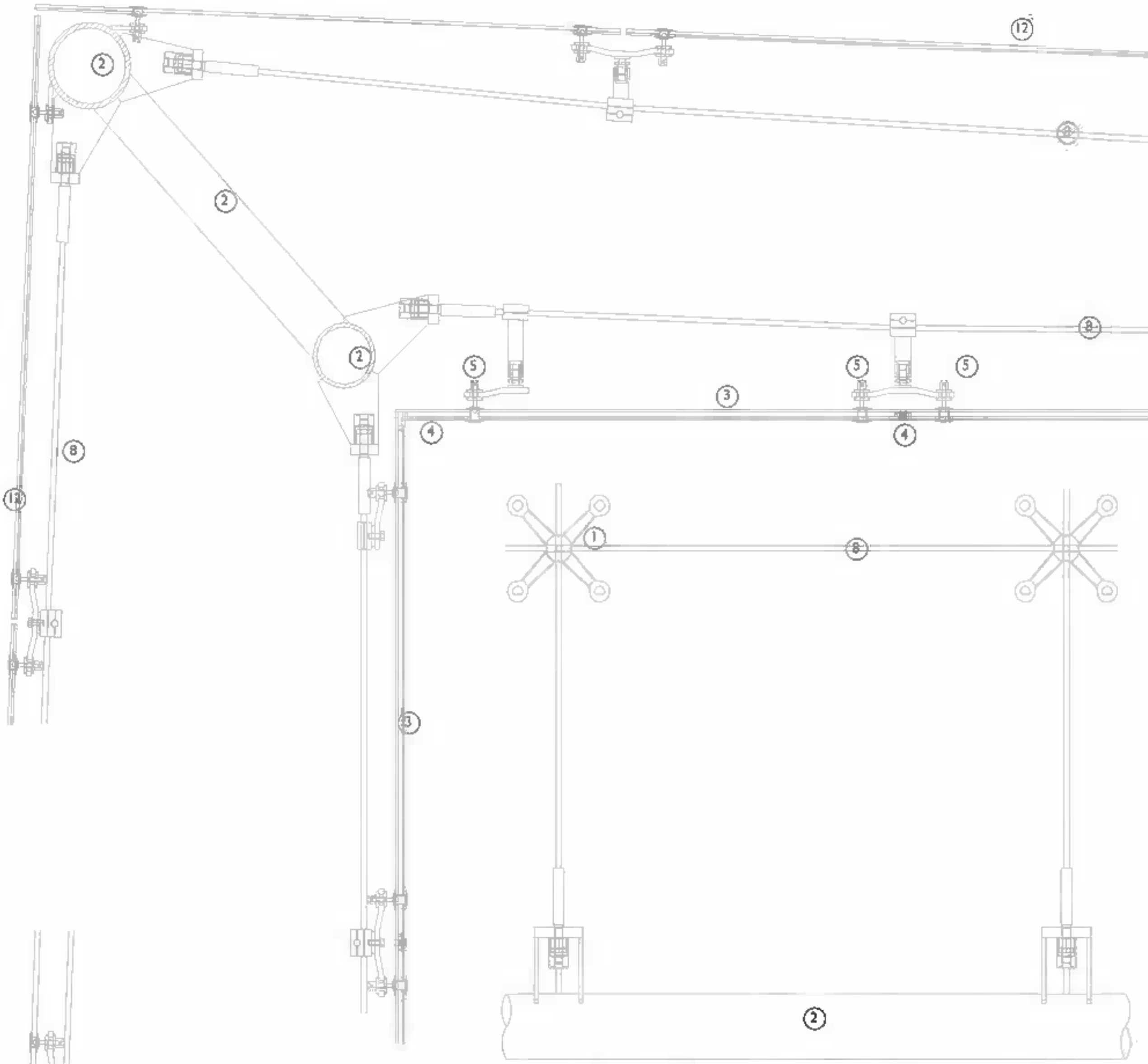
bolt fixed roofs have a wide sight line, the continuity of the glass and its reflections obscure the effect of the fritting and silicone seals behind.

Larger rooflights

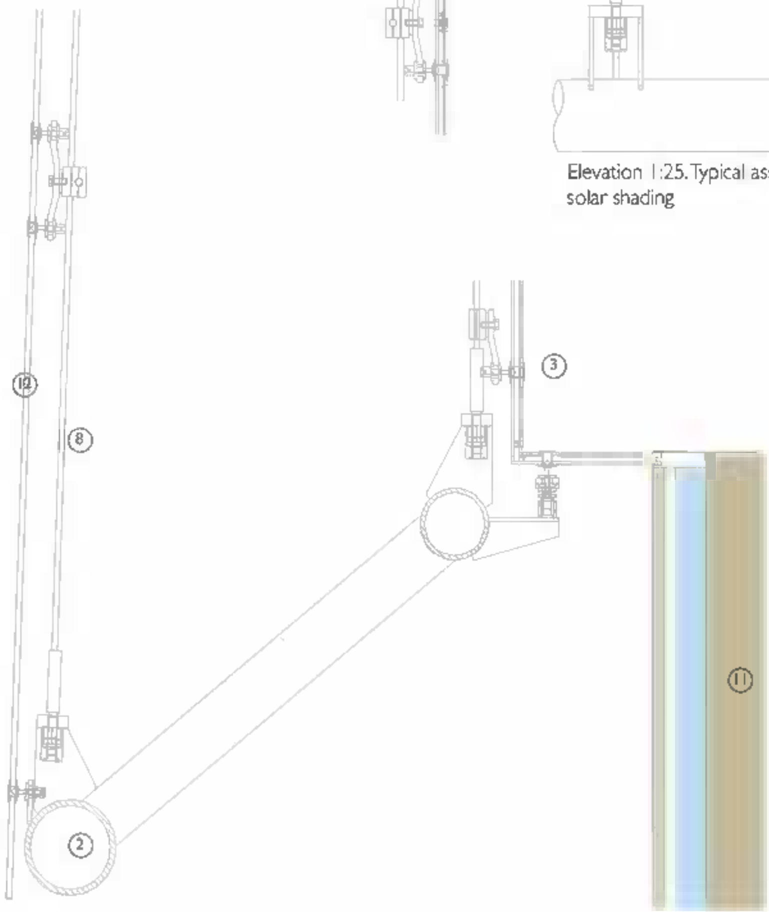
For bigger rooflights up to around 5.0 metres high and 8.0 metres wide, lightweight hollow mild steel sections, together with stainless steel cables are commonly used. This rooflight size suits glass sizes which are around 2000mm x 2000mm for horizontally-set units and around 2000mm x 2500mm high for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



3-D detail view showing fixing method of twin wall roof with double glazed units



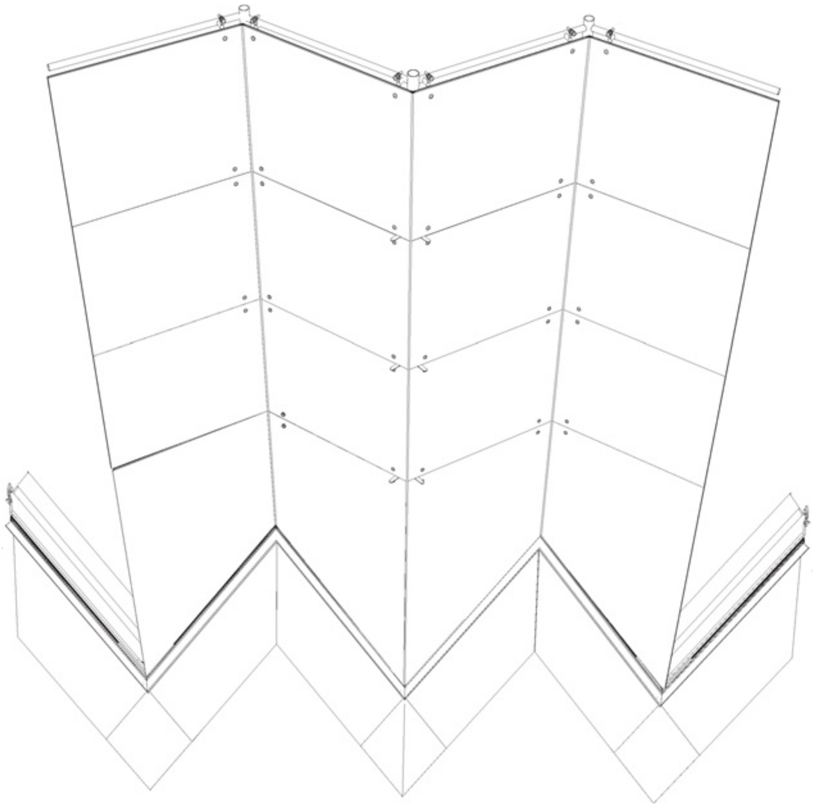
Elevation 1:25. Typical assembly of twin wall roof with double glazed units and solar shading



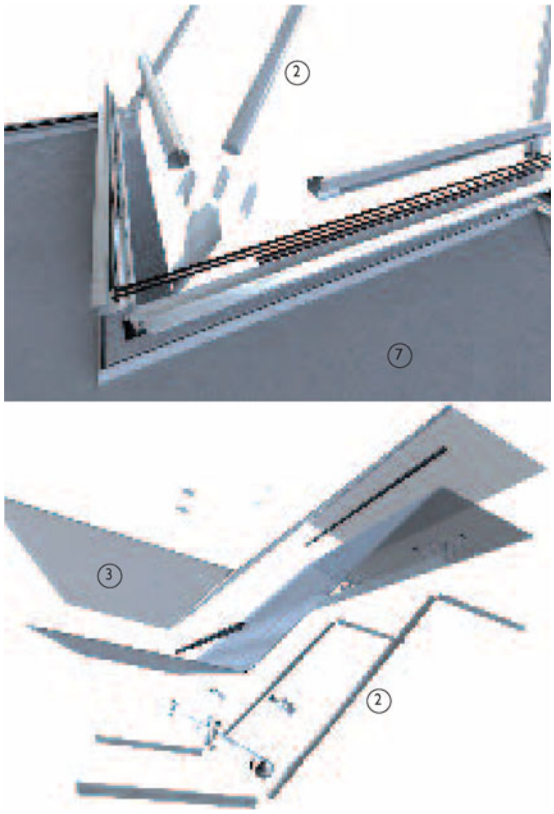
Vertical section 1:25. Typical assembly of twin wall roof with double glazed units and solar shading

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
12. Single glazed solar shading glass

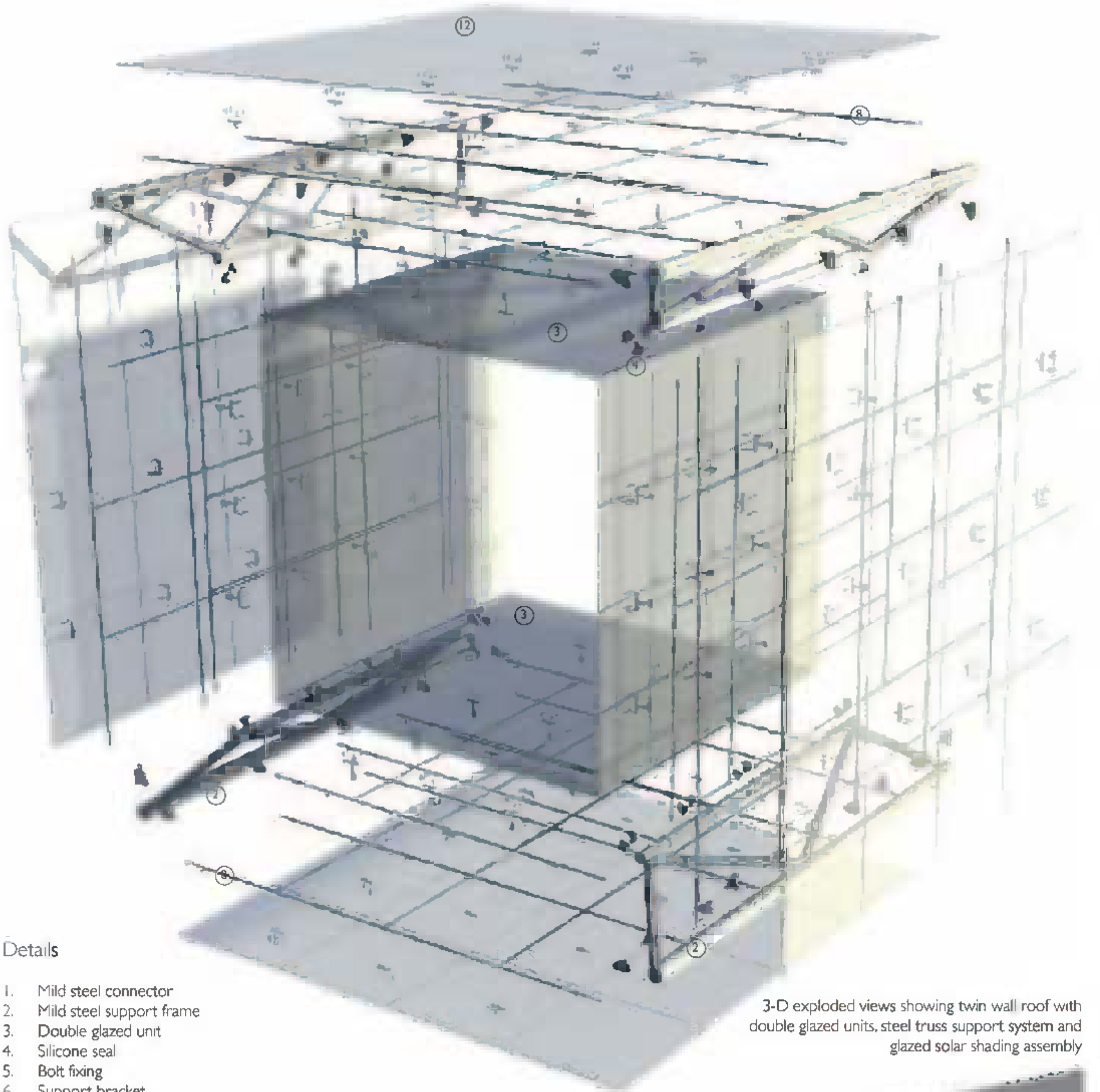


3-D view of underside of typical glazed pitched roof assembly



3-D exploded detail views of bolt fixed glazing

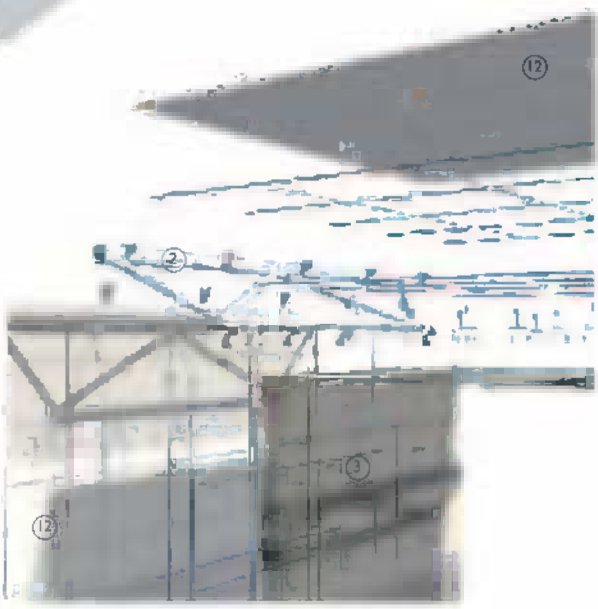
3-D exploded view of bolt fixed glazed roo

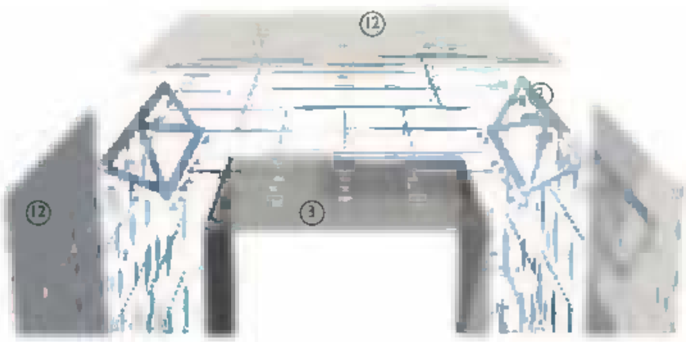


Details

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
12. Single glazed solar shading glass

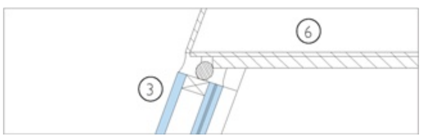
3-D exploded views showing twin wall roof with double glazed units, steel truss support system and glazed solar shading assembly



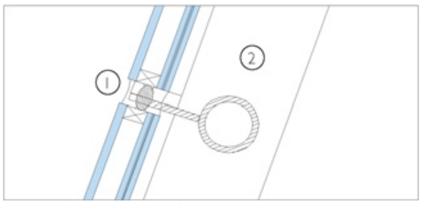


3-D view of typical conical rooflight assembly

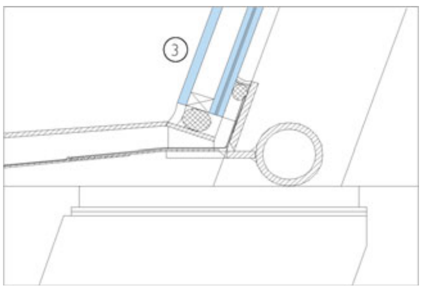
Vertical section 1:25. Generic conical rooflight, typical assembly



Vertical section 1:5. Junction with adjacent material



Vertical section 1:5. Glass to glass junction



Vertical section 1:5. Junction with upstand

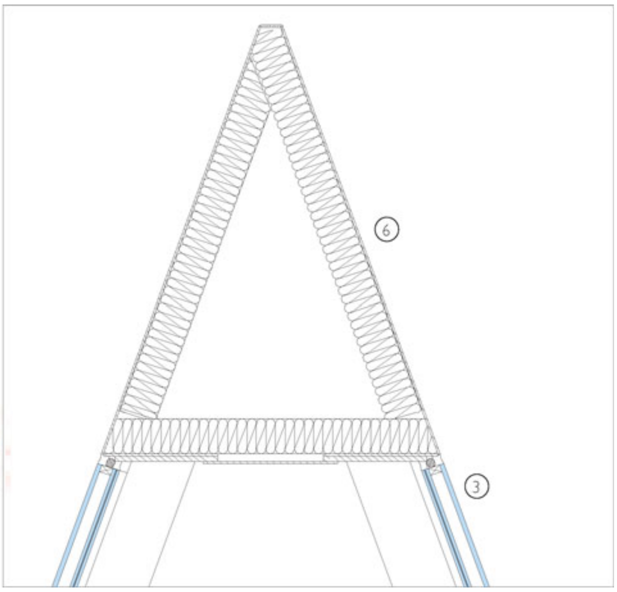
The method of silicone bonding glass to aluminium framing is well developed for use in glazed curtain walling to provide visually smooth glass facades with no visible cappings. The use of silicone sealed rooflights, discussed in an earlier section, can be taken a step further to become a full bond without 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.

Four examples are discussed in this section. The generic conical rooflight has curved double glazed units bonded to an aluminium frame. Silicone bonding avoids cover caps which would have to be curved both vertically and horizontally, and which would be extremely difficult to fabricate. The generic rectangular rooflight can be bonded together without a supporting structure, with the glass providing its own support. A flat monopitch rooflight can be bonded to a frame to provide a small rooflight from one double glazed unit. The use of laminated glass sheets can make a glass deck strong enough to walk on. Similar to a glass floor used inside a building, it must also take heavier traffic loadings and be weathertight.

Generic conical rooflight

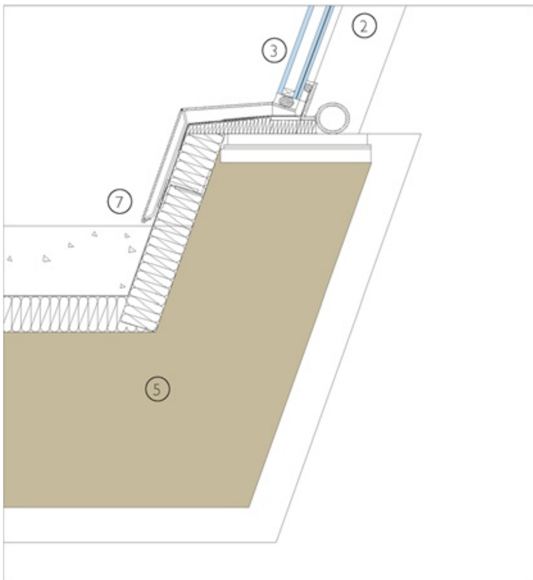
In a generic conical rooflight, a lightweight steel frame is used to support double glazed units that form a rooflight. The structural frame comprises box sections set vertically,

3-D view from below of typical conical rooflight assembly

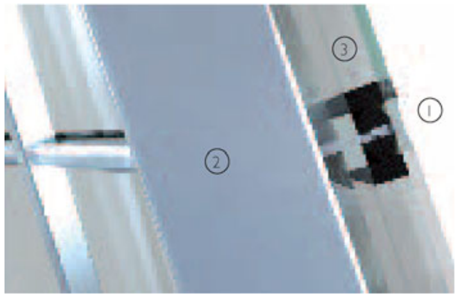


Vertical section 1:10. Junction with adjacent material

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



Vertical section 1:10. Base upstand

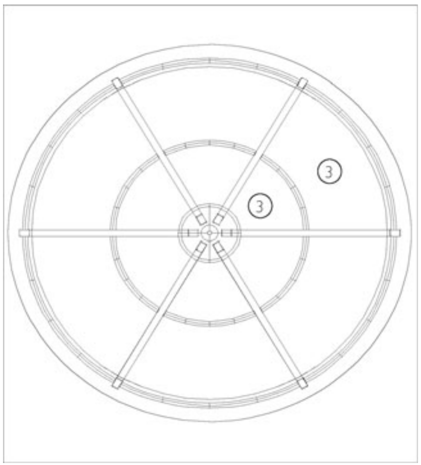


3-D detail view of glass to glass junction in conical rooflight

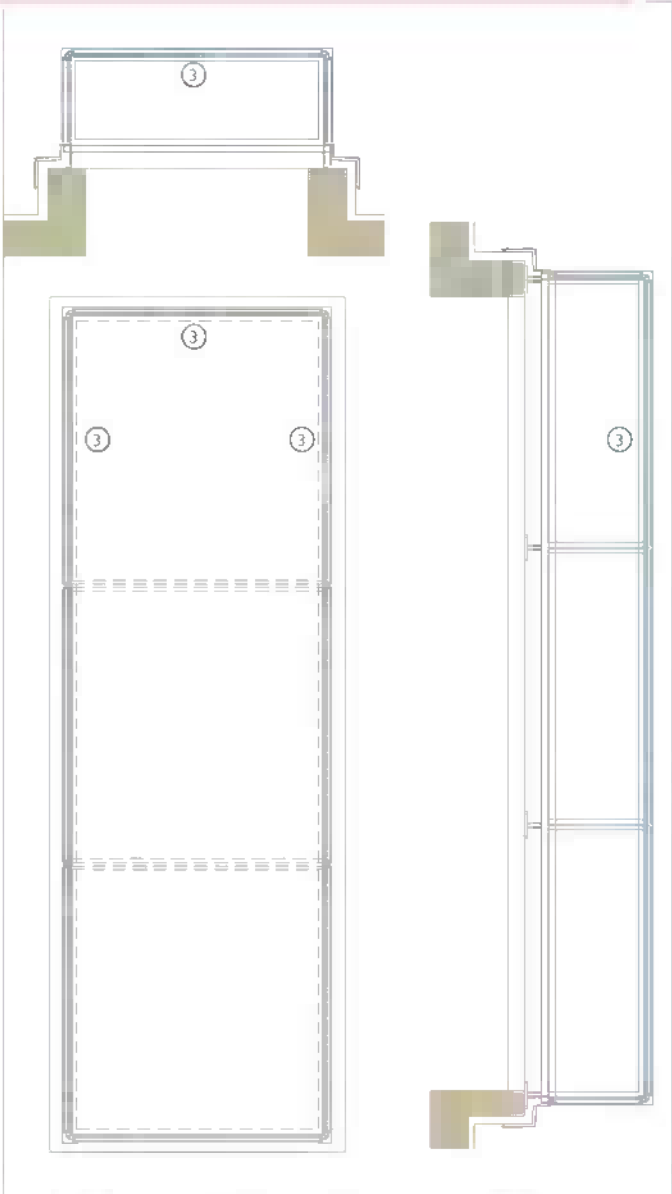
3-D detail view of frame in conical rooflight

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. 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 outlets, for example. 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.

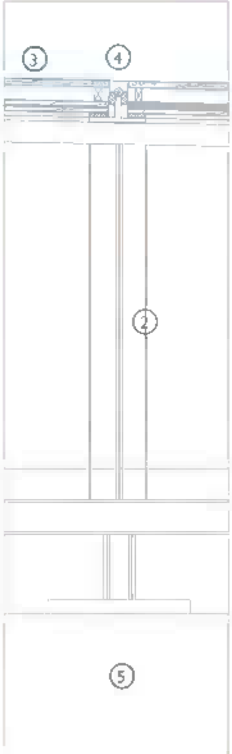
At the top of the rooflight, a metal panel is used to seal the pointed form. The glass can be continued almost to the top, with only a small pointed metal cover, but this example aims to show how the glass is sealed to another material set above it. The metal cover is folded inwards at its junction with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



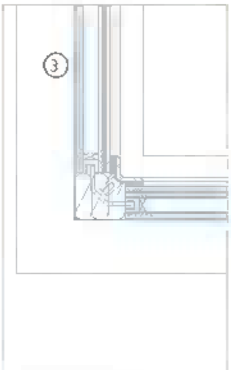
Key plan



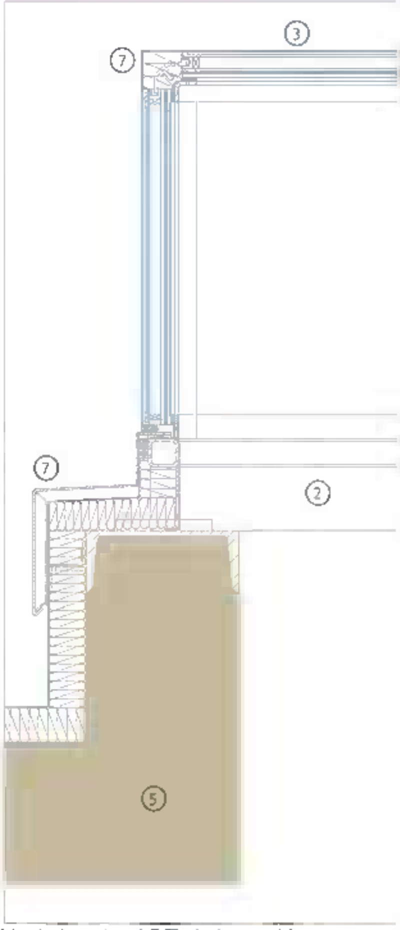
Plan, section, elevation 1:25 Rooflight with glass supports, typical assembly



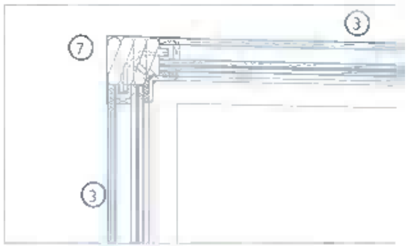
Vertical section 1:5. Typical assembly



Horizontal section 1:5. Typical assembly



Vertical section 1:5. Typical assembly



Horizontal section 1:5. Typical assembly

Details

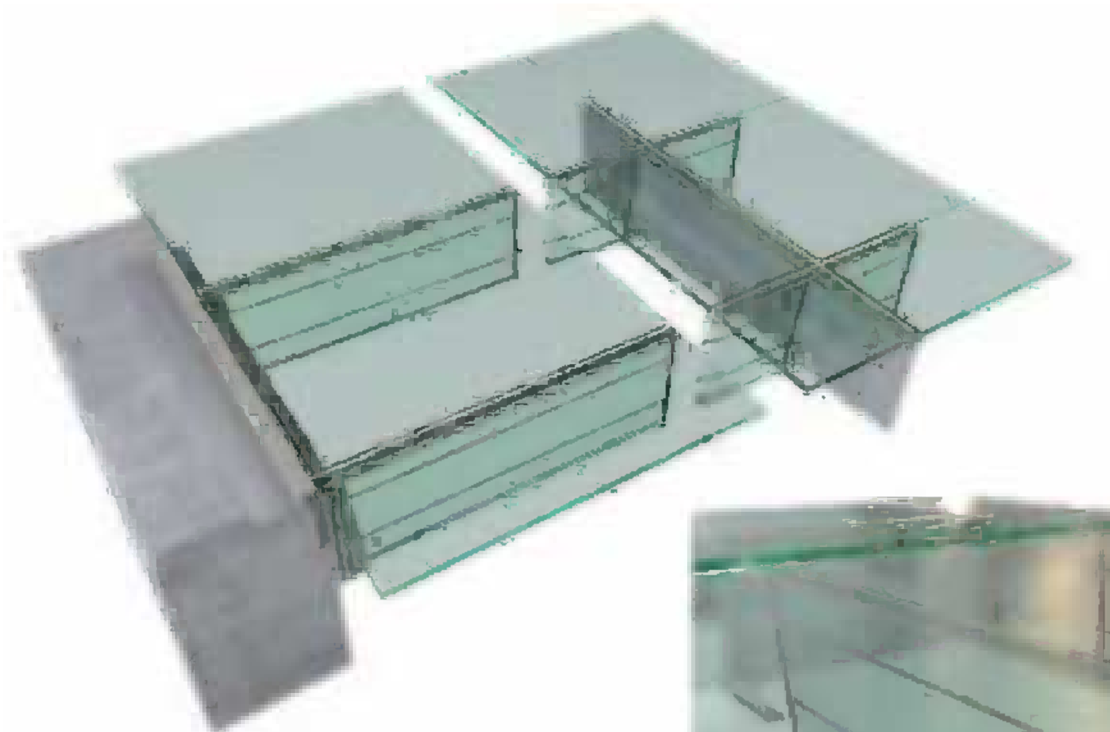
1. Silicone bond
2. Mild steel support frame
3. Single glazed laminated glass panel
4. Silicone seal
5. Concrete base
6. Insulated metal panel
7. Folded metal flashing
8. Reinforced concrete support frame

or mineral fibre quilt to provide a continuity of thermal insulation.

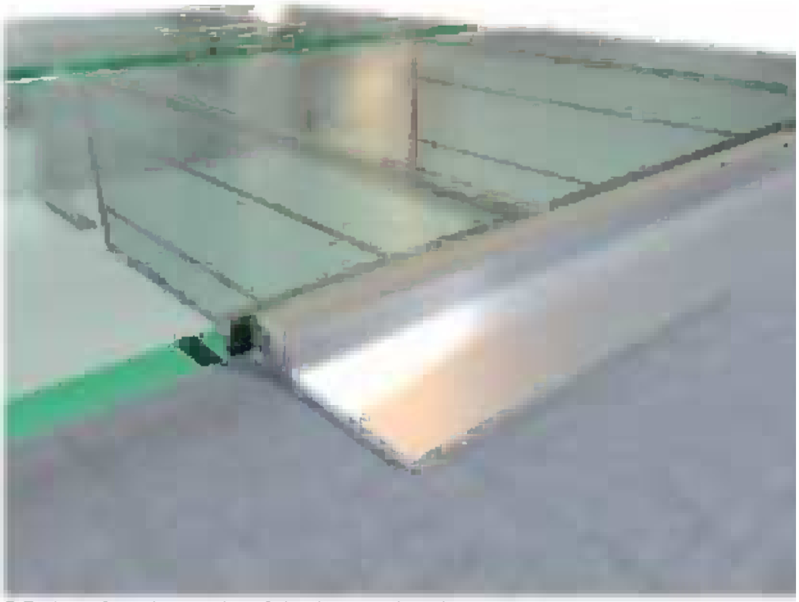
The use of silicone bonding in this rooflight avoids the need to use visually obtrusive bolt fixings, allowing the form of the rooflight to be seen more clearly. In some countries, additional restraining clips are required on the outside of the glass, at the corners, but this additional safety feature is dependent upon the individual rooflight design and the local building codes.

Generic rectangular rooflight

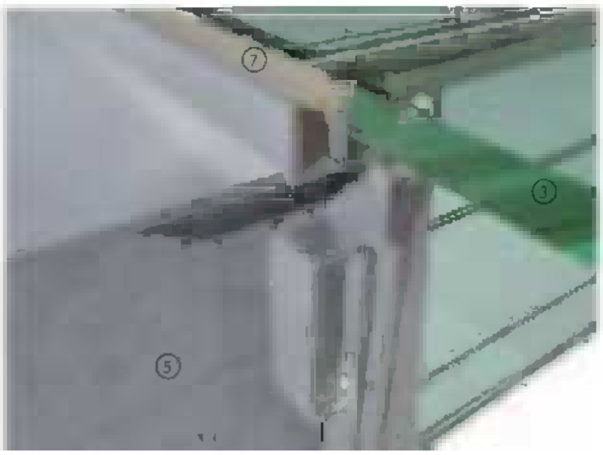
The generic rectangular rooflight can be constructed without a supporting frame. Mechanical restraint is provided at the corners in the form of pressure plate clips. The double glazed units at the corners are fabricated with a recessed groove on the two sides of the panel forming the corner in order 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 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



3-D view of rooflight with glass supports and central steel support beam



3-D view of junction at edge of glass beam and steel support



3-D detail of connection between glass beam and concrete wall

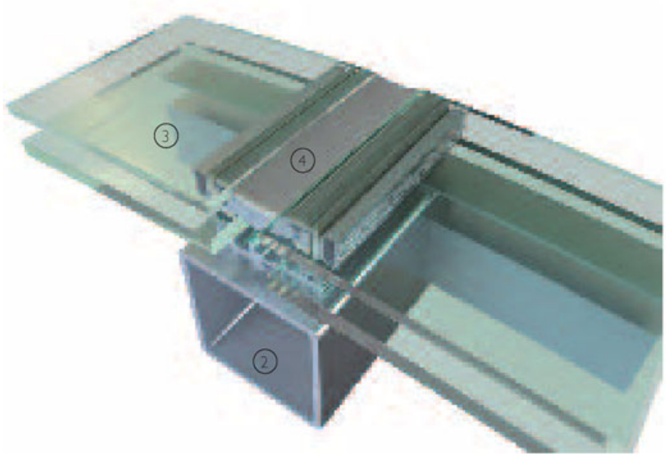
seal with an aluminium angle set on the inside face to provide a second seal.

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. The waterproof membrane for the adjacent roof extends up the concrete 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.

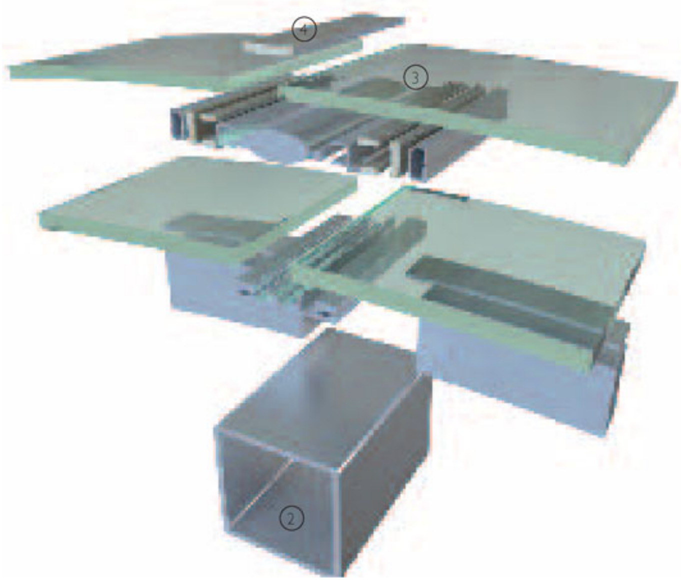
The inside face of the double glazed unit at its base is bonded to an inner metal angle. The outside face of the glass is sealed to the metal flashing below with silicone. Any water that passes through the outer seal is drained to the external face of the roof membrane beneath.

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 appear

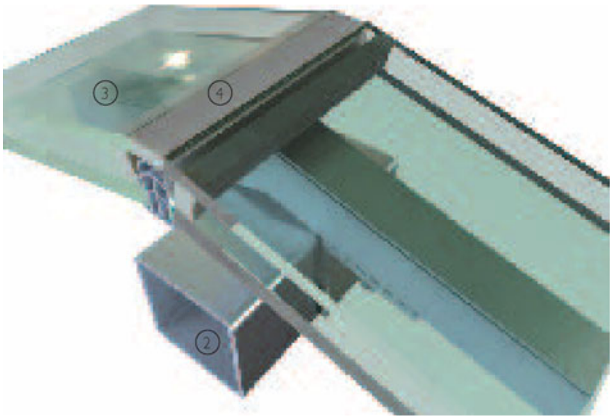
3-D detail of connection between glass beam and concrete wall



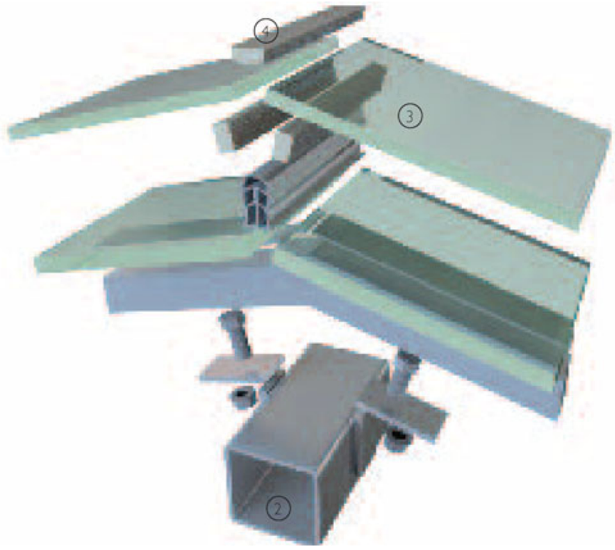
3-D view of glass to glass junction



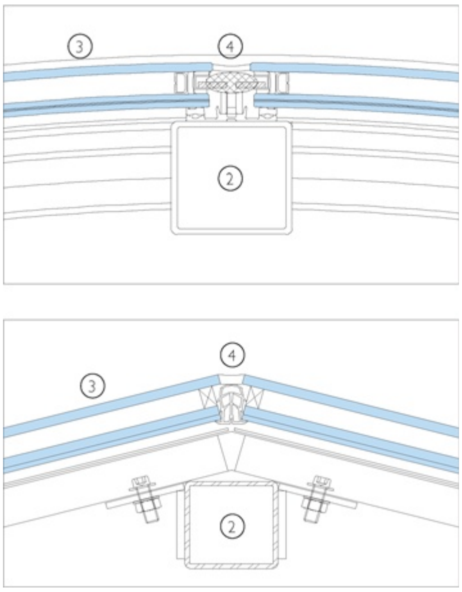
3-D exploded view of glass to glass junction



3-D view of glass to glass junction



3-D exploded view of glass to glass junction



Horizontal sections 1:5. Glass to glass junction

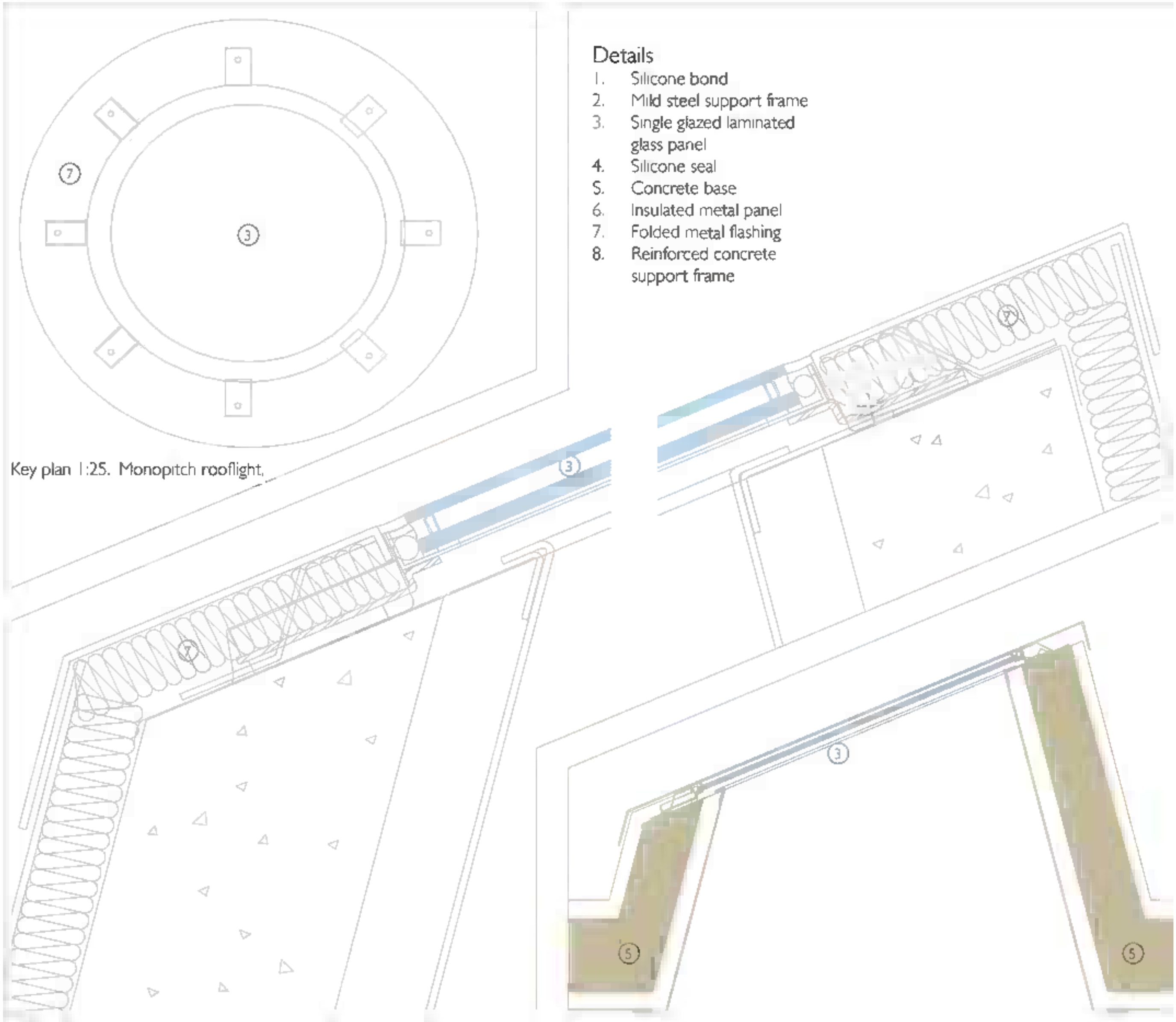
ance to the flashing, or by adding a layer of decking to conceal the upstand. Decking is usually in the form of open jointed concrete slabs or timber boards.

Generic monopitch rooflight

The monopitch rooflight 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. A metal panel forms 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 ten years. Previously used only inside buildings for walkways and stairs, they are now being used as fully waterproofed external 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



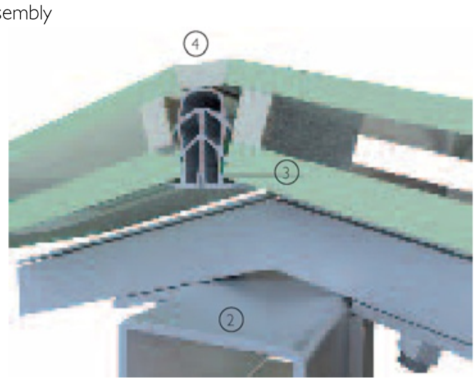
Vertical section 1:5. Monopitch rooflight, typical assembly

Vertical section 1:25. Typical assembly

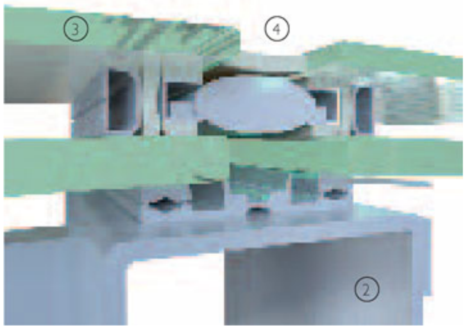
glass is exposed to the outside, but is supported on its underside, allowing heat to enter but not to escape. Where black coloured edge 'fritting' is used, the situation is made difficult. However, double glazed roof decking is in development and will no doubt become much more common over the next ten 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.

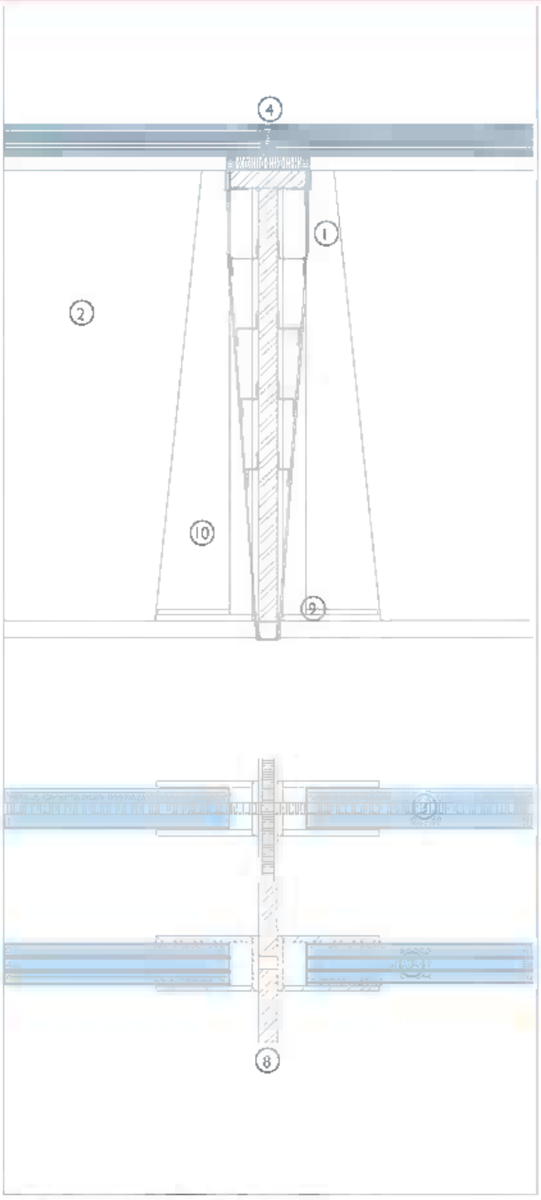
The details here show alternatives for both steel beam and glass beam supports to the glass panels. The supporting structure has a glass beam set in the centre, spanning the full length of 6000mm. Its depth is approximately 600mm, but the beam depth will vary depending upon the individual design. The 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. Each glass has 20-25mm bearing, with a

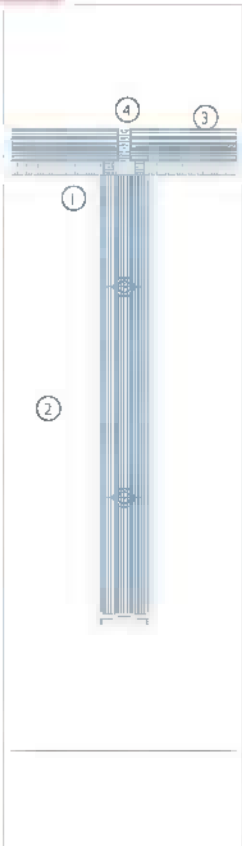


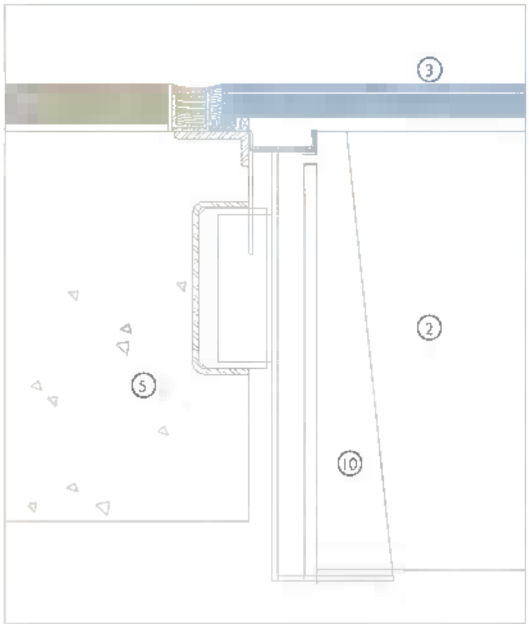
3-D detail view of glass to glass junction

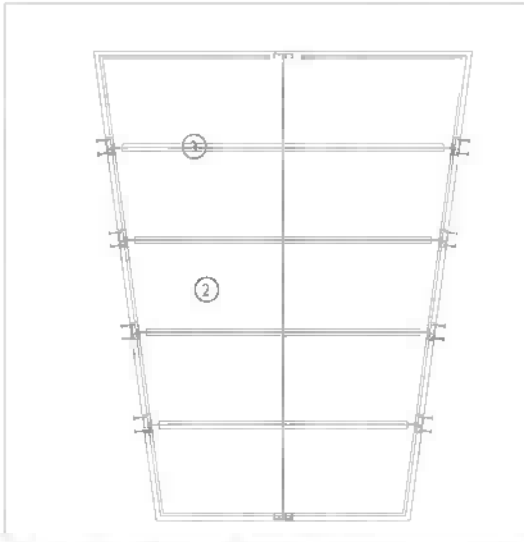


3-D detail view of glass to glass junction









Vertical sections 1:10. Typical assembly

Key Plan. Laminated glass roof which can be walked on, typical assembly

Details for glass deck

1. Silicone bond
2. Structural glass beam
3. Single glazed laminated glass panel
4. Silicone seal
5. Concrete base
6. Insulated metal panel
7. Folded metal flashing
8. Mild steel plate beam as alternative support
9. Folded aluminium decorative cover
10. Steel aluminium support 'shoe'

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, 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. 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.

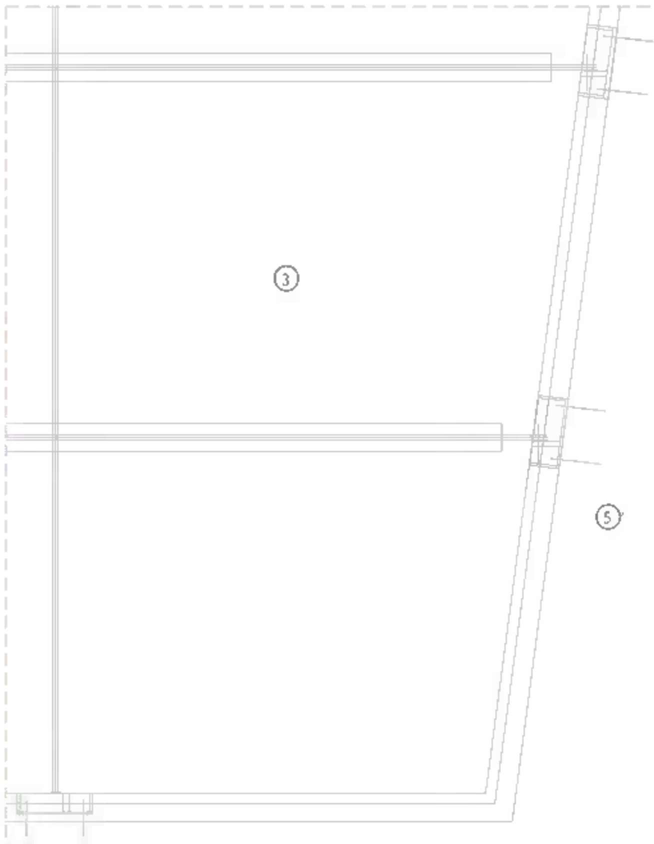
Typical glass deck panel sizes range from 1000mm x 1000mm to 1500mm x 1500mm. Both panel size and overall glass thickness are determinants in the overall rigidity of the glass deck and its associated vertical deflections. Typical vertical deflections for the glass build-ups, given below, range from 0.2mm 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 = 36mm 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

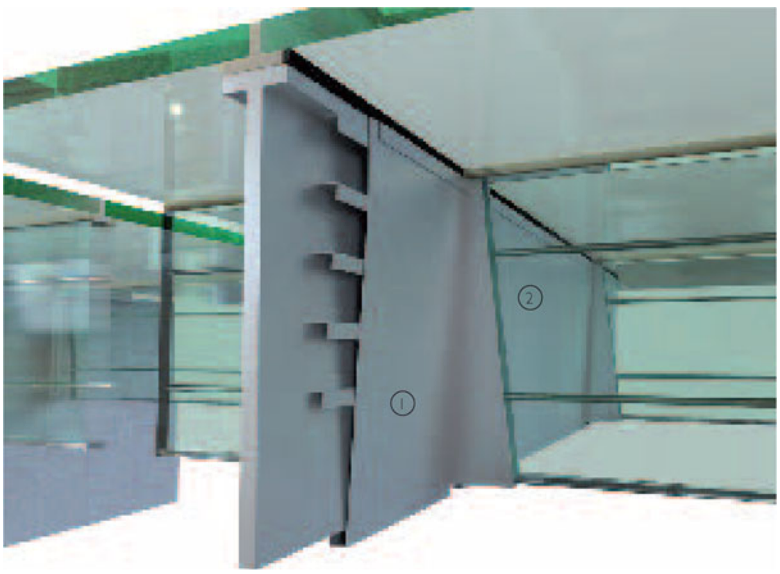
ertical and horizontal sections 1:25. Typical assembly

-D detail of steel support beam

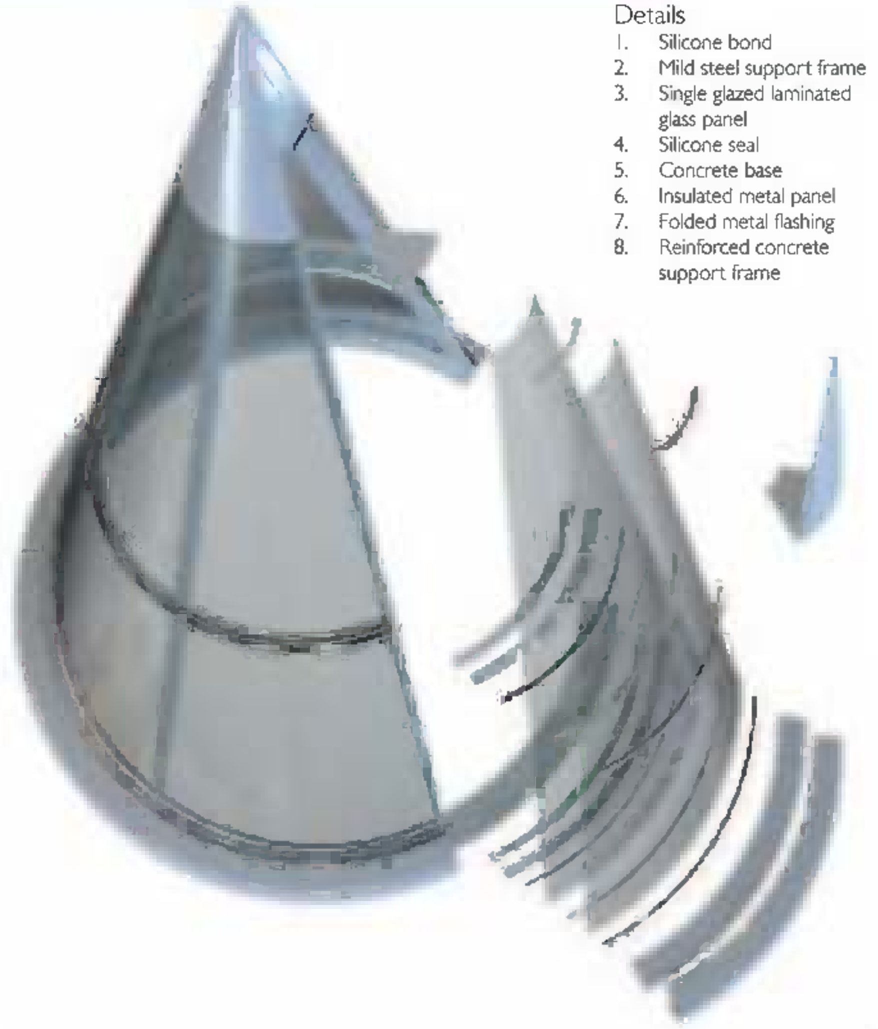


cleats in the manner of steel framed floor construction. Both methods require at least one of the glass beams to be drilled in order to bolt the metal component to the beam. When bolting a glass beam to a steel beam, the same principles apply of using a metal shoe. The drilling of glass is a well established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



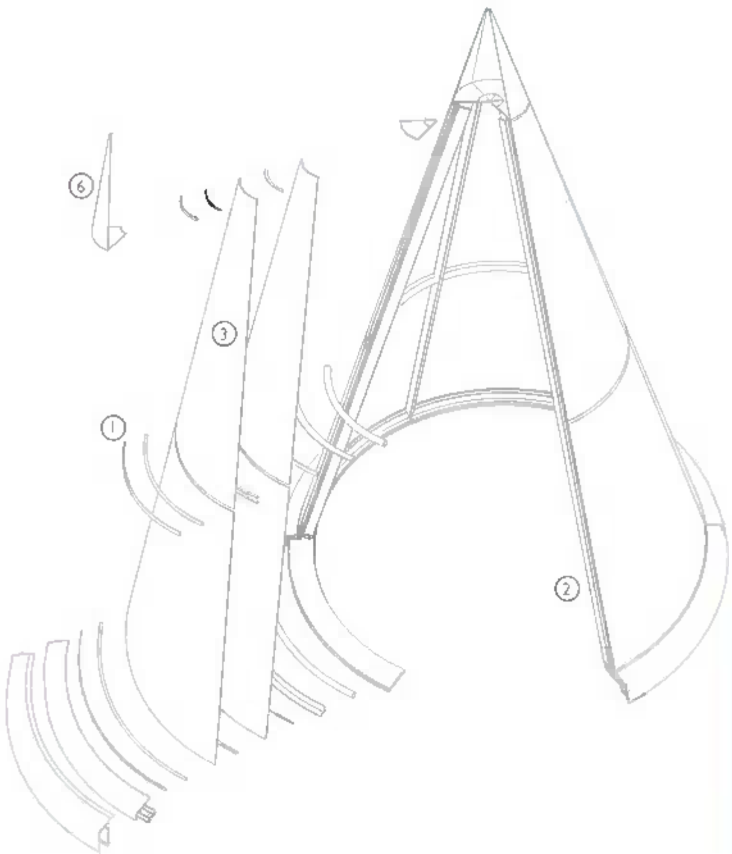
3-D detail of steel support beam



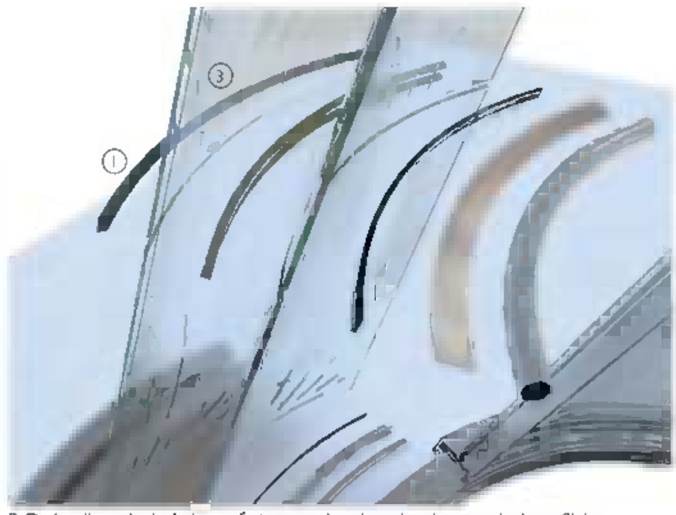
Details
1. Silicone bond
2. Mild steel support frame
3. Single glazed laminated glass panel
4. Silicone seal
5. Concrete base
6. Insulated metal panel
7. Folded metal flashing
8. Reinforced concrete support frame

3-D detail view of point at top of conical rooflight assembly

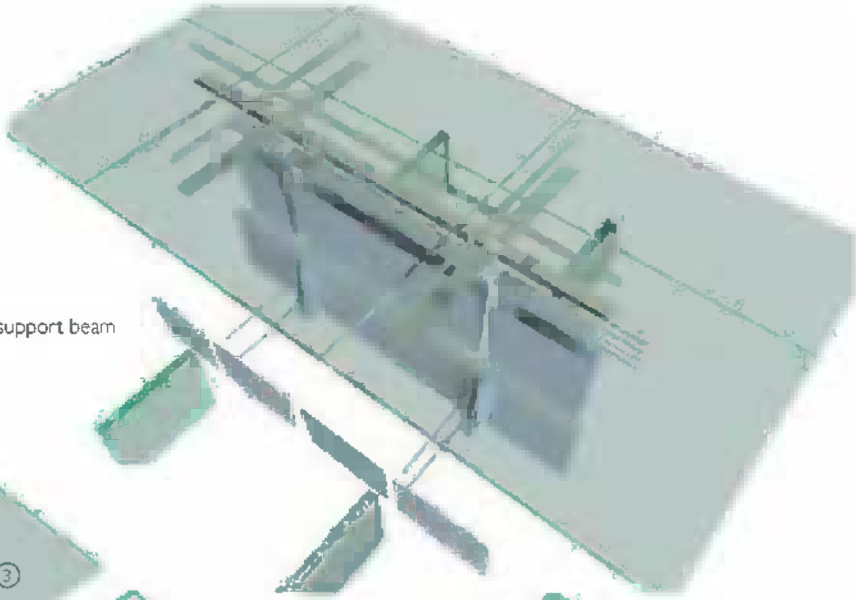
3-D exploded view of typical conical rooflight assembly



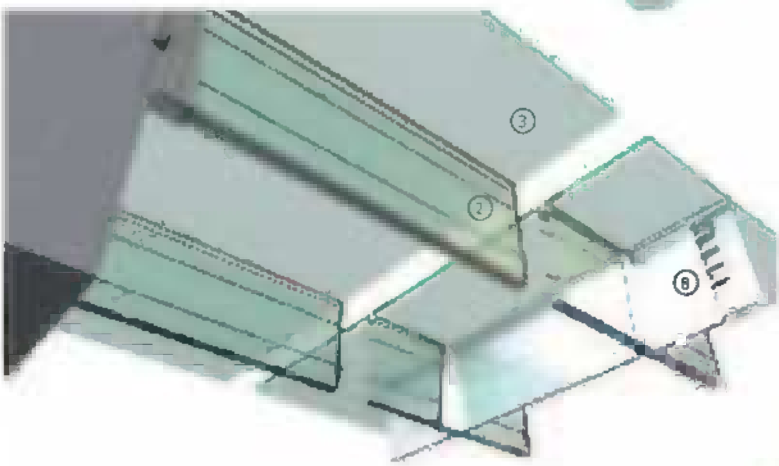
Exploded axonometric view of typical conical rooflight assembly



3-D detail exploded view of glass to glass junction in a conical rooflight



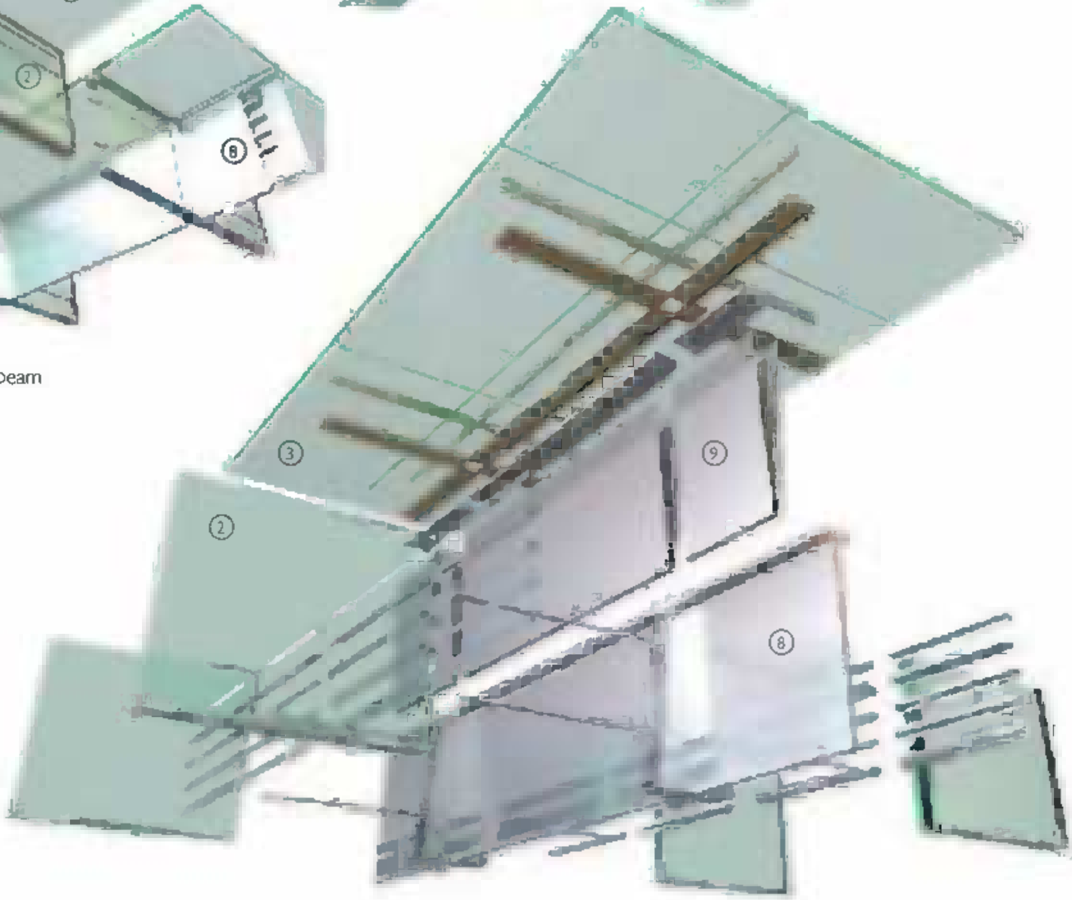
3-D exploded view of glass beam with central steel support beam



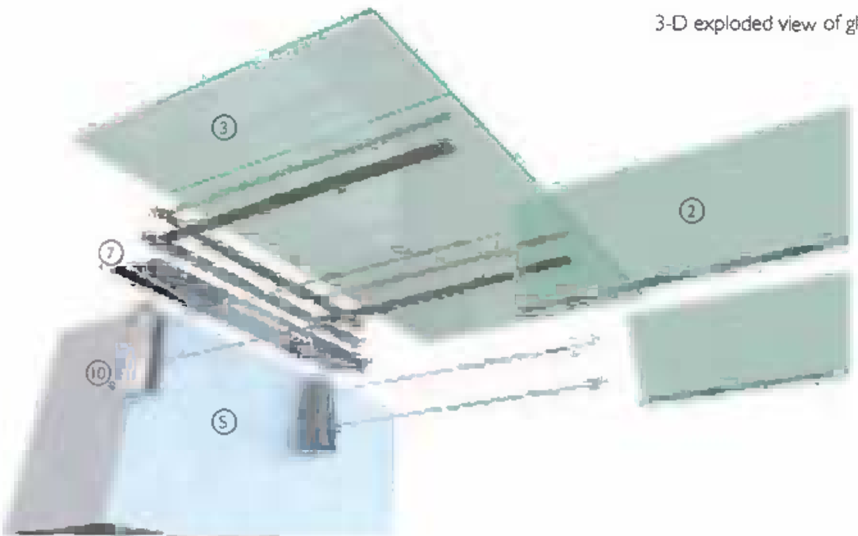
3-D view of glass beam with central steel support beam

Details for glass deck

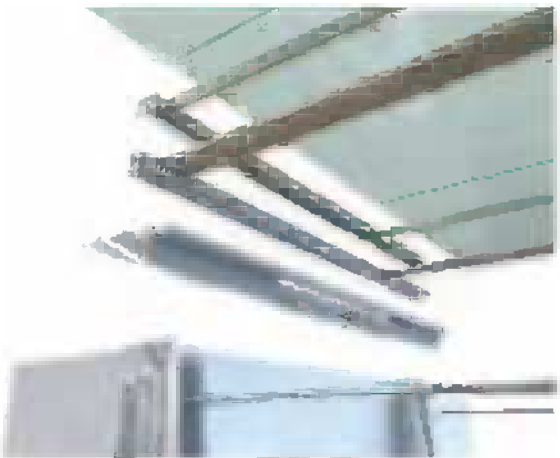
1. Silicone bond
2. Structural glass beam
3. Single glazed laminated glass panel
4. Silicone seal
5. Concrete base
6. Insulated metal panel
7. Folded metal flashing
8. Mild steel plate beam as alternative support
9. Folded aluminium decorative cover
10. Steel aluminium support 'shoe'



3-D exploded view of glass beam with central steel support beam



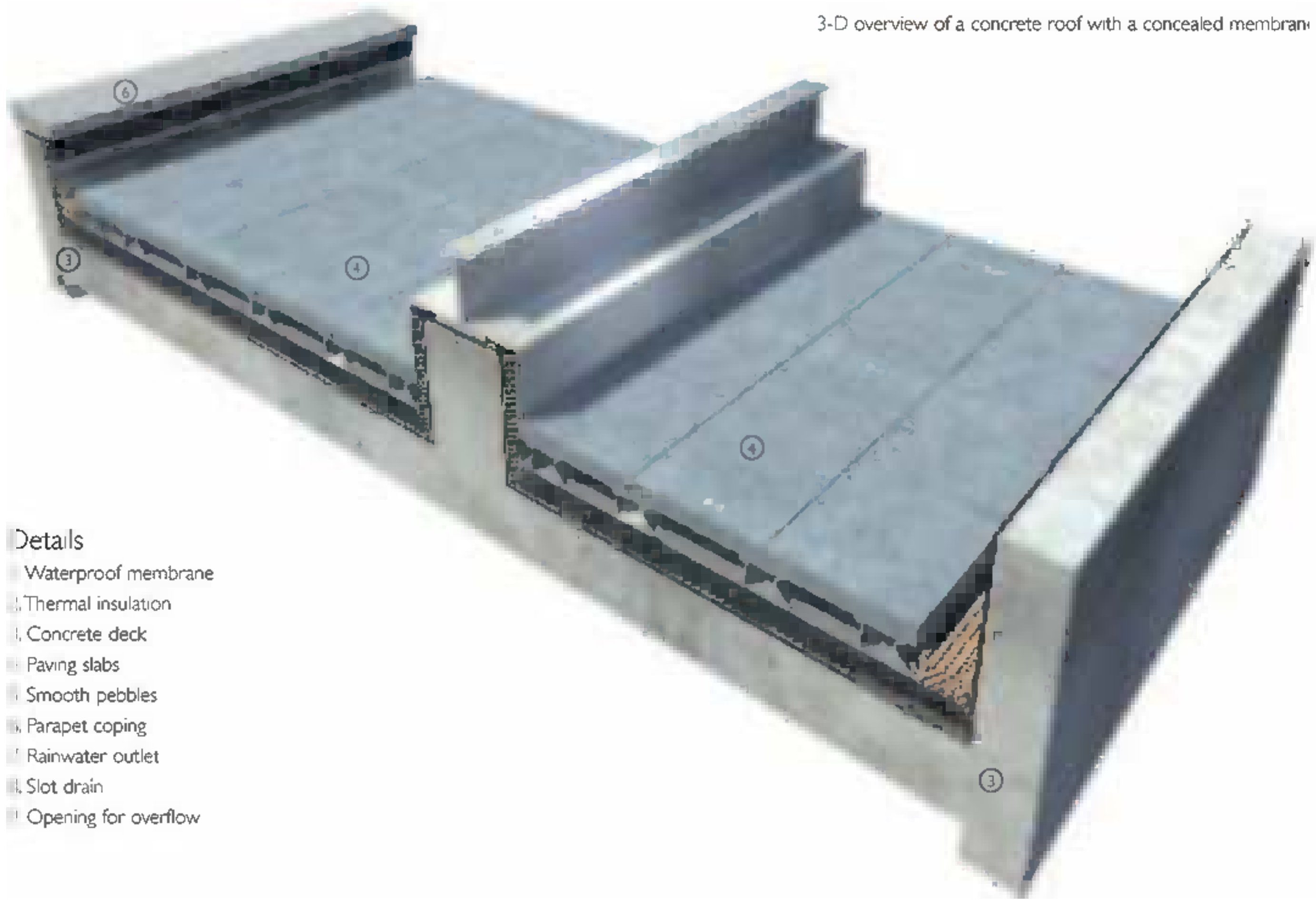
3-D exploded view of connection between concrete wall and glass beam supports



3-D exploded view of junction at edge of glass beam and steel support

9

CONCRETE ROOFS



Materials

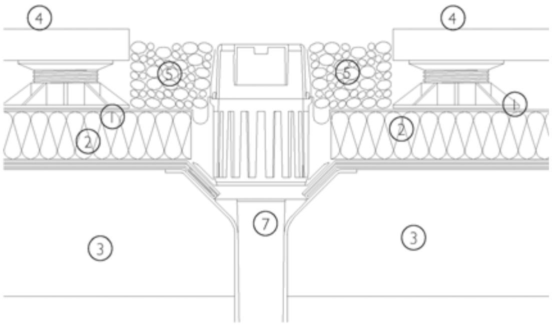
Bitumen has traditionally been used as a waterproof layer, applied while hot in liquid form onto a concrete roof slab. As it cools it hardens, forming an impervious membrane, but will soften again if heated by the effects of solar radiation. For this reason, in order to keep the material cool, bitumen 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 25mm. One of the limiting factors with bitumen is folding the material through an angle. When the material turns through a right angle from the horizontal 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.

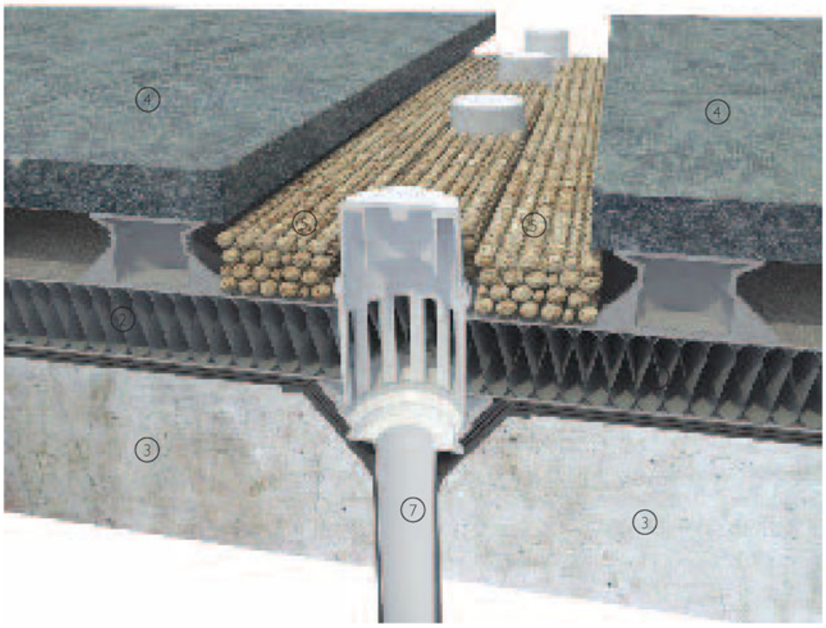
With the development of much thinner membranes in thermoplastics and elastomers, together with their competitive costs, there have been considerable efforts made by manufacturers over the past 20 years to make the bitumen layers thinner, to reduce the material required while enhancing its properties of strength and flexibility. This has been achieved by replacing the thick two-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 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.

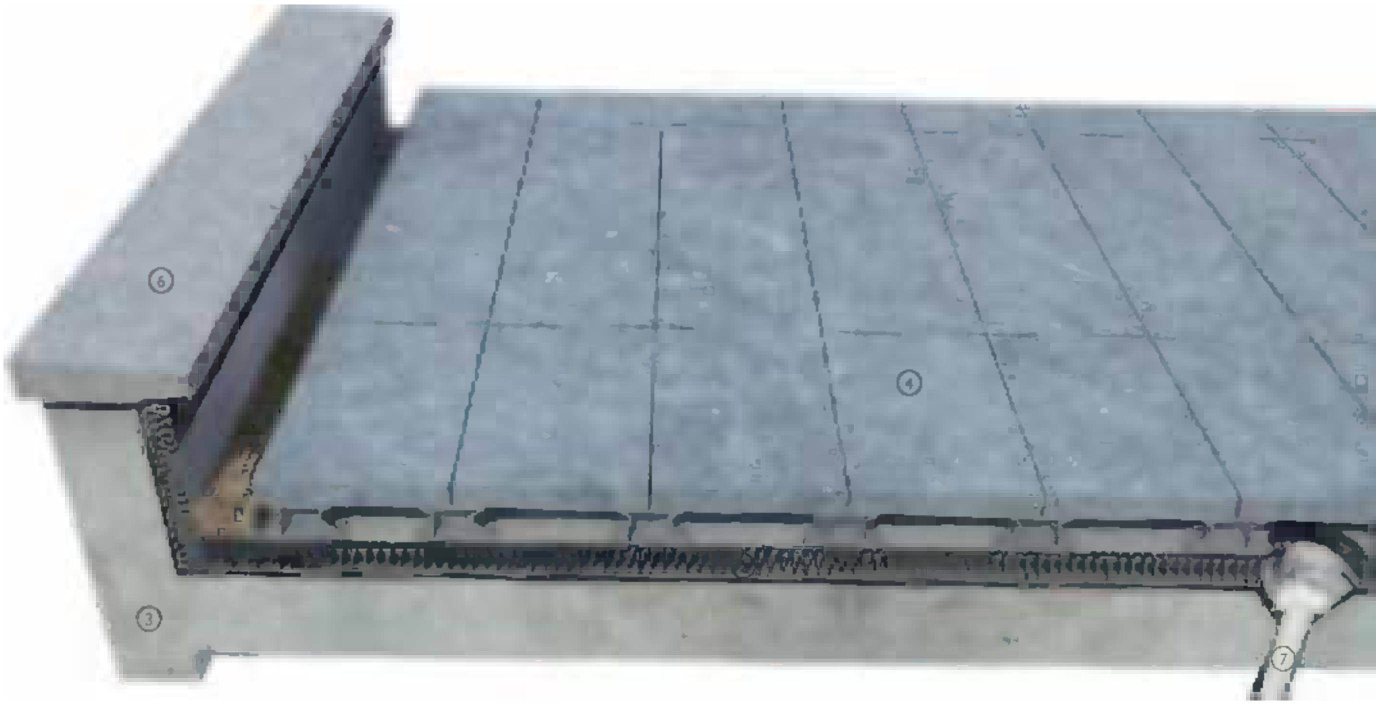
Typically upstands are formed before the main areas of roof are waterproofed in order to allow external walls to be completed. When an area is completed, the roof deck is waterproofed and finished, with areas of flat roof being bonded continuously to the already completed upstands. This avoids the need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



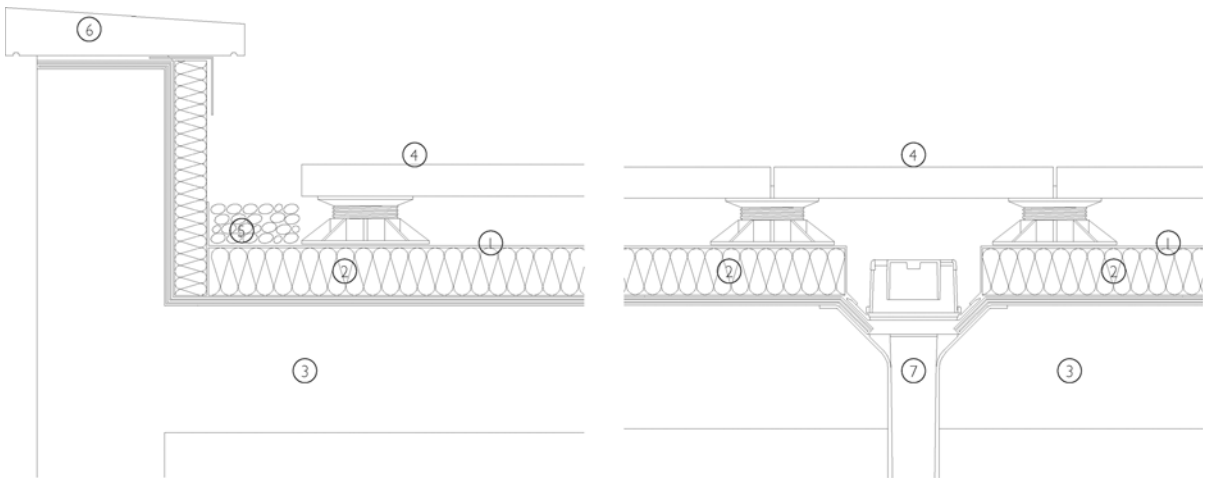
Vertical section 1:10. Rainwater outlet



3-D view of rainwater outlet



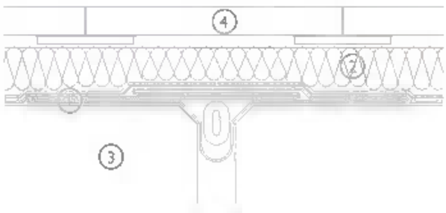
3-D view of parapet and rainwater outlet



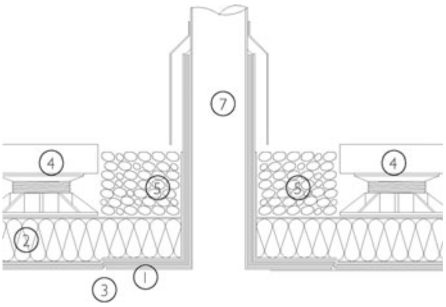
Vertical section 1:10. Parapet and rainwater outlet

Details
Waterproof membrane
Thermal insulation
Concrete deck
Paving slabs
Smooth pebbles
Parapet coping
Rainwater outlet
Slot drain
Opening for overflow

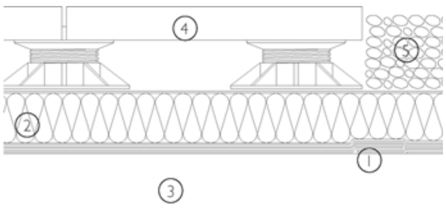
3-D view showing expansion joint in concrete slab



Vertical section 1:10. Expansion joint in concrete slab



Vertical section 1:10. Base of balustrade

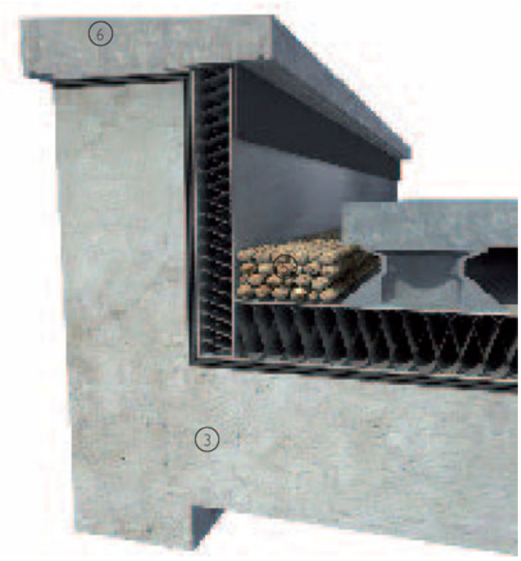


Vertical section 1:10. Parapet detail

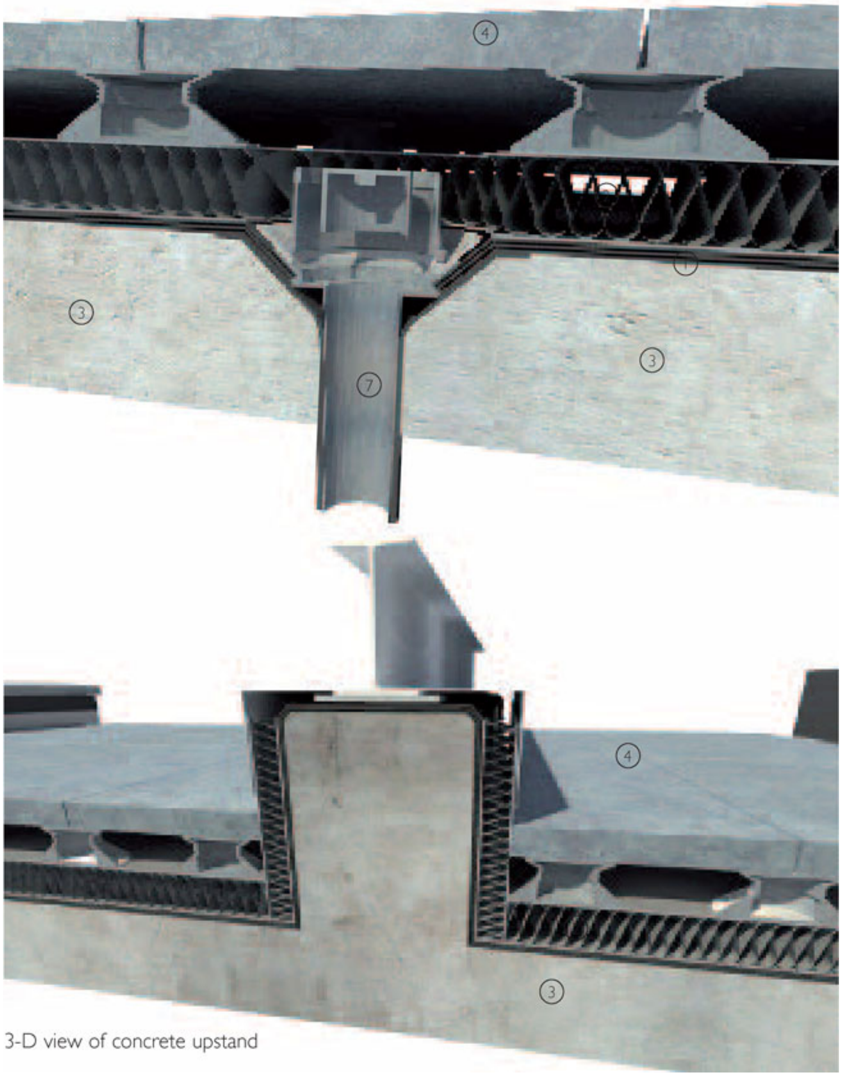
Concealed membrane roofs are typically in 'inverted' roof configuration with either open joints or sealed joints in the top layer that covers the thermal insulation, usually paving. In the open joint version, the membrane, bonded to the concrete slab, is covered by a protection layer, with closed cell, rigid thermal insulation set on top. A polyester filter sheet is set on top, with paving or smooth pebble ballast on top to hold the insulation in place as well as to walk on. Pebbles are 20mm-40mm diameter, while paving slabs are around 600 x 600mm in size, 30 mm-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.

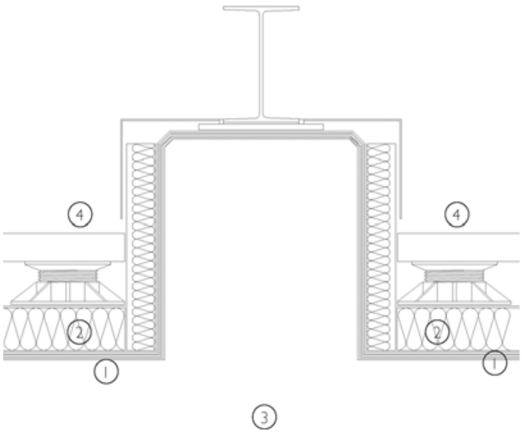
Structural joints

The main advantage of concealed membranes 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, 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.



3-D detail of roof parapet





Vertical section 1:10. Concrete upstand

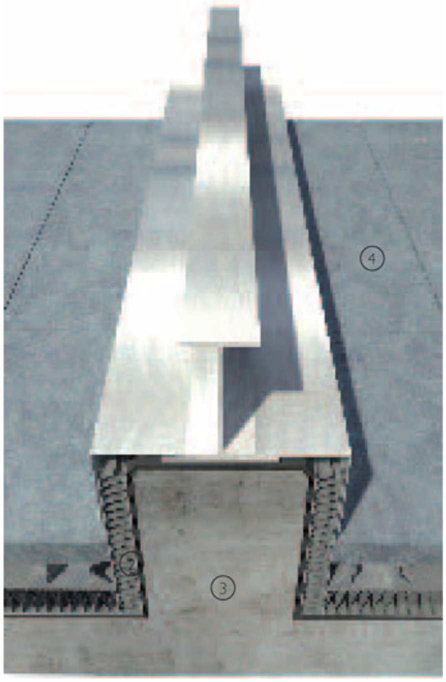
3-D view of concrete upstand

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.

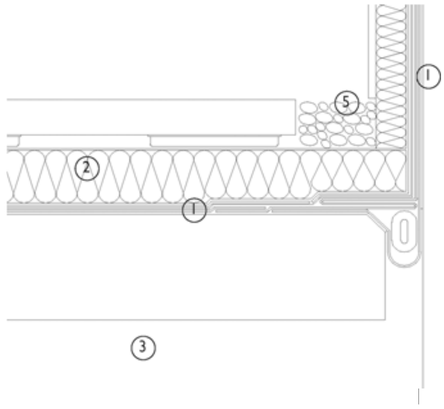
The top of the joint is finished as level as possible with the adjacent areas of roof to allow water to drain freely from the roof. The reinforcing membrane is sometimes folded down into the gap, separated from the membrane below with a foam backing rod. It can be difficult to drain water from this groove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

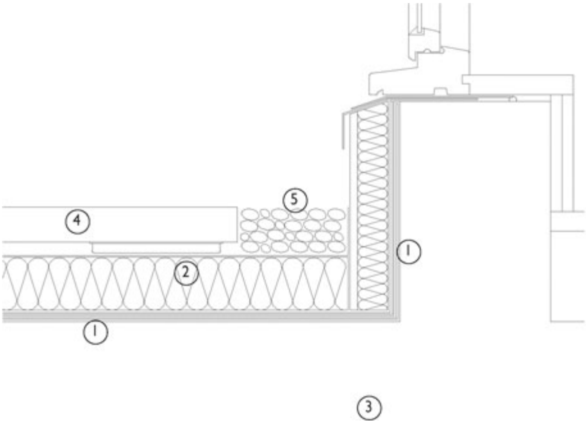
Proprietary metal-based expansion joints are used to form part of the visible finishes, typically with sealed roof finishes. In this case the seal is formed by bonding a strip of membrane to the metal assembly. The metal expansion joint assembly is fixed on top of the membrane, which still dips down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



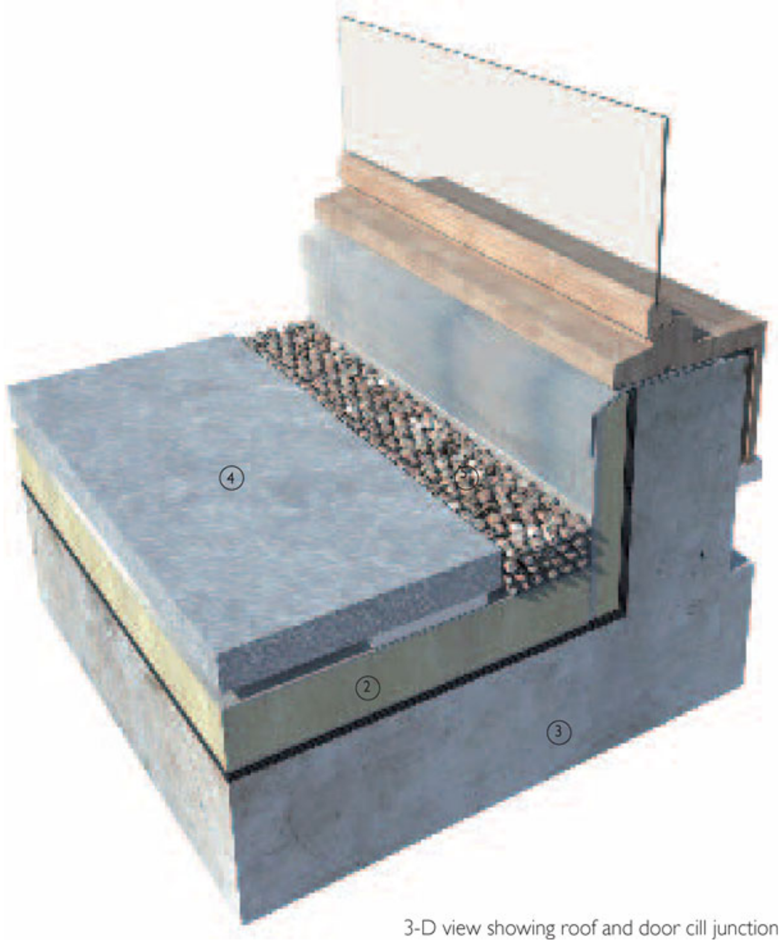
3-D view showing concrete upstand



Vertical section 1:10. Junction of external wall and roof slab



Vertical section 1:10. Door sill



3-D view showing roof and door cill junction

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, with a foam backing rod being provided where there is a risk of damage during construction.

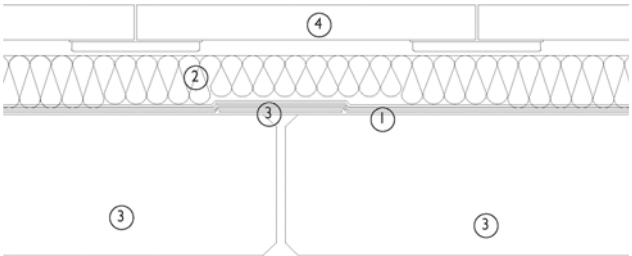
Parapet upstands

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.

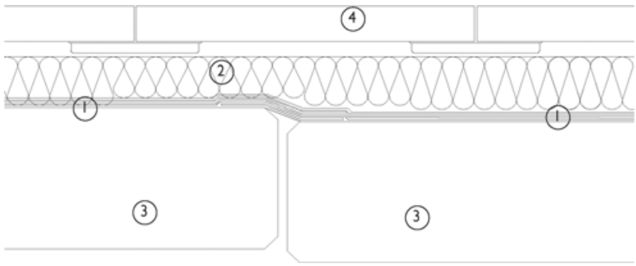
In generic examples, a low parapet wall is terminated by a concrete or stone coping. The waterproof membrane extends up the height of the upstand, which runs horizontally to form a full damp proof course underneath the coping. This ensures that the membrane provides a continuous waterproof layer at the 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 this case, an open jointed arrangement of paving slabs is adopted, 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 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 other instances the paving is continued up the parapet upstand. In an example where the cill to the external door covers the opening, and is supported from the base of the opening, the waterproofing stops at the edge of the opening. The termination of the membrane varies with each situation.

Balustrades and plinths

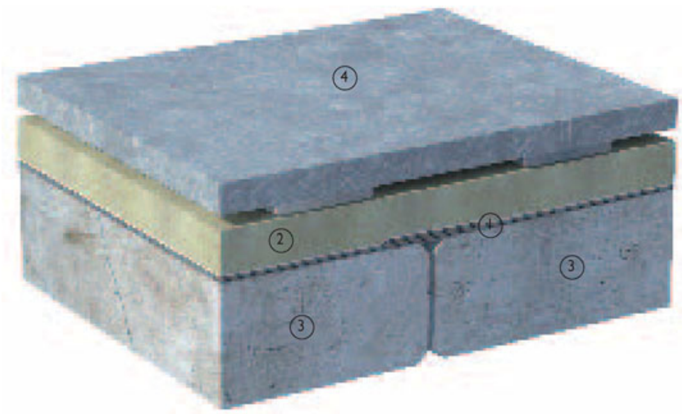
Balustrade posts can be fixed to a base plate which is set onto the finished waterproof membrane. The balustrade base plate is bolted through the membrane to the concrete slab below. If the membrane has an additional protection layer, then this is usually omitted around the base plate to give a more 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



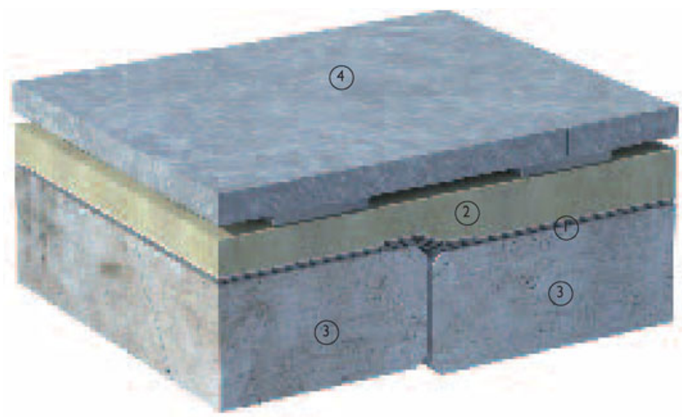
Vertical section 1:10. Expansoin joint in concrete slab



Vertical section 1:10. Expansoin joint in concrete slab



3-D view showing closed expansion joint in concrete slab

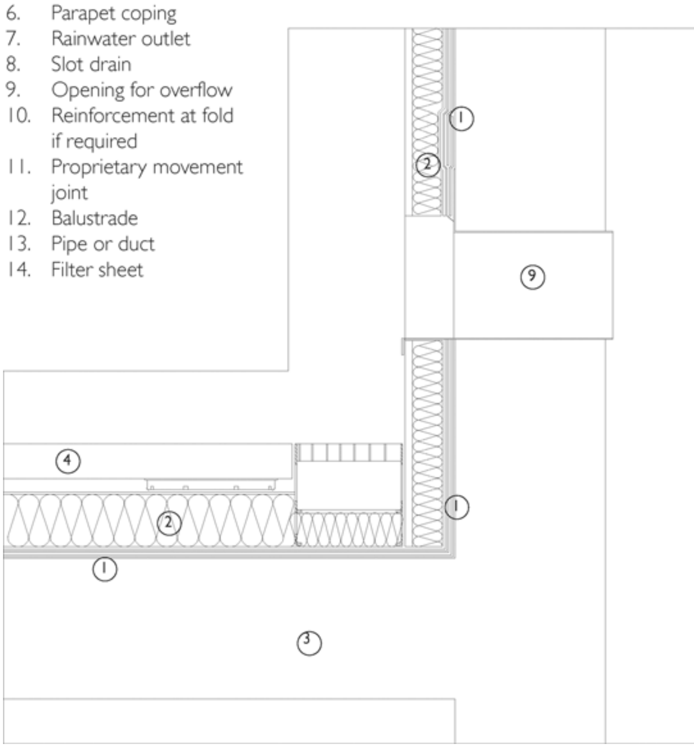


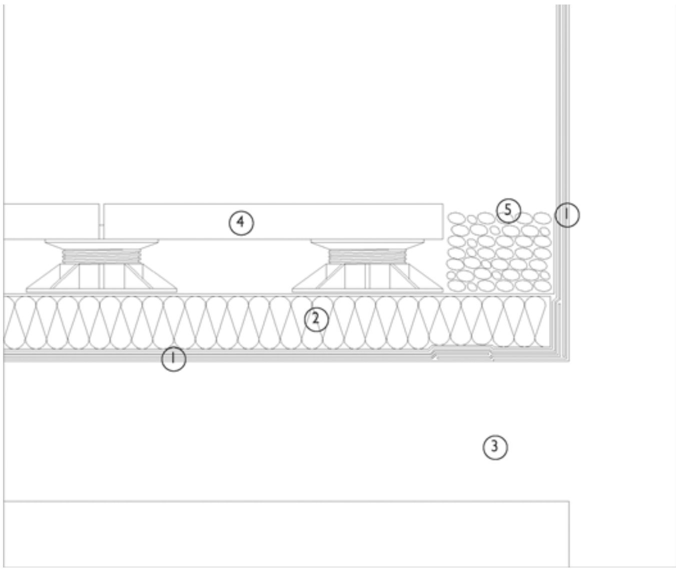
3-D view showing open expansion joint in concrete slab

3-D section view showing junction of external wall and roof with overflow

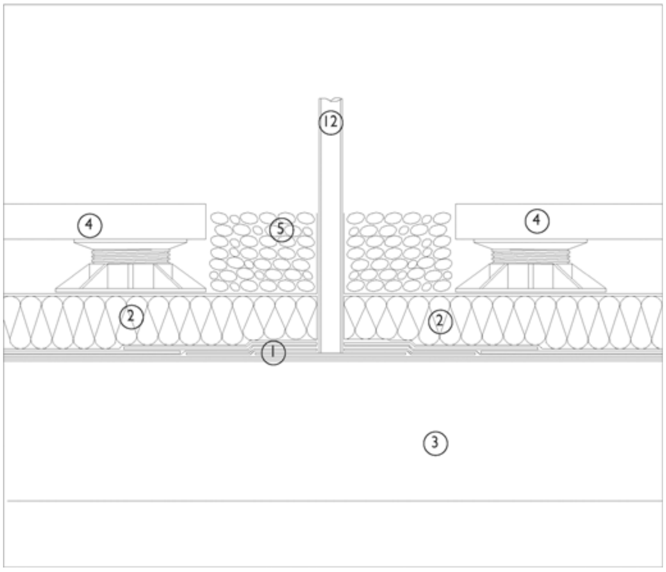
Details
1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Slot drain
9. Opening for overflow
10. Reinforcement at fold if required
11. Proprietary movement joint
12. Balustrade
13. Pipe or duct
14. Filter sheet

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



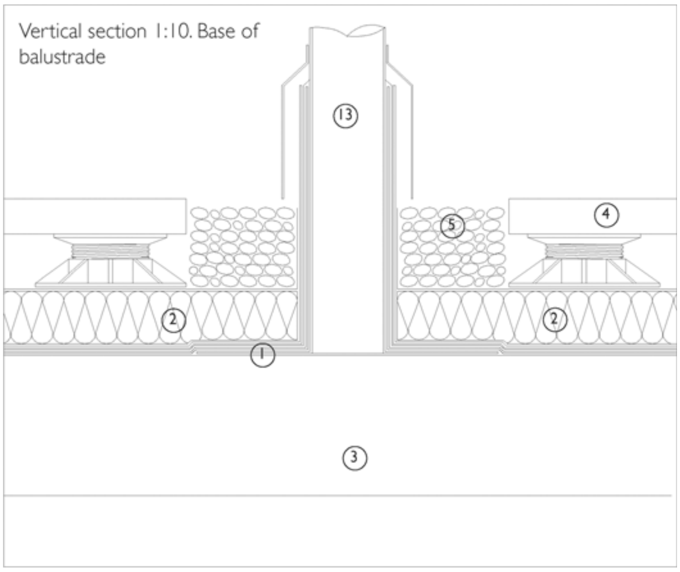


Vertical section 1:10. Junction of external wall and roof slab

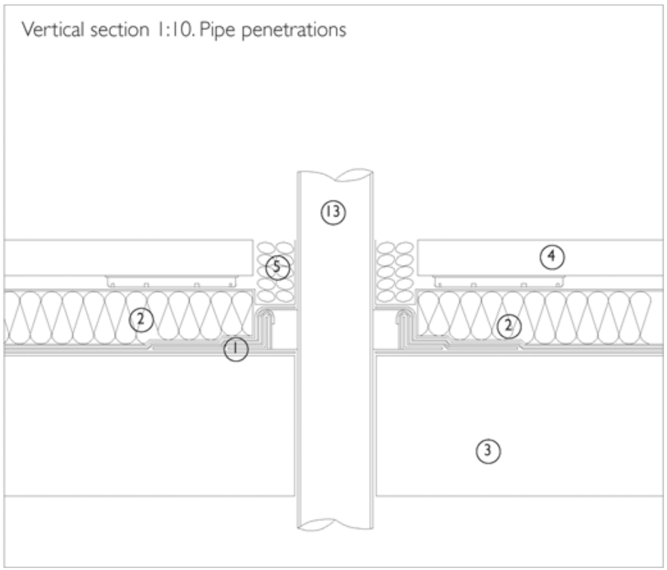


Vertical section 1:10. Base of balustrade

Vertical section 1:10. Base of balustrade



Vertical section 1:10. Pipe penetrations



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

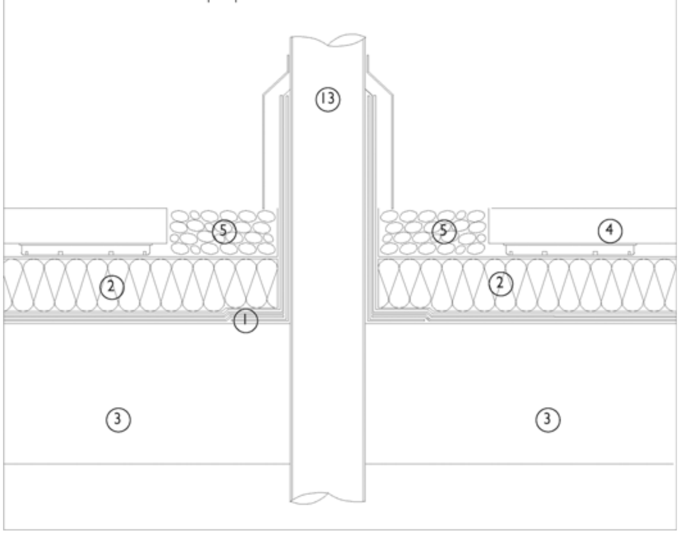
detail, is wrapped around the balustrade post below the level of the paving.

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. Some configurations incorporate 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.

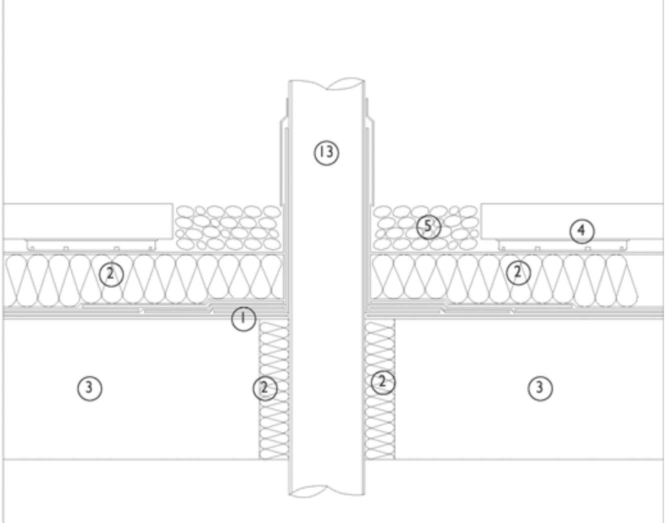
Rainwater outlets

Some rainwater outlets are set at the level of the waterproof membrane, whereas other roof configurations are drained at both the level of the sealed paving and the level of the waterproofing layer. The base of the rainwater outlet can alternatively be 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. The rainwater outlet could be fixed in the same way, but in this case the cover would be much lower, since rainwater is drained only at the edges of the cover, and not through its full height. The filter sheet could also be 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

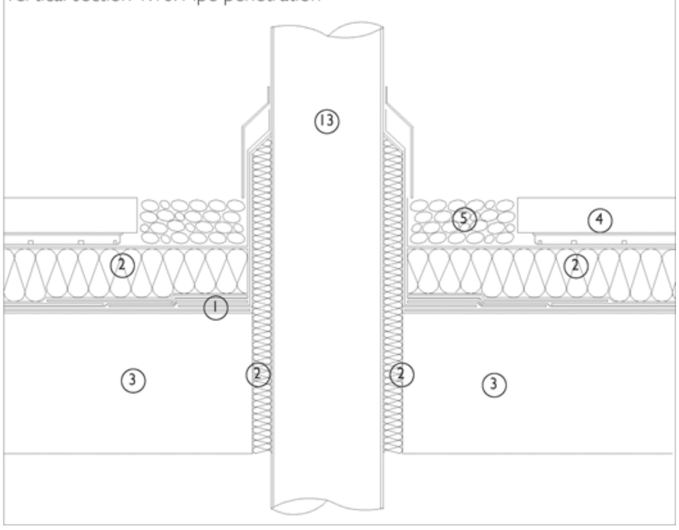
Vertical sSection 1:10. Pipe penetration

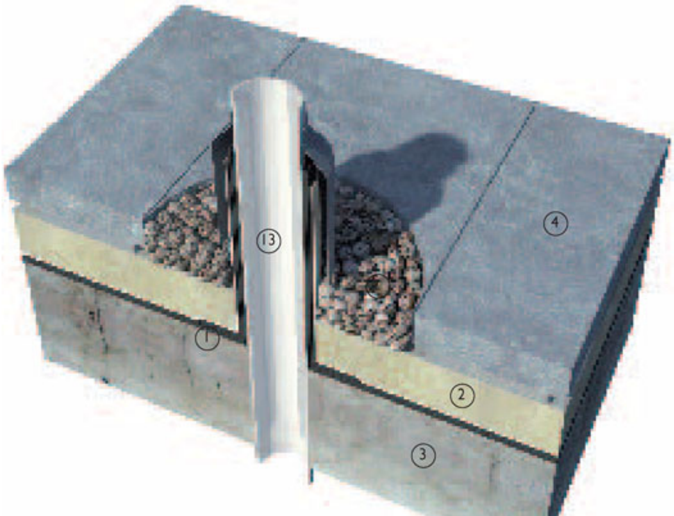


Vertical section 1:10. Pipe penetration



Vertical section 1:10. Pipe penetration





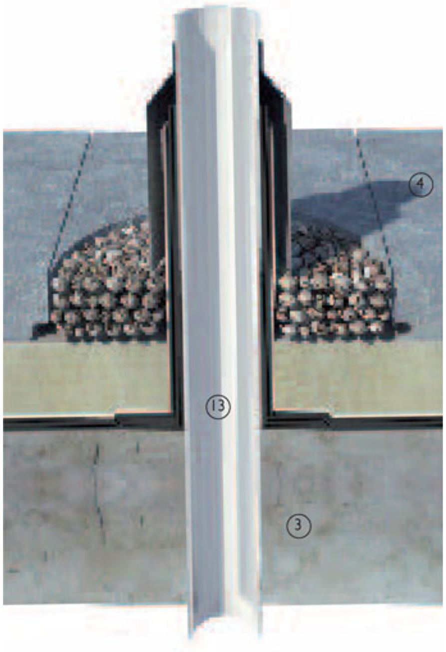
3-D section view showing pipe penetration in concrete roof with concealed membrane

immediately above to remove any debris that might collect in the gap between the rainwater outlet and the thermal insulation adjacent to it.

In other examples, the rainwater could be 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 two-way outlet is fixed in two parts. A 25mm gap is shown between the parapet wall and the edge of the paving slab to allow rainwater to drain into the outlet.

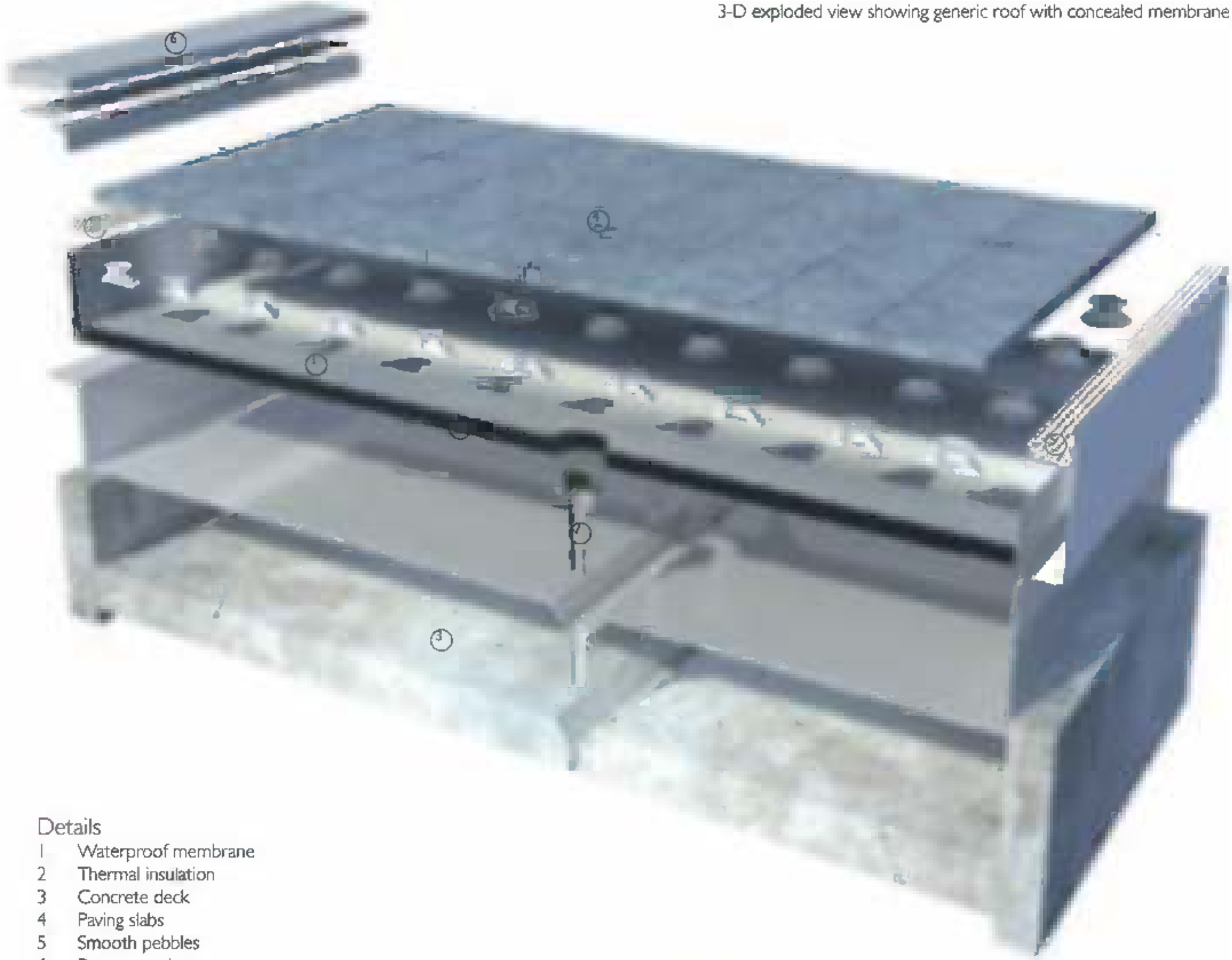
Penetrations for pipes and ducts

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. In some siutations, 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. The pipe flashing detail can allow the pipe to be both thermally insulated and independent of the enclosing sealed sleeve.

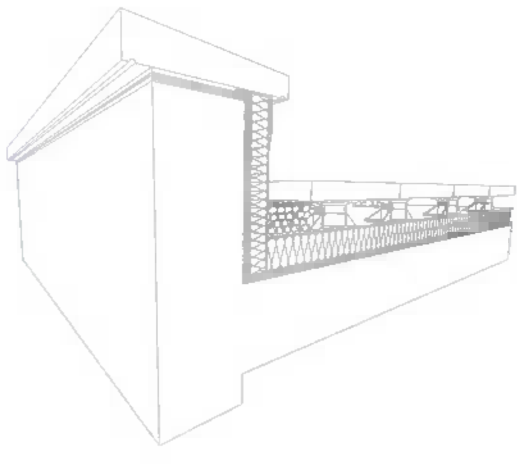


3-D section view showing pipe penetration in concrete roof with concealed membrane

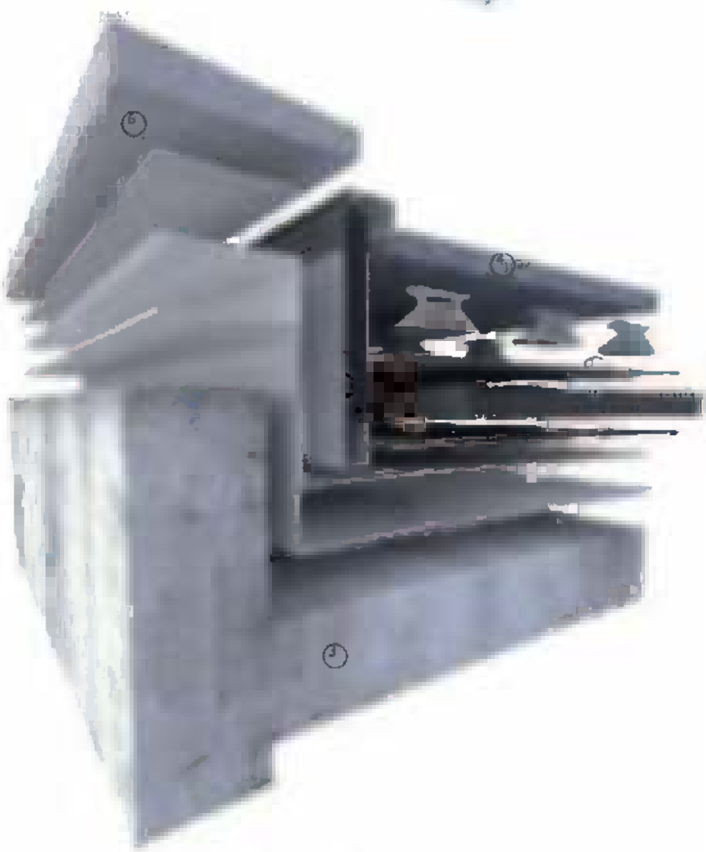
3-D exploded view showing generic roof with concealed membrane



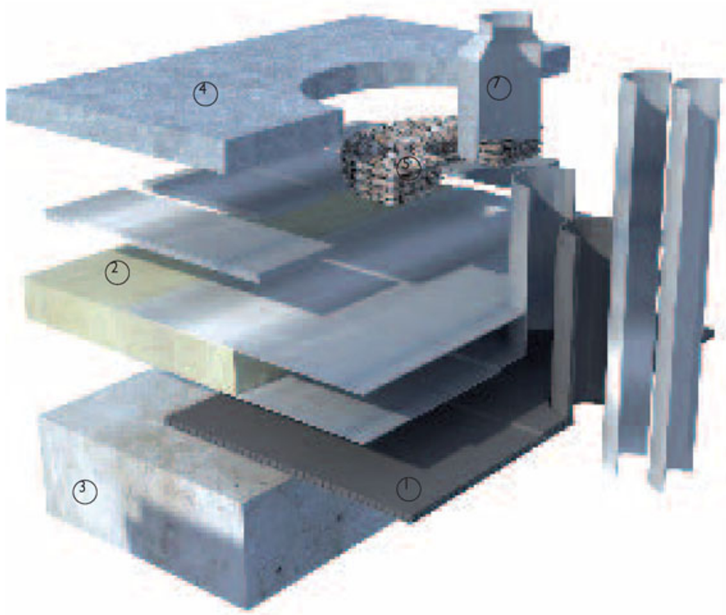
Details
1 Waterproof membrane
2 Thermal insulation
3 Concrete deck
4 Paving slabs
5 Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Slot drain
9. Opening for overflow
10. Reinforcement at fold if required
11. Proprietary movement joint
12. Balustrade
13. Pipe or duct
14. Filter sheet



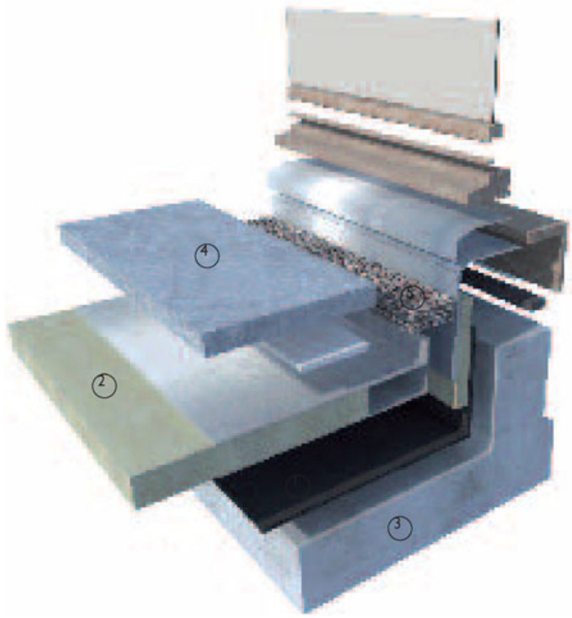
3-D view showing parapet condition on concrete roof with concealed membrane



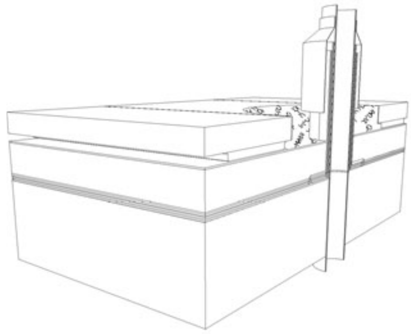
3-D exploded view showing parapet condition on concrete roof with concealed membrane

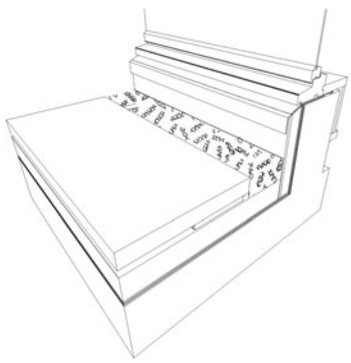


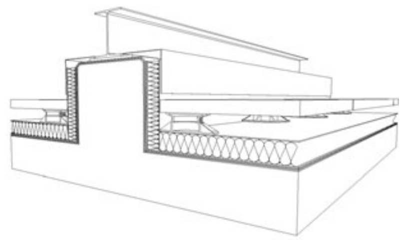
3-D exploded view showing pipe penetration in concrete roof with concealed membrane



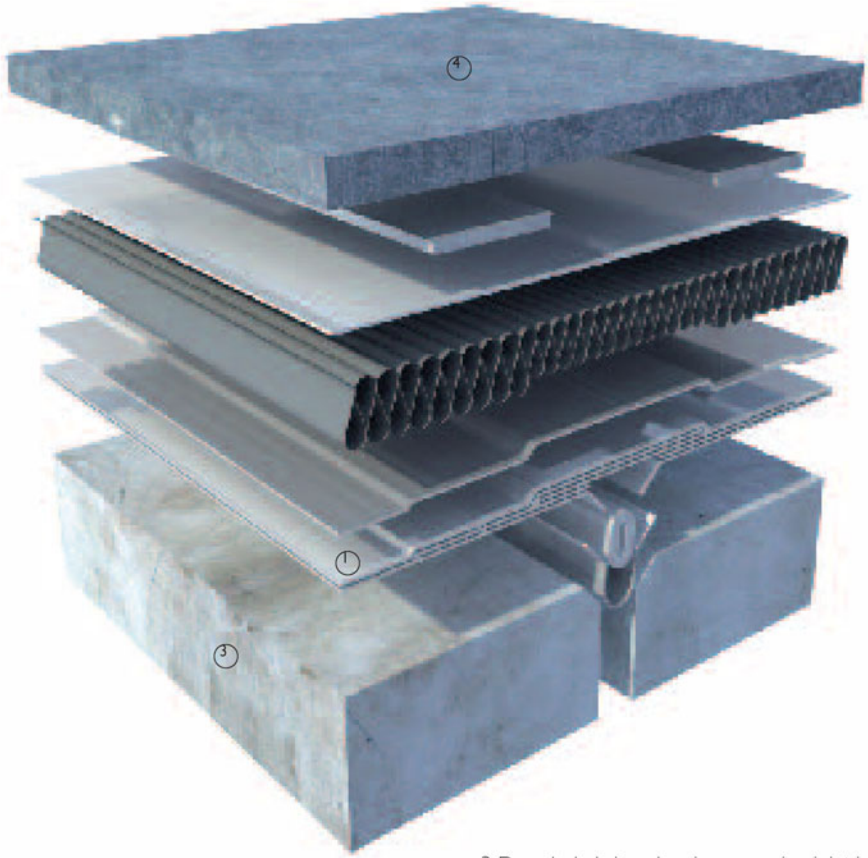
3-D exploded view showing door cill junction on concrete roof with concealed membrane



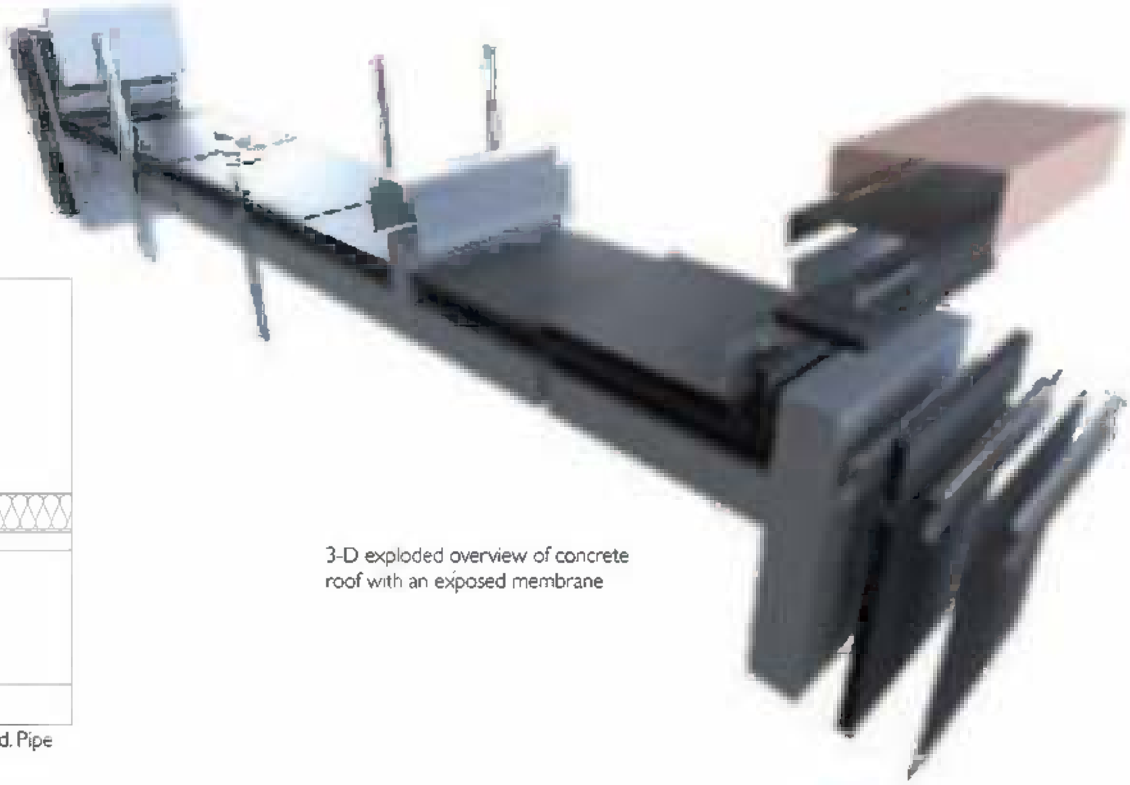




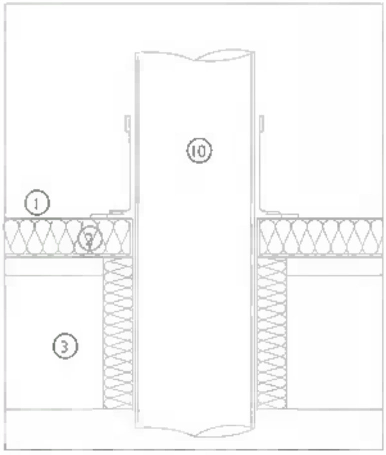
3-D exploded view showing upstand condition on concrete roof with concealed membrane



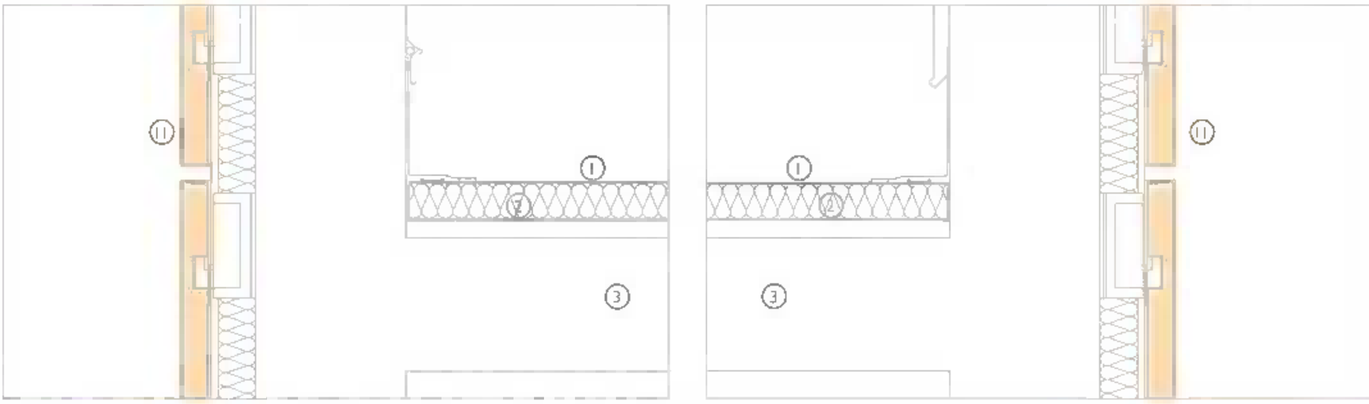
3-D exploded view showing expansion joint in concrete roof with concealed membrane



3-D exploded overview of concrete roof with an exposed membrane



Vertical section 1:10. Bonded method. Pipe penetration

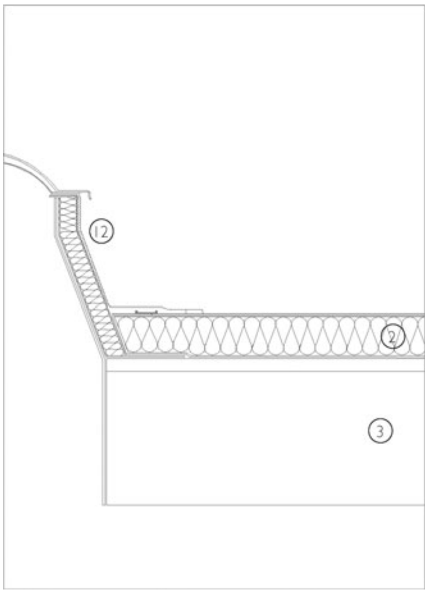


Vertical sections 1:10. Bonded method. Junctions of external wall and roof slab

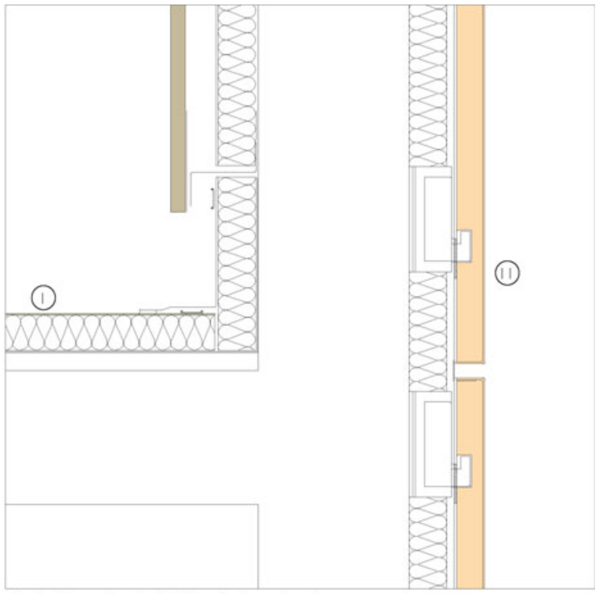
3-D view of junction of external wall and roof slab

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

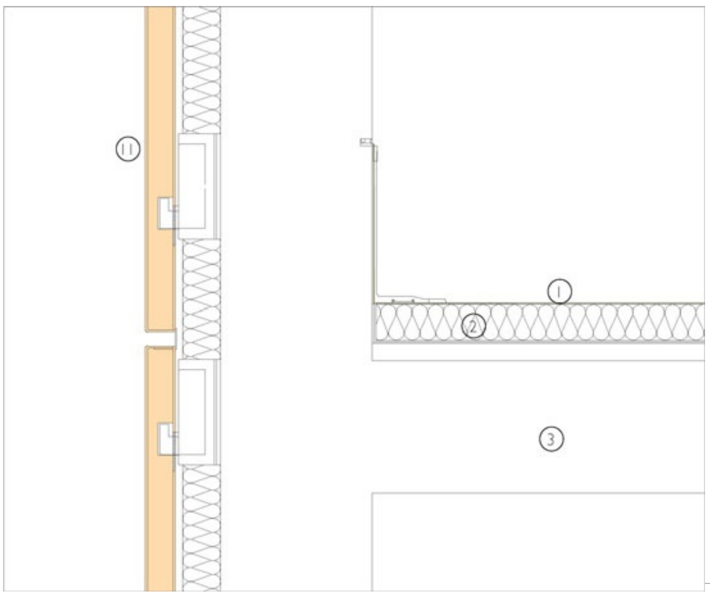


Vertical section 1:10. Bonded method.
Junction with rooflight



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

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



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

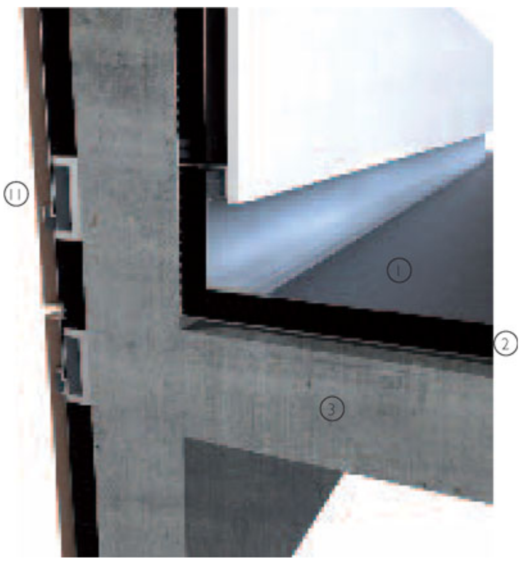
3-D view of junction between external wall and roof slab

weakness of these materials was partially overcome by introducing added sacrificial layers. Although this had the advantage of reducing the 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.

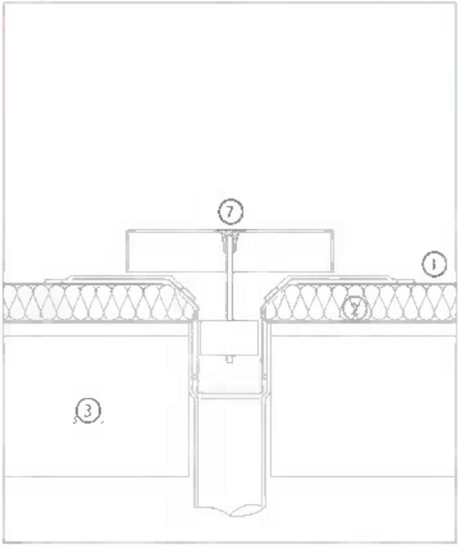
The introduction of polymer-based membranes provided economic waterproofing materials that were more flexible than their bitumen-based predecessors. First introduced in the 1960s and 1970s, they became much more widely used in the 1980s and 1990s. The increased flexibility of the new sheet materials 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

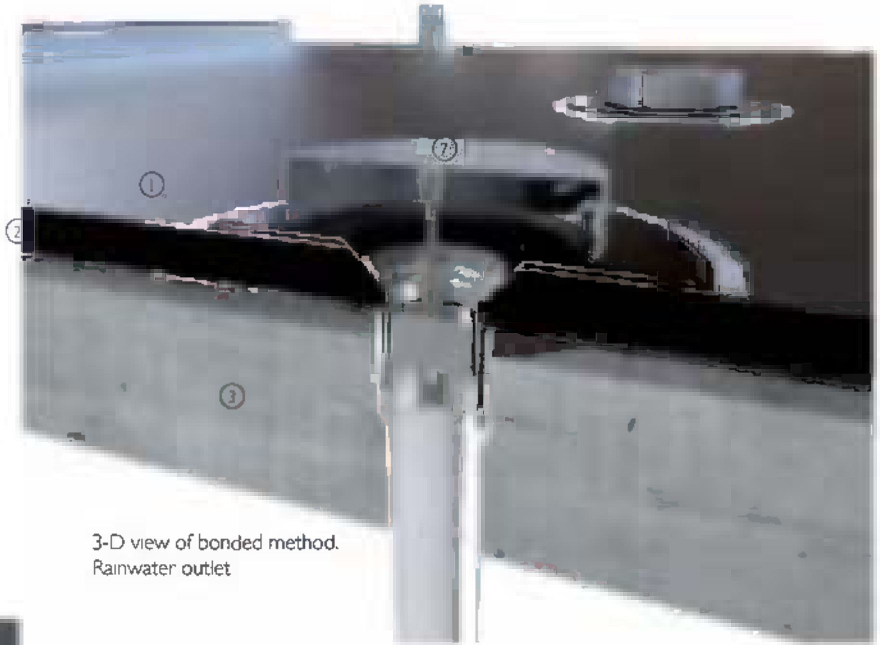
The main advantage of the polymer-based sheet materials is their ability to be cut and formed to complex shapes, allowing them to take up shapes precisely, sometimes pre-formed in the factory before being delivered to site. Single layer membranes are very practical on roofs with a large number of penetrations,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



3-D detail view of junction between external wall and roof slab

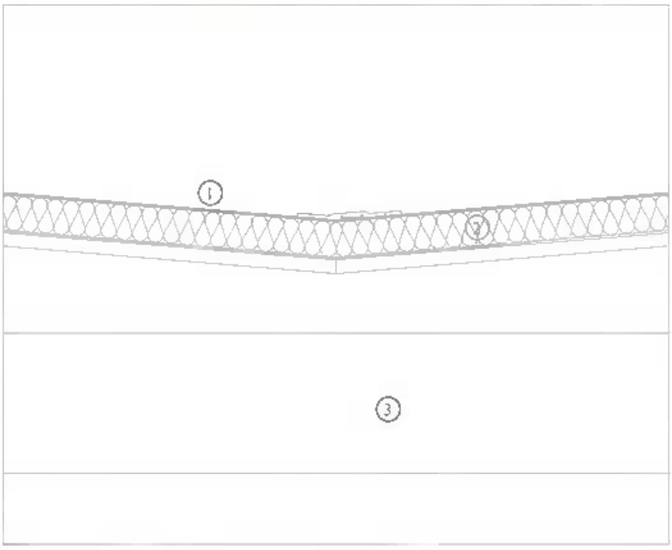


Vertical section 1:10. Bonded method. Rainwater outlet

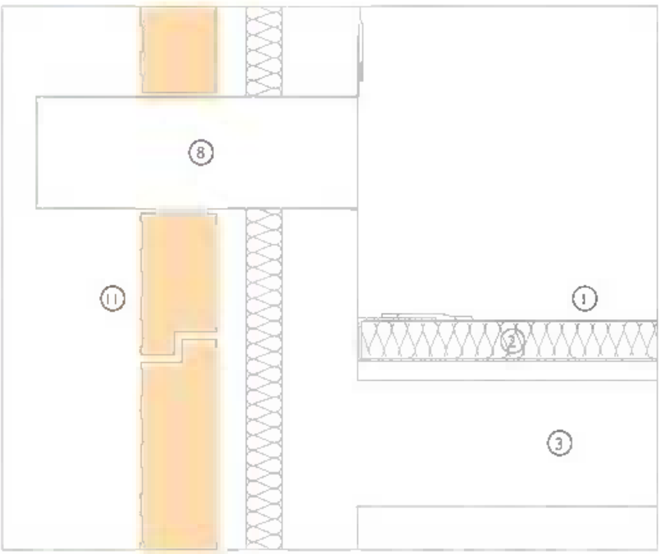


3-D view of bonded method.
Rainwater outlet

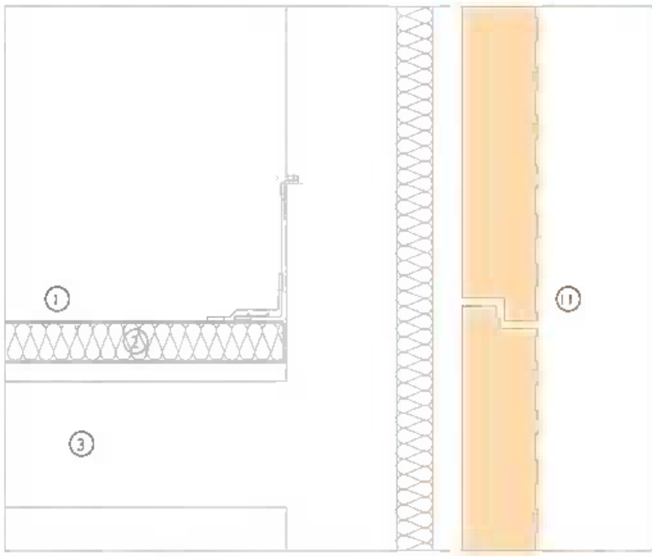
3-D view of bonded method. Rainwater outlet



Vertical section 1:10. Bonded method. Roof fold



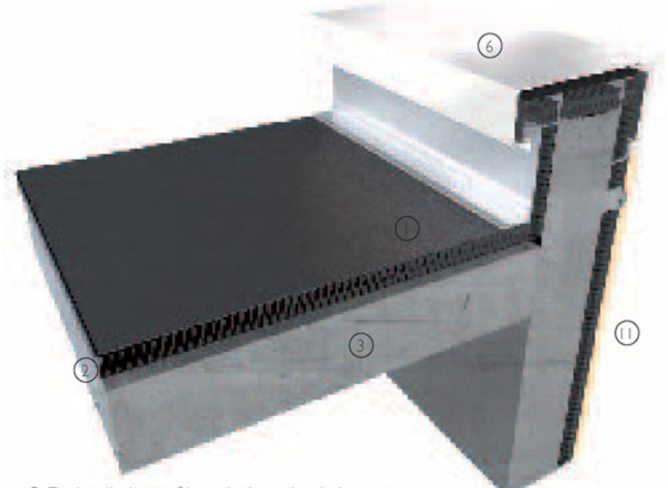
Vertical section 1:10. Mechanical fastening method. Roof overflow



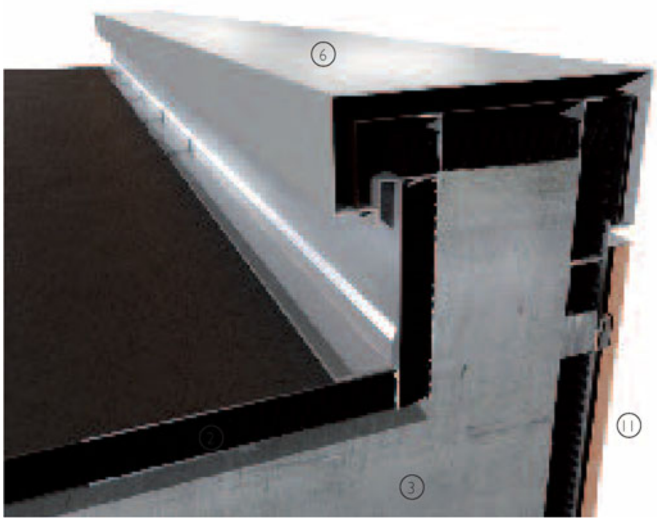
Vertical section 1:10. Mechanical fastening method. Junctions of external wall and roof slab

Details

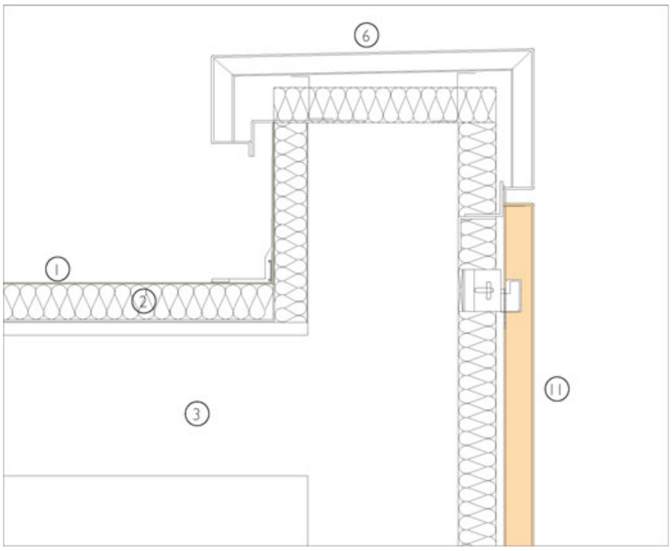
1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Opening for overflow
9. Balustrade
10. Pipe or duct
11. External wall
12. Rooflight



3-D detail view of bonded method. Low parapet.



3-D view of bonded method. Low parapet.



Vertical section 1:10. Bonded method. Low parapet

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 thermoplastics 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.

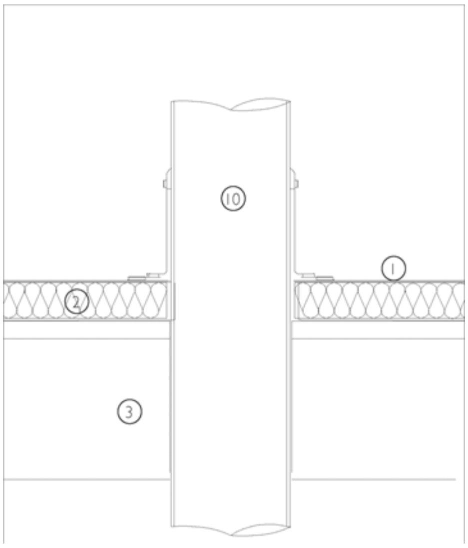
Both elastomers and thermoplastics can be mechanically fixed, bonded or secured with ballast to the concrete deck beneath. Developments in these materials have led to them being used on timber decks and profiled metal decks in addition to the concrete decks discussed here. Both thermoplastic and EPDM 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 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 1960s as a very lightweight and relatively economic roofing material, and have become widely used in recent years. Membranes in this material were first developed in Europe in the late 1960s and were used in the US from the 1970s onwards. PVC sheet material is usually reinforced with glass fibre to give it increased rigidity that is easier to bond to the substrate.

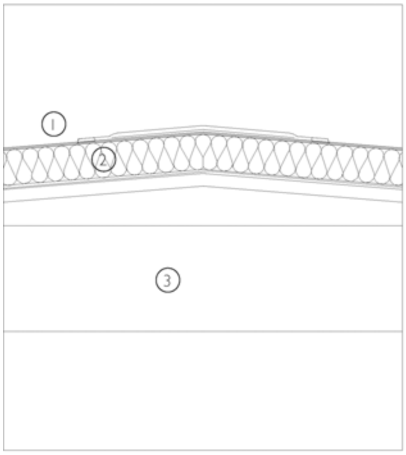
The PVC used in membranes is plasticised (PVC-P), unlike the unplasticised PVC (PVC-U, or uPVC) used to make window frames and rainwater drainage components. PVC-P is rigid at normal external temperatures, but softens when heated, making it flexible and allowing strips or sheets to be welded together 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 resulting in mechanical fixing methods being 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 are typically 1.5mm - 3.0mm thick, while EPDM membranes are typically 1.0mm - 1.5mm thick.

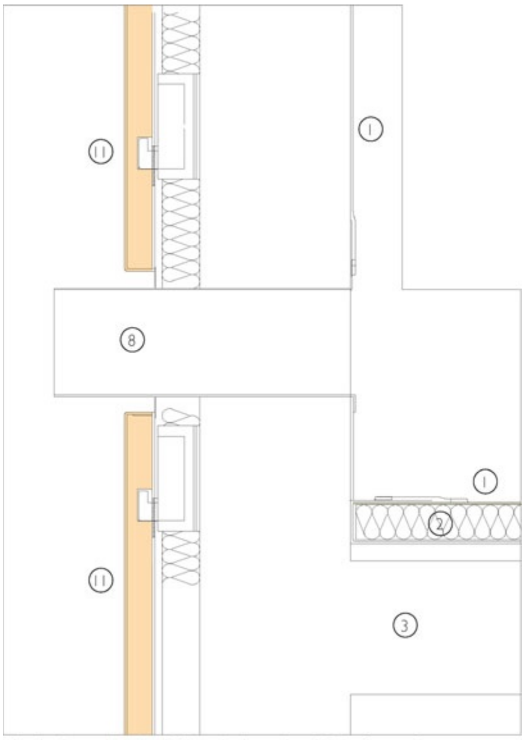


Vertical section 1:10. Bonded method. Pipe penetration

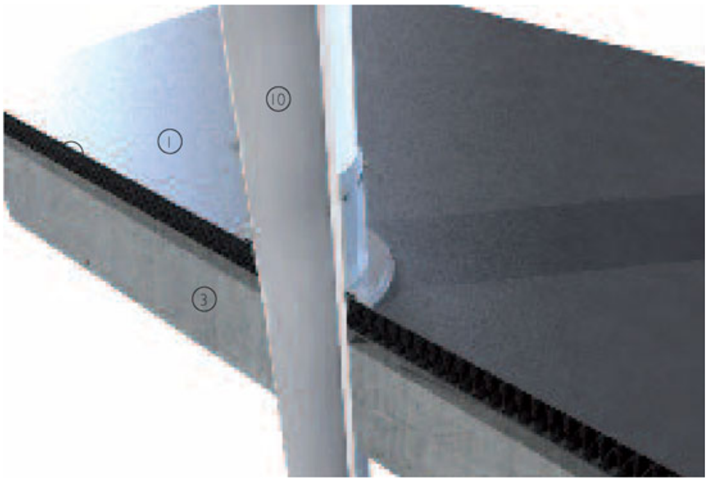
Details
1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Opening for overflow
9. Balustrade
10. Pipe or duct
11. External wall
12. Rooflight



Vertical section 1:10. Bonded method. Roof fold



Vertical section 1:10. Bonded method. Roof overflow



3-D view of bonded method. Pipe penetration

3-D view of bonded method. Pipe penetration

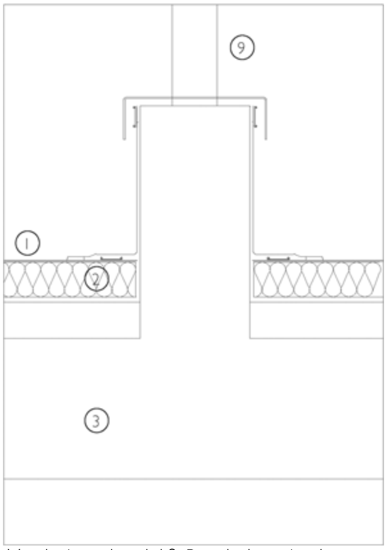
FPO (TPO) membranes

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 it is PVC-P which is self-extinguishing when flame is applied.

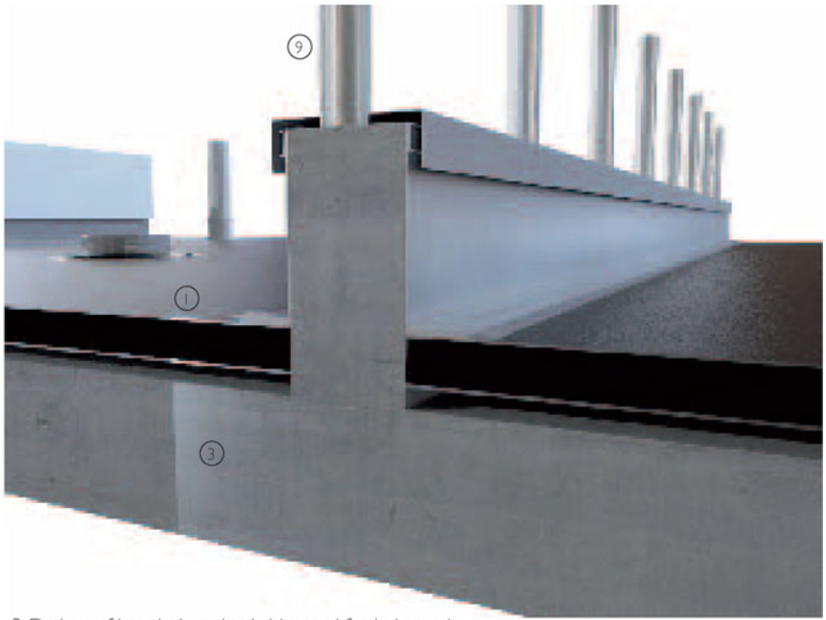
Mechanically fixed method

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.

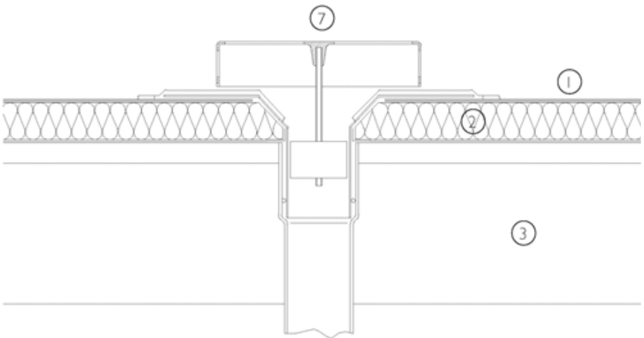
Membranes can also be secured by point fixings rather than by pressure plates. 50-75mm diameter rigid plastic discs are used to hold the build-up in place. These are



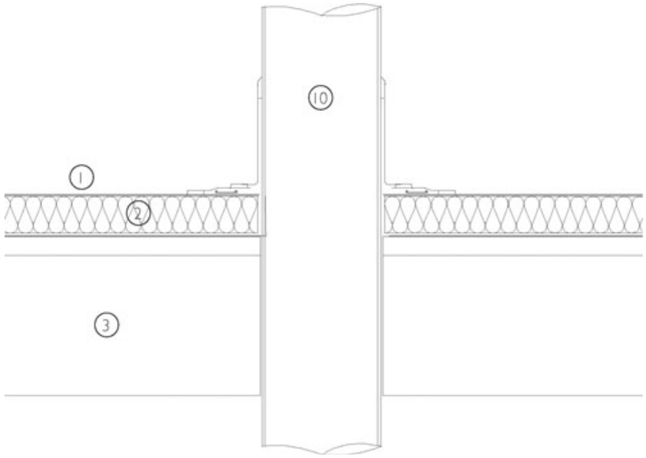
Vertical section 1:10. Bonded method.
Upstand for balustrade



3-D view of bonded method. Upstand for balustrade



Vertical section 1:10. Mechanical fastening method. Rainwater outlet



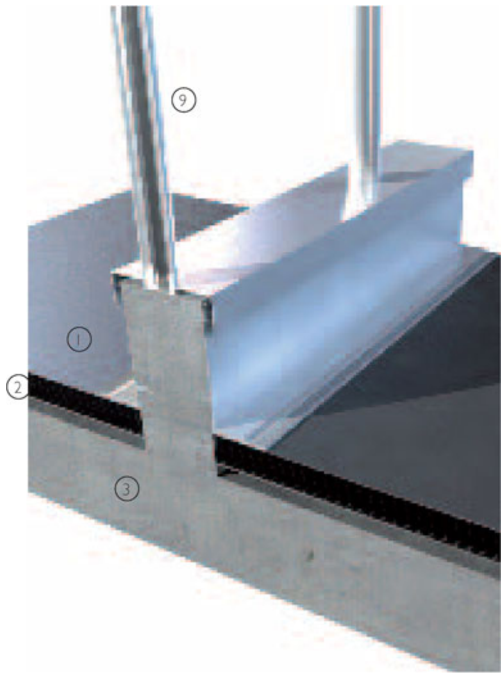
Vertical section 1:10. Mechanical fastening method. Pipe penetration

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 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.

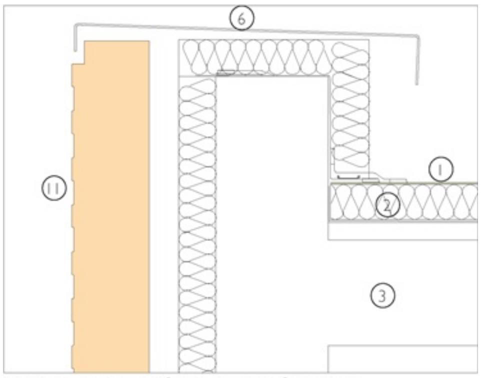
Bonded membranes have a visually smooth appearance, making it suitable where the roof surface is seen from points around the building. It can be more difficult to achieve the bonding required for high wind uplift conditions, but this is a matter of individual design. This fixing method still requires



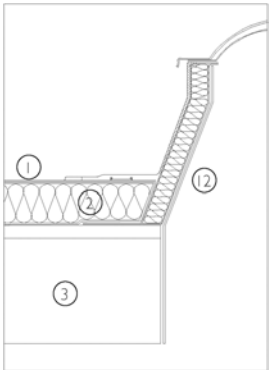
3-D view of bonded method. Upstand for balustrade

Details

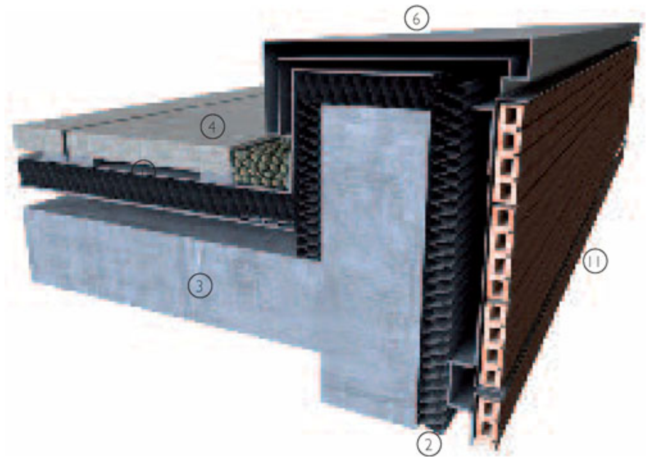
1. Waterproof membrane
2. Thermal insulation
3. Concrete deck
4. Paving slabs
5. Smooth pebbles
6. Parapet coping
7. Rainwater outlet
8. Opening for overflow
9. Balustrade
10. Pipe or duct
11. External wall
12. Rooflight



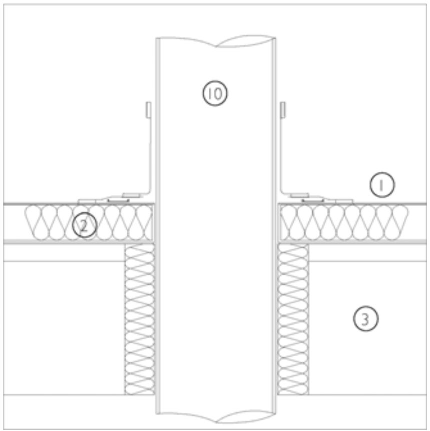
Vertical section 1:10. Mechanical fastening method. Low parapet



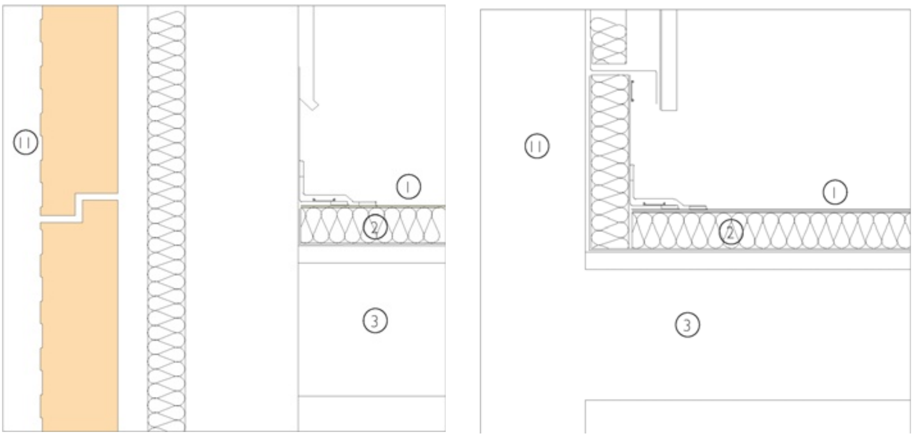
Vertical section 1:10. Mechanical fastening method. Junction with rooflight



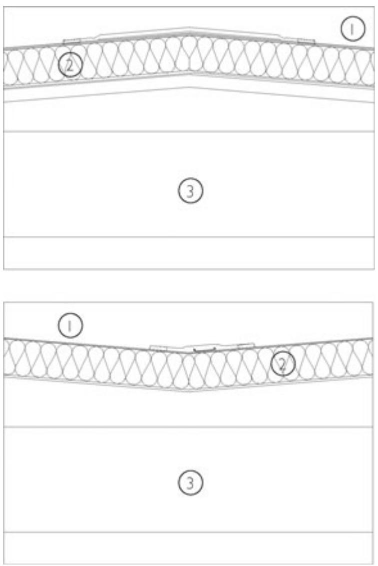
3-D view of low parapet on exposed membrane concrete roof with ballast



Vertical section 1:10. Mechanical fastening method. Pipe penetration



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



Vertical sections 1:10. Mechanical fastening method. Roof fold

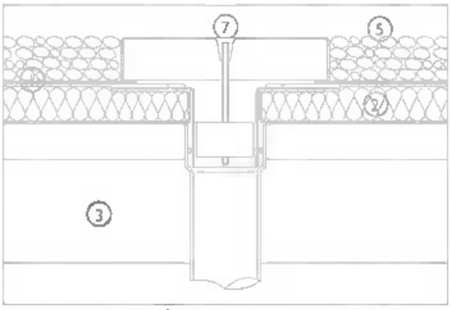
mechanical fixing at the edges, and around openings such as rooflights.

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.

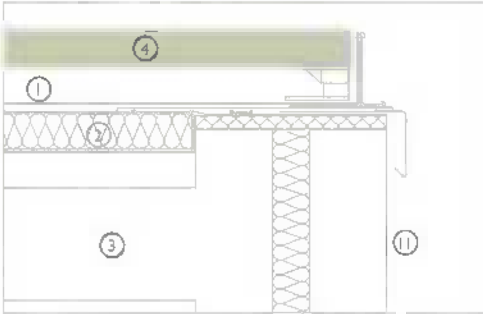
Ballasted roofs

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.

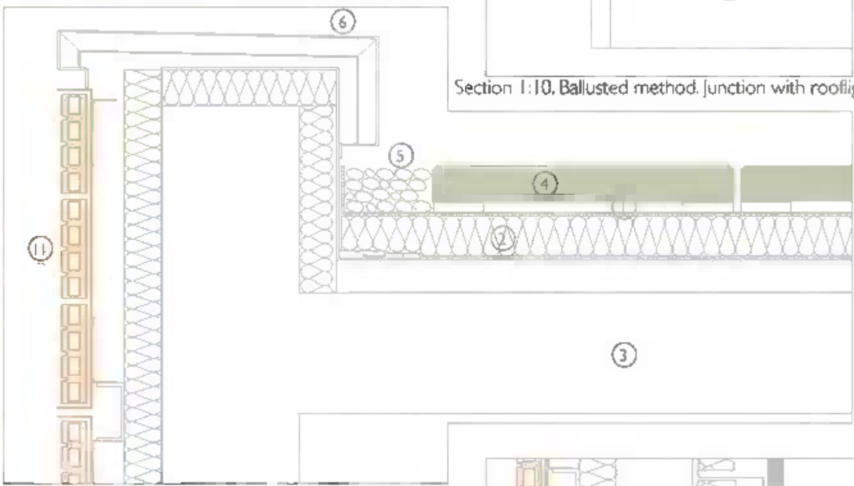


Vertical section 1:10. Ballusted method. Rainwater outlet

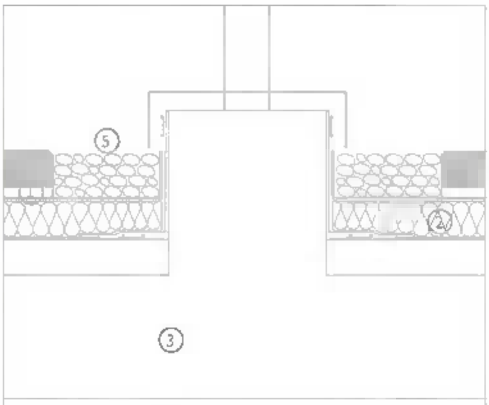
Section 1:10. Ballusted method. Junction with rooflight



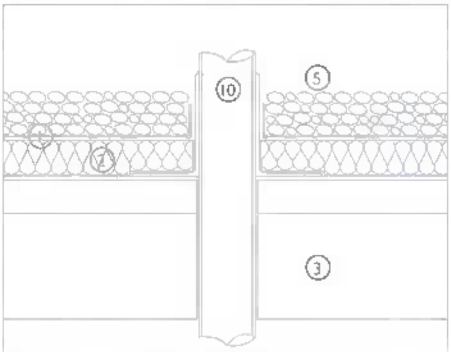
Vertical section 1:10. Ballusted method. Eaves



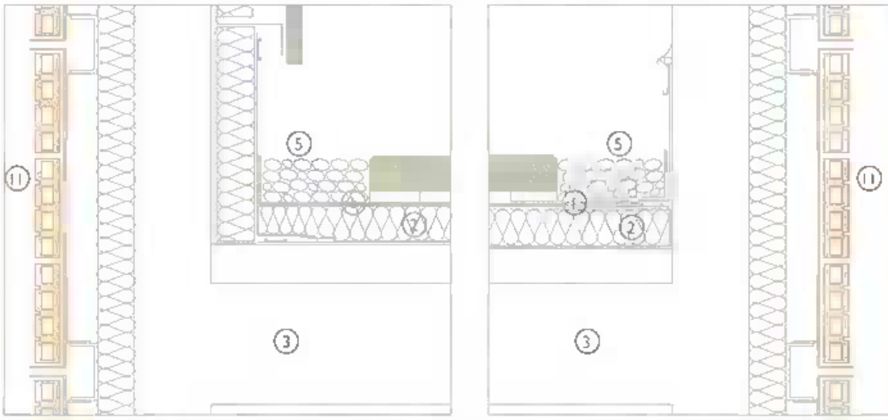
Vertical section 1:10. Ballusted method. Low parapet



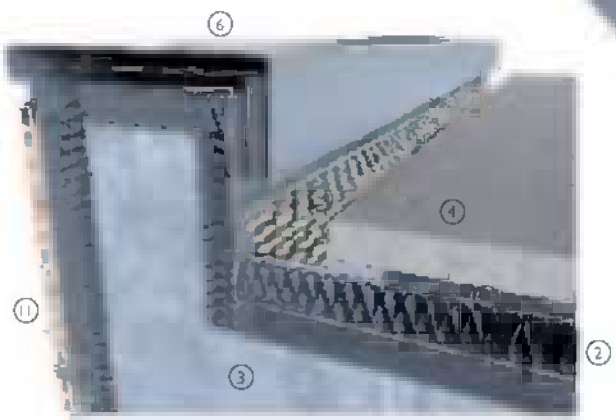
Vertical section 1:10. Ballusted method. Upstand for balustrade



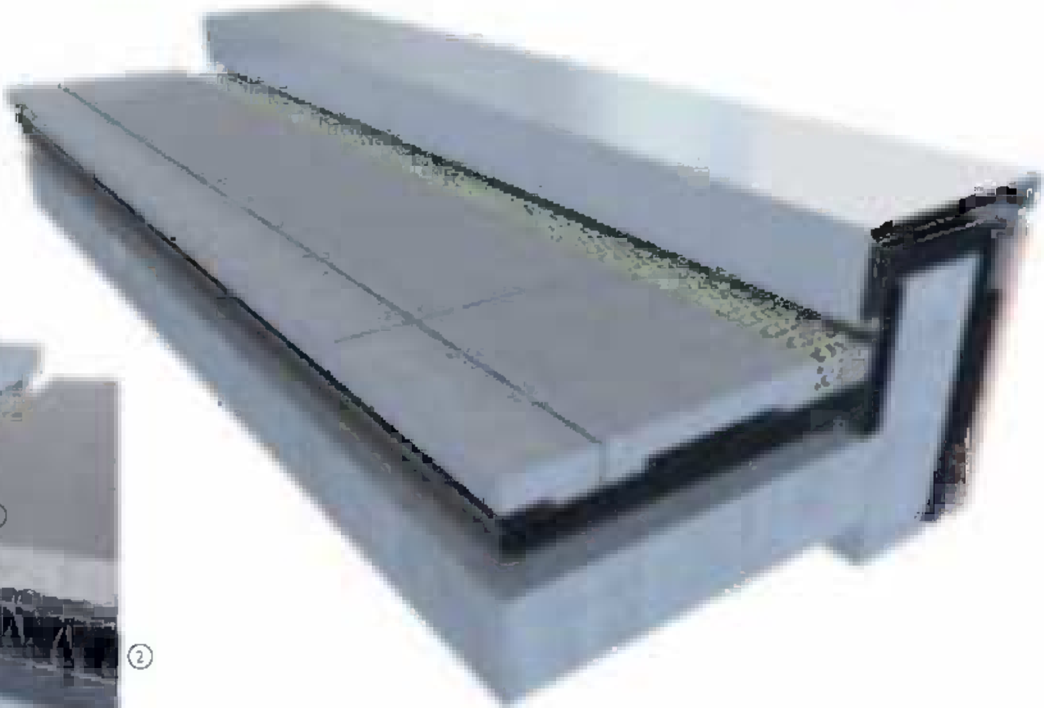
Vertical section 1:10. Ballusted method. Pipe penetration



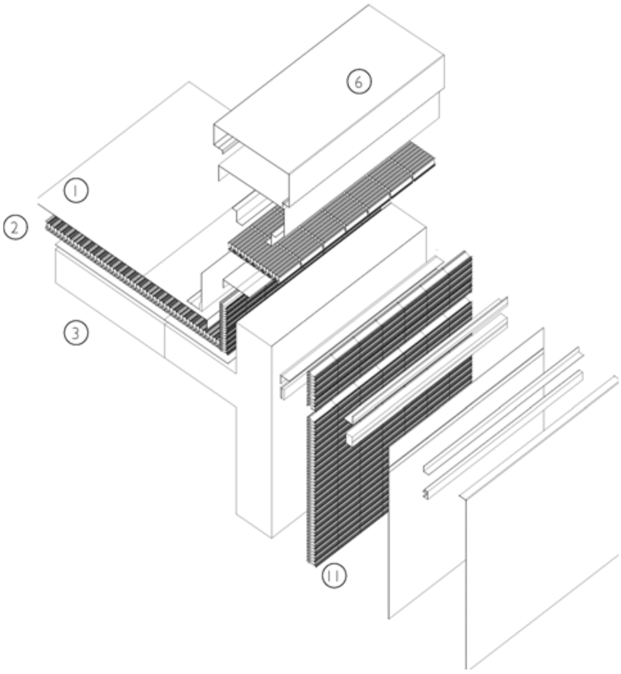
Vertical sections 1:10. Ballusted method. Junctions of external wall and roof slab



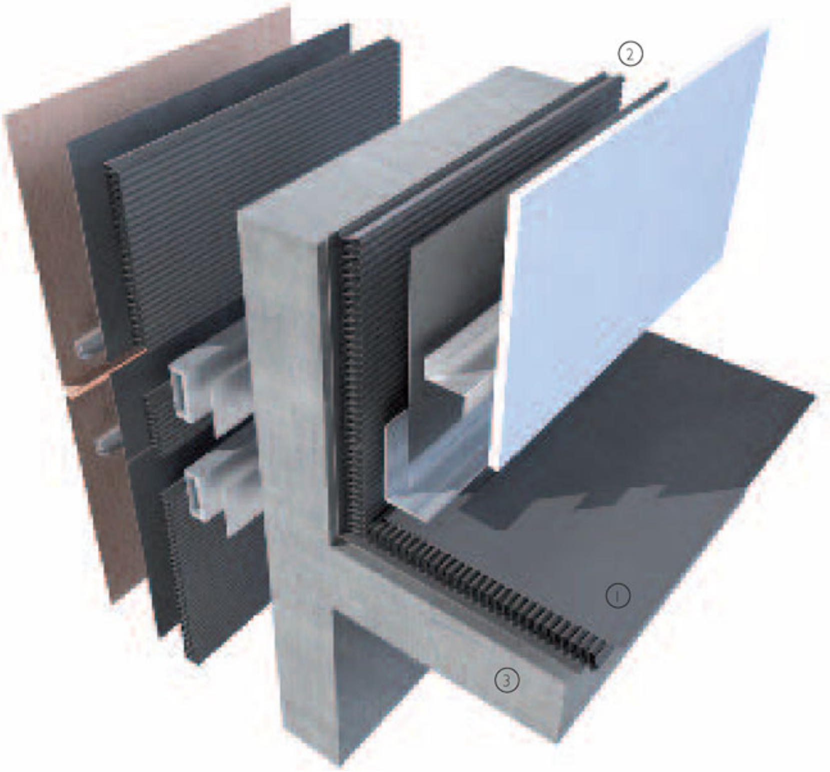
3-D view of exposed membrane concrete roof with ballast


3-D view of exposed membrane concrete roof with ballast

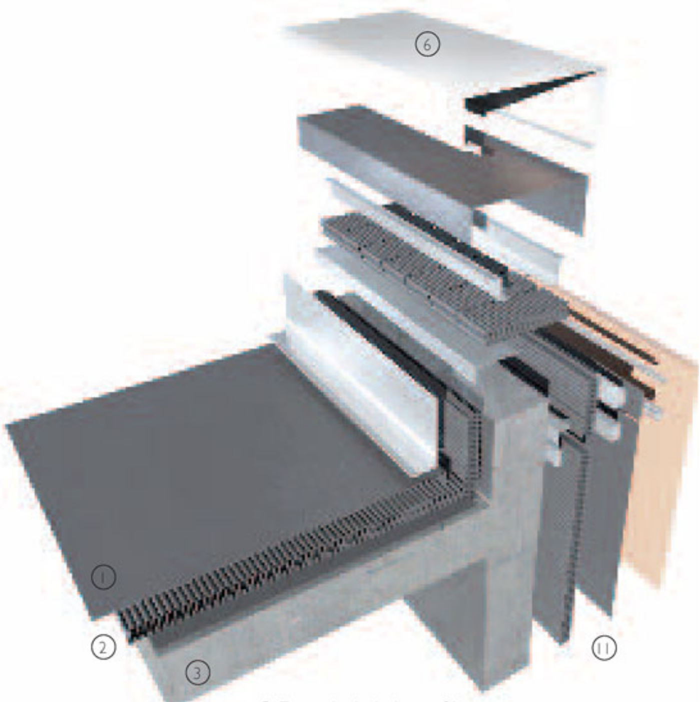
3-D exploded overview of concrete roof with an exposed membrane



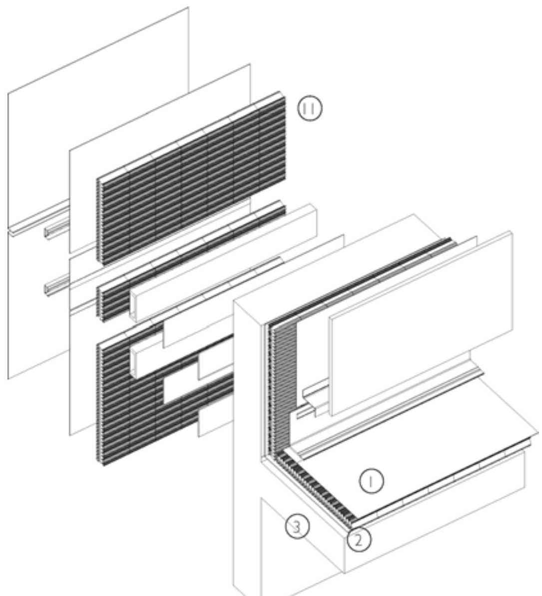
Exploded axonometric view of junction between roof slab and external wall



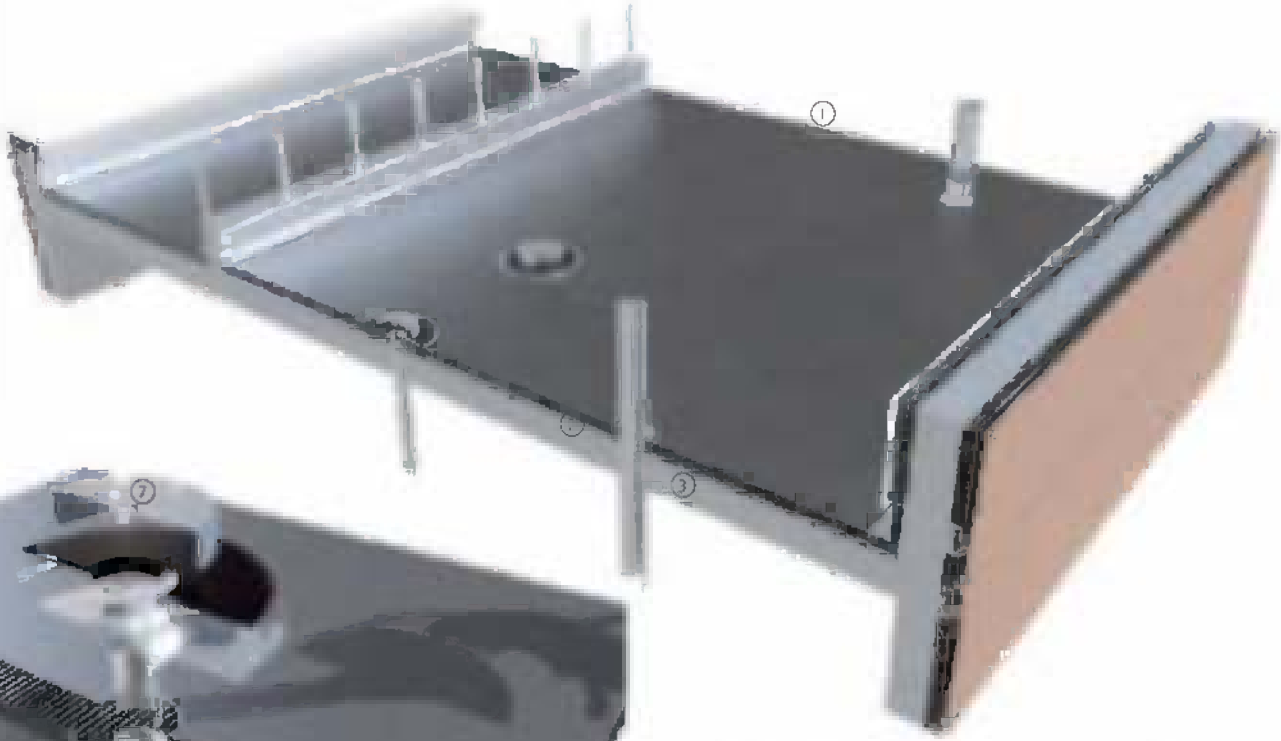
3-D exploded view of junction between roof slab and external wall



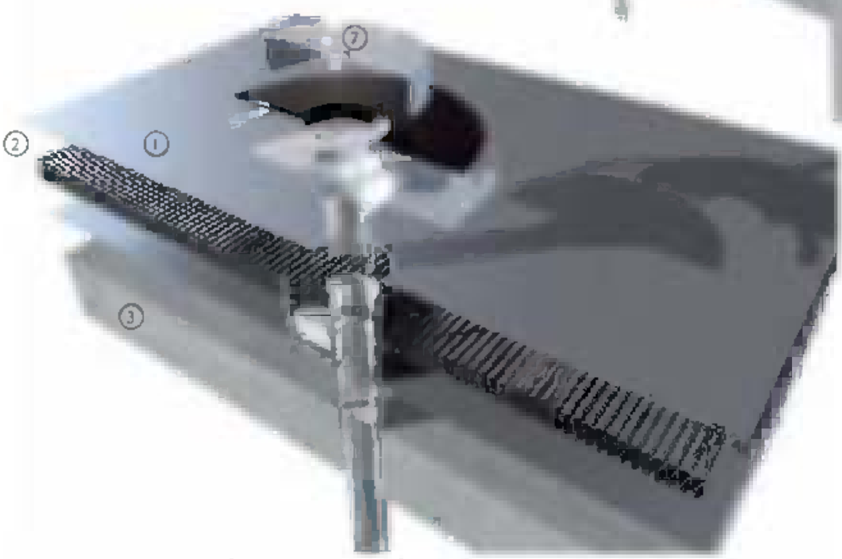
3-D exploded view of low parapet



Exploded axonometric view of low parapet

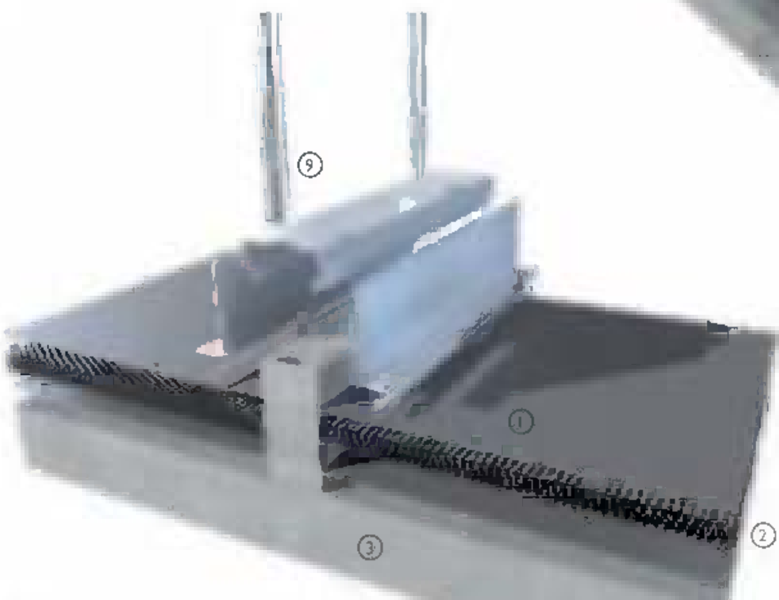


3-D overview of concrete roof with an exposed membrane



3-D exploded view of rainwater outlet within exposed membrane roof

3-D exploded view of pipe penetration

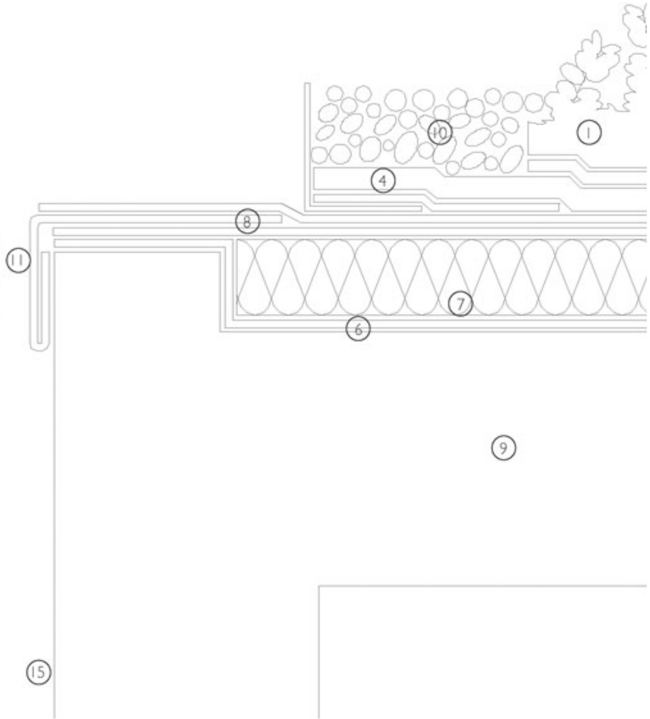


3-D exploded view of upstand with railings

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

3-D overview of concrete roof with light (sedum) planting



Vertical section 1:5. Parapet condition in lightly planted roof

System design

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 flowers 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 avoid the need to walk across the planting.

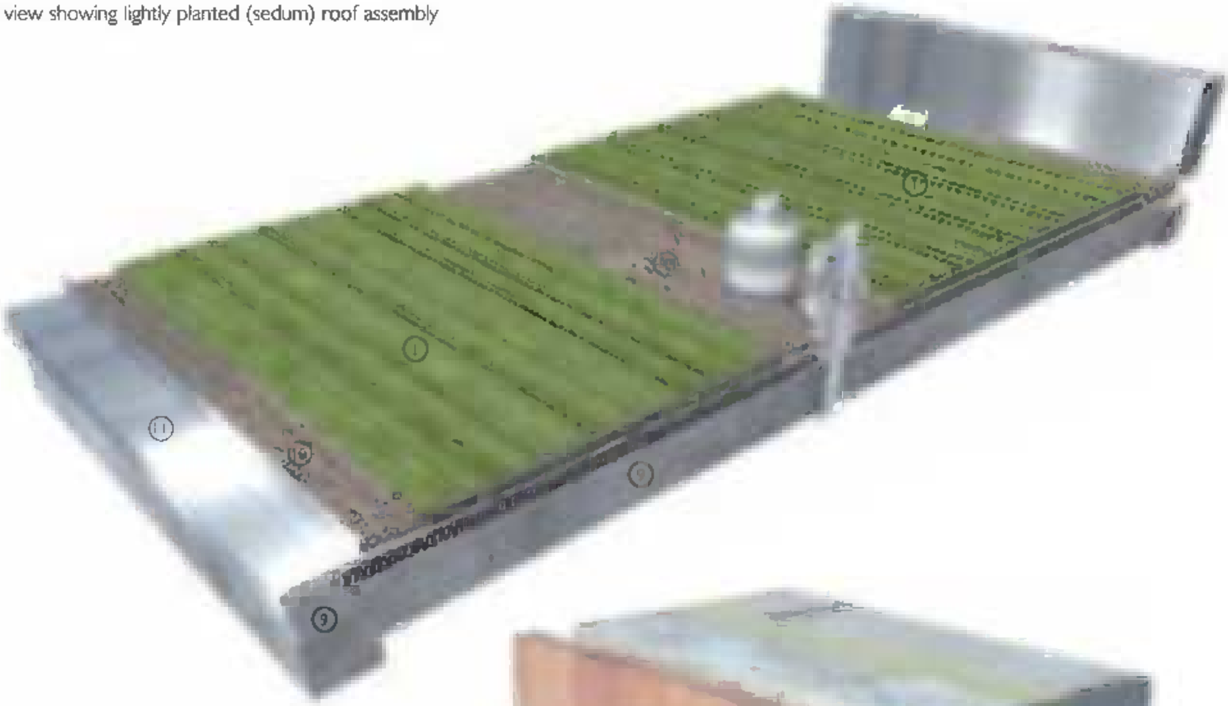
Heavy planted roofs permit a wide variety of plants, shrubs and trees to grow on a concrete roof deck. Due to the size and intensity of the planting they require an automated irrigation system, usually from pipes set into the soil that provide a trickle water feed to the soil at specific times which 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 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

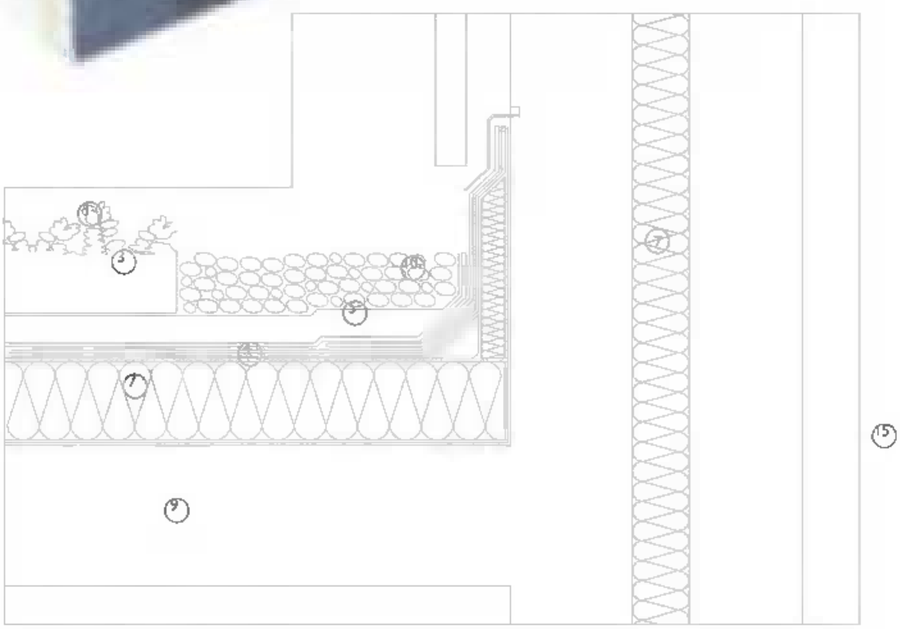
Both light planted and heavy planted roofs have a similar build-up, comprising typically a top layer of planting, with a growing medium or soil beneath. A filter layer is set underneath, and below this, a drainage layer and moisture mat. Beneath this lowest layer is set thermal insulation if required.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

3-D view showing lightly planted (sedum) roof assembly

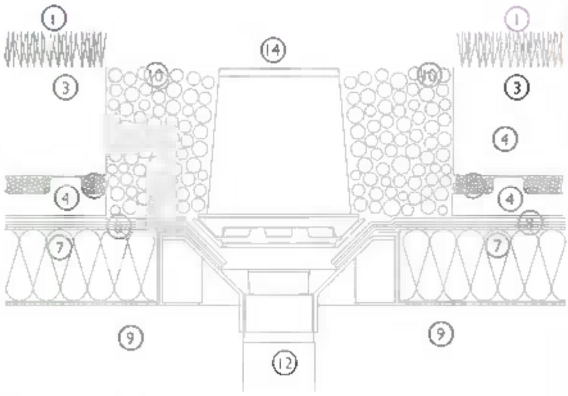


3-D view showing parapet junction in heavily planted roof

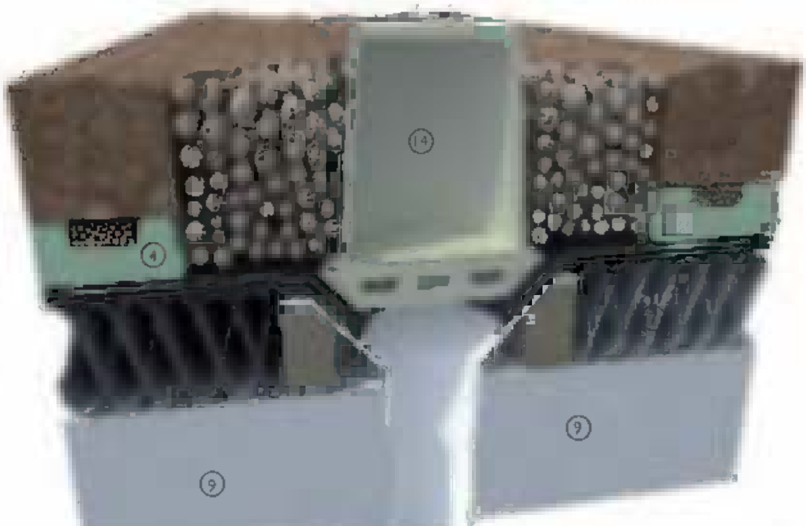
Details
1. Light vegetation
2. Heavy vegetation
3. Soil / growing medium
4. Filter sheet
5. Drainage layer
6. Waterproofing layer
7. Thermal insulation
8. Vapour barrier
9. Concrete deck
10. Smooth gravel
11. Coping
12. Pipe / duct
13. Supply pipe
14. Rainwater outlet
15. Wall cladding



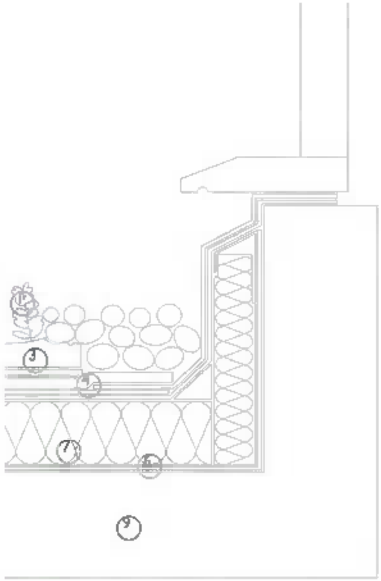
Vertical section 1:10. Light planting. Parapet junction



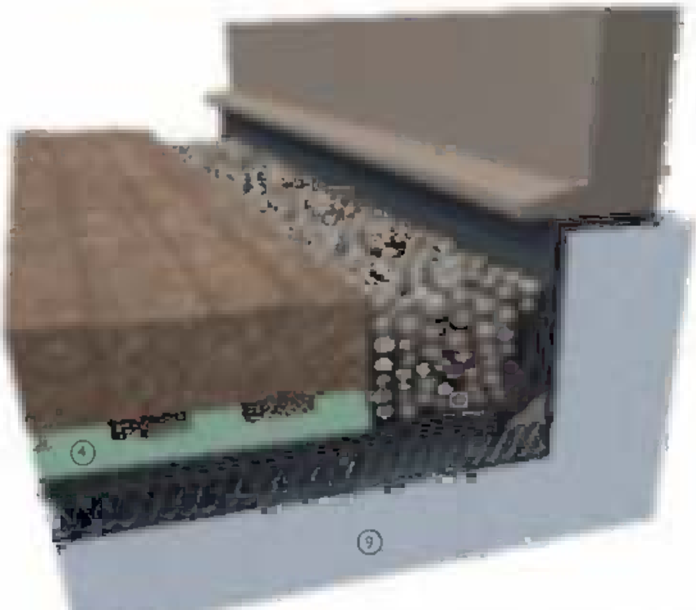
Vertical section 1:10. Light planting. Rainwater outlet



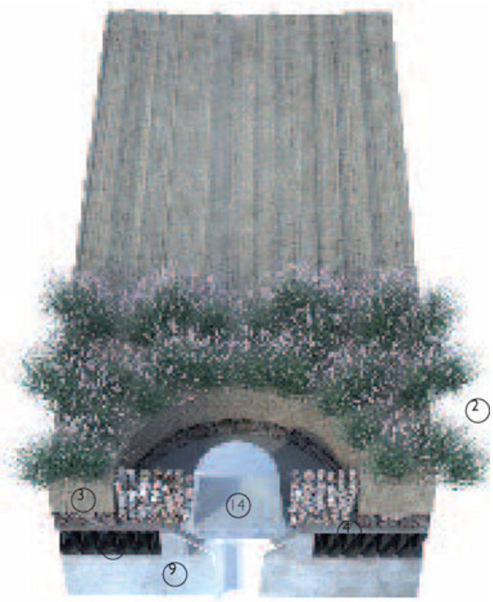
3-D detail of rainwater outlet in lightly planted roof



Vertical section 1:10 Junction between lightly planted roof and door cill



3-D detail of cill junction in heavily planted roo



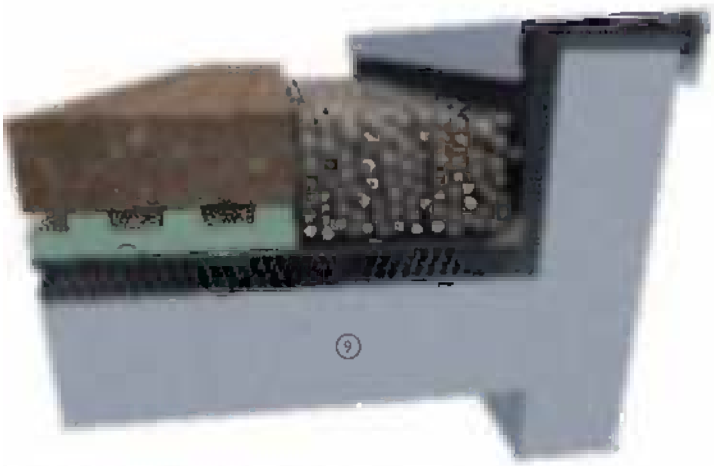
3-D detail showing rainwater outlet in planted roof

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.

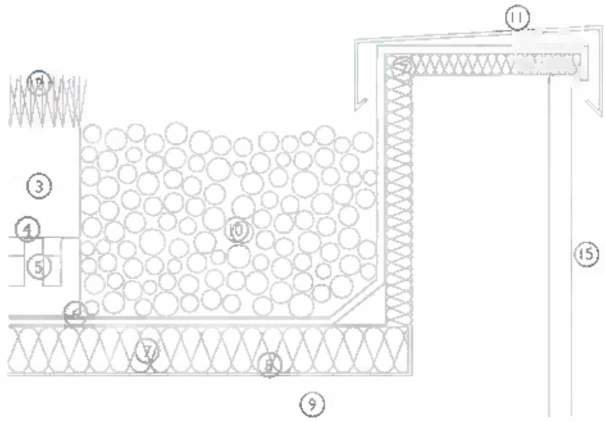
To prevent the passage of organic matter and fine particles into the water drainage system, a filter sheet is set underneath the planting. This sheet is lapped up the sides of the planting, where it meets an upstand, to the level of the planting.

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 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

-D overview of concrete roof with heavy planting



D detail of parapet junction in heavily planted roof



Vertical section 1:10 Heavy planting parapet

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.

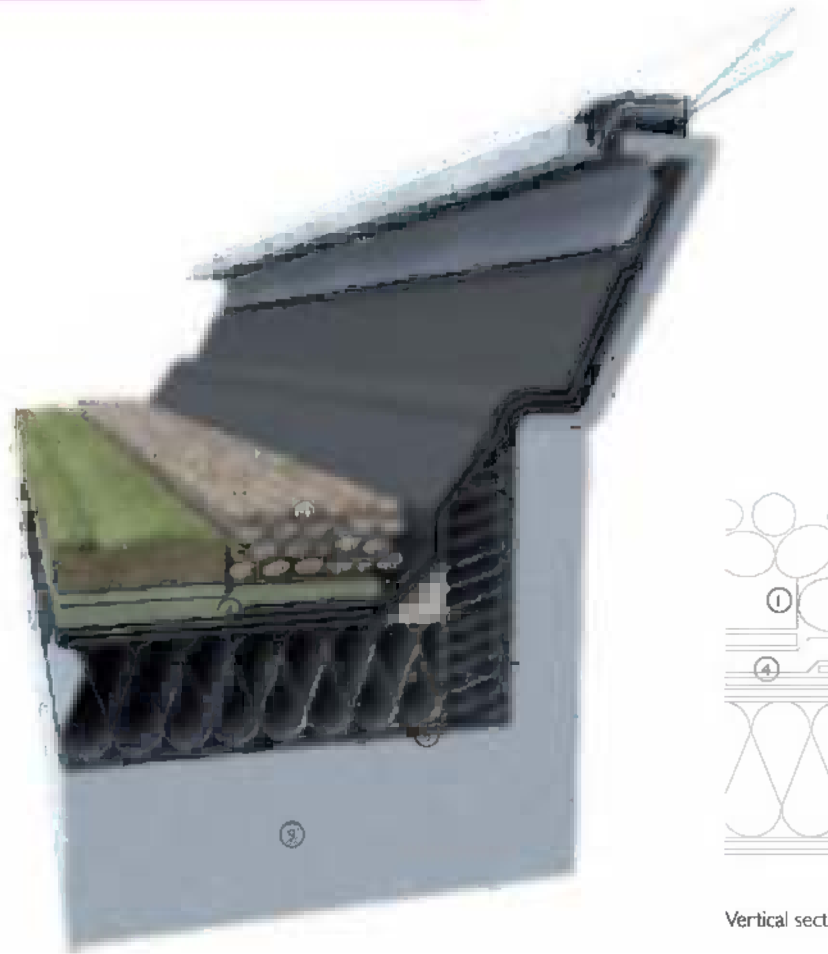
Soil depth

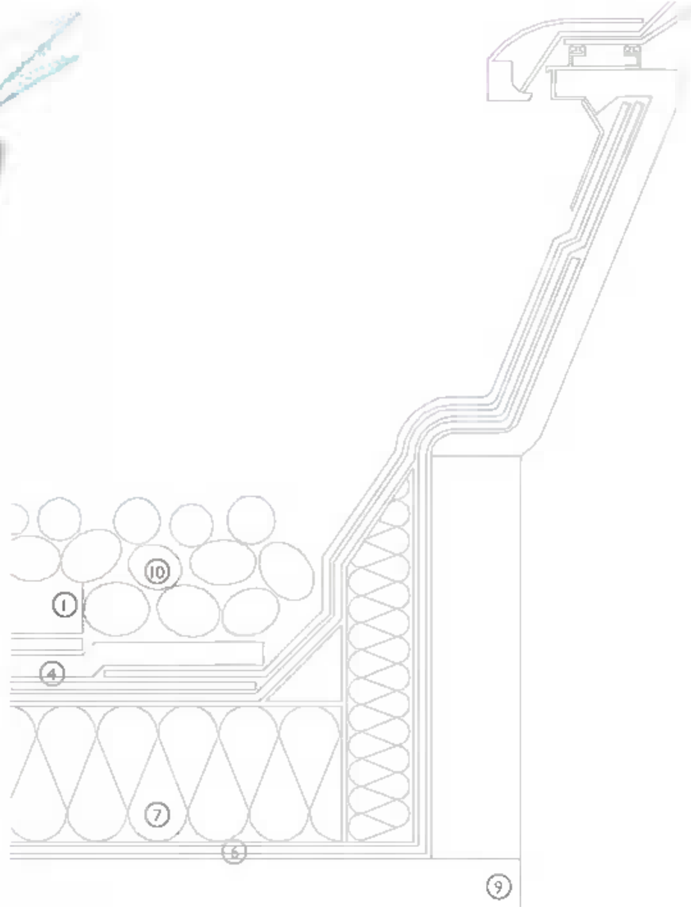
The soil depth in light planted roofs ranges from 50mm to around 150mm, weighing a minimum of around 70kg/m^2 of roof area. Water is stored in the growing medium and drainage layer, making it efficient in mild, temperate climates. Light planted roofs can be grown on both nominally flat roofs and on sloping 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.

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





Vertical section 1:5. Light planting to rooflight junction

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 falls, 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 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 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, particularly 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.

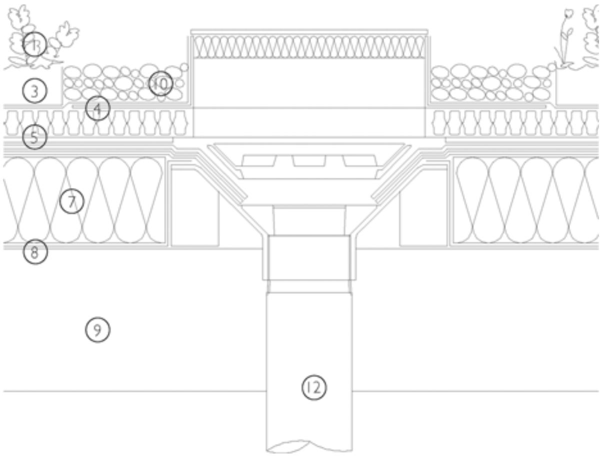
Vegetation barriers are provided at roof perimeters, upstands, duct penetrations and rainwater outlet points to avoid damage to the adjacent construction that would be caused by plants. Pebbled strips with a minimum width of 300mm are used, with river washed pebbles of 16mm to 32mm diameter.

Rainwater outlets

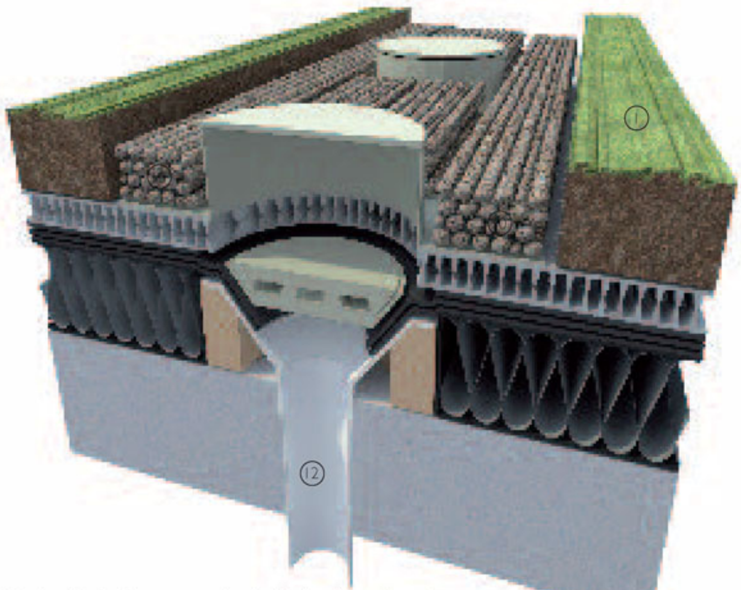
The filter layer is dressed up around the vertical edges of the rainwater outlets. An access cover is provided for maintenance purposes. Water drains at the level of the waterproof membrane, which is dressed into the base of the outlet.

Balcony planters

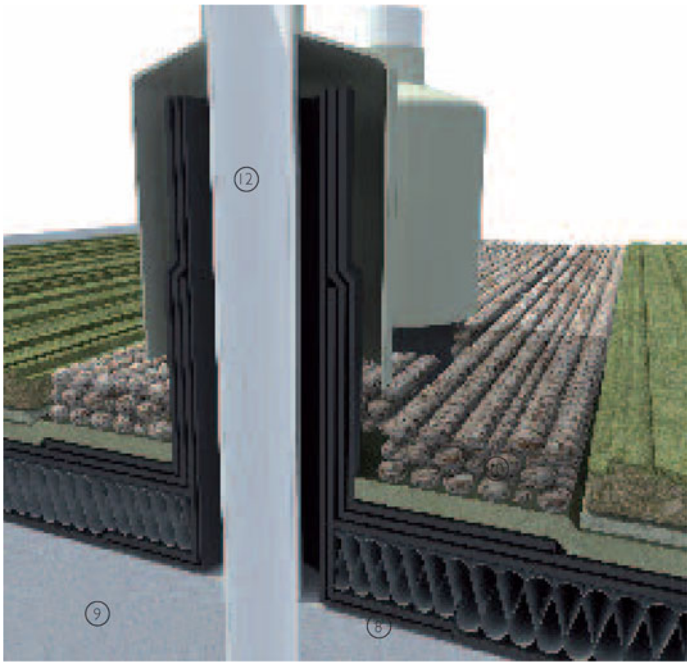
Planting troughs with automatic irrigation and a drainage system can be incorporated at roof level into curtain wall facades. In some



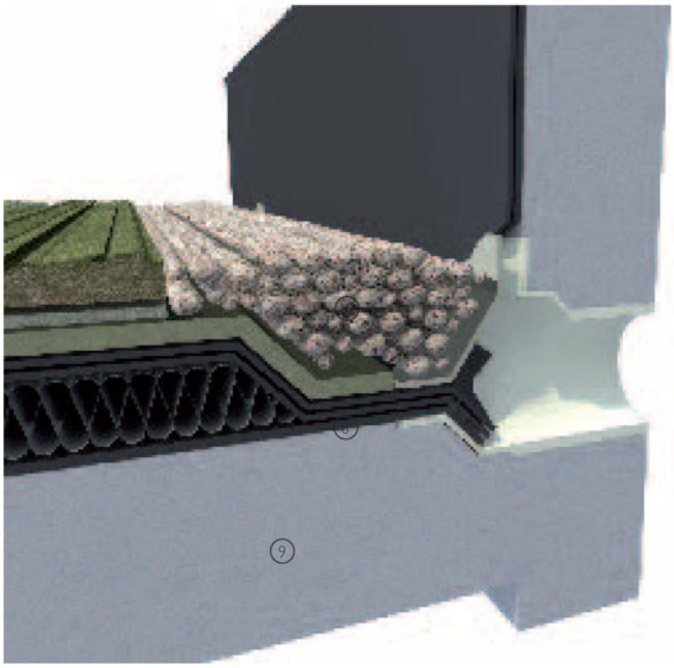
Vertical section 1:10. Rainwater outlet



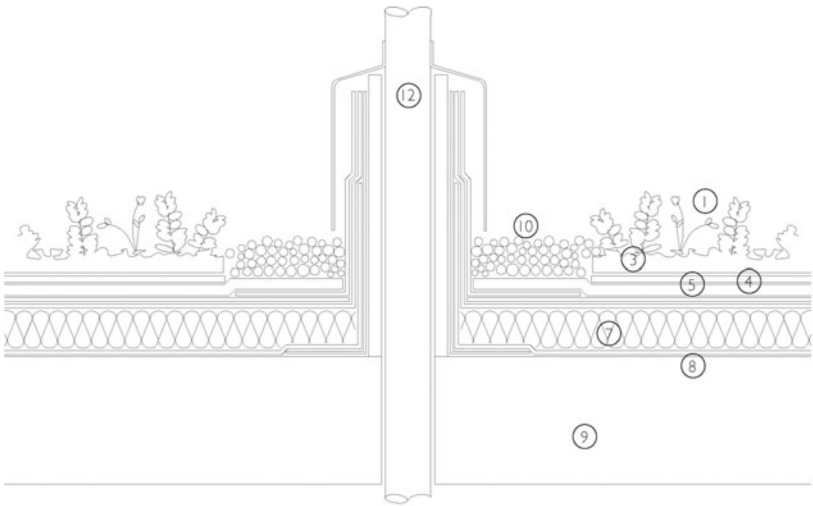
3-D detail of rainwater outlet in lightly planted roof



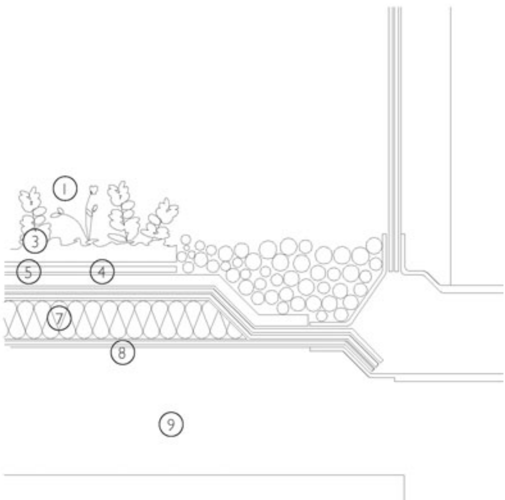
3-D detail of pipe penetration in lightly planted roof



3-D detail of two-way outlet in lightly planted roof

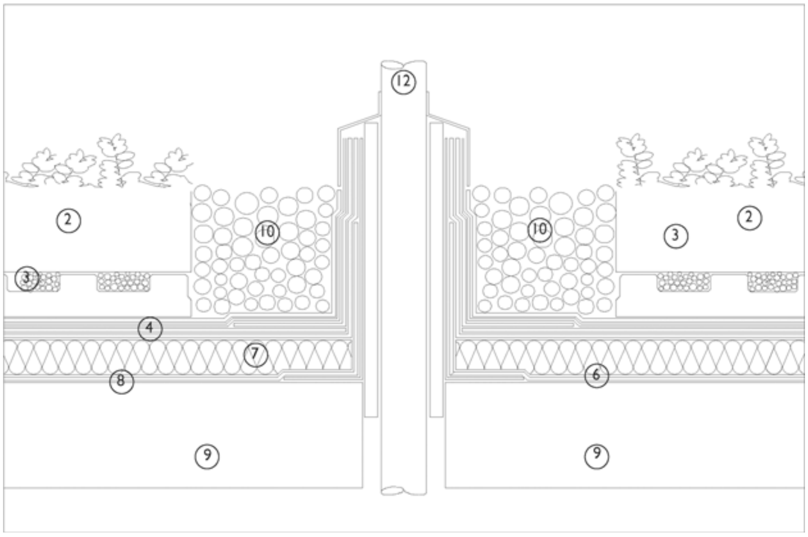


Vertical section 1:10. Light planting. Rooflight upstand

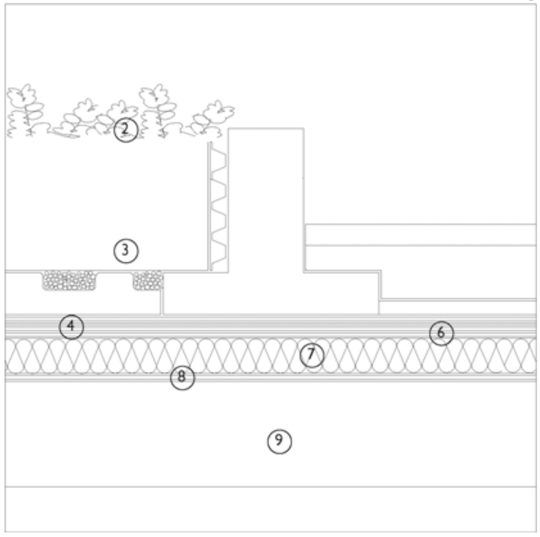


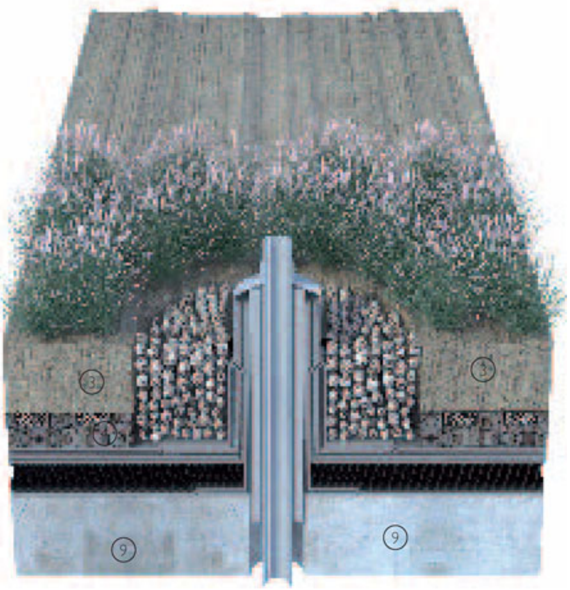
Vertical section 1:10. Rooflight upstand in lightly planted roof

Vertical section 1:10. Heavy planting. Pipe penetration.



Vertical section 1:10. Heavy planting. Cill junction. Planter edge.





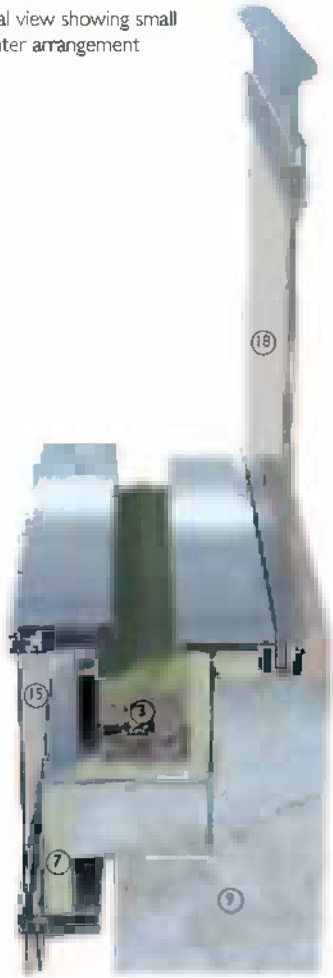
3-D details of pipe penetration in heavily planted roof

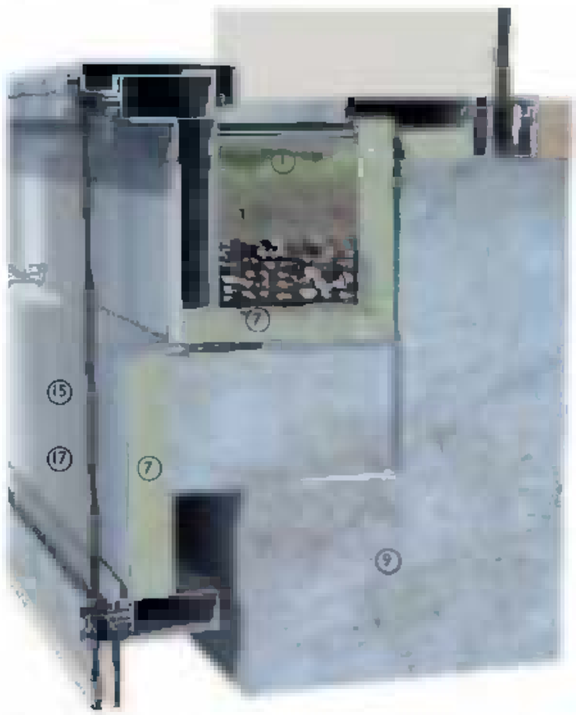
Details
1. Light vegetation
2. Heavy vegetation
3. Soil / growing medium
4. Filter sheet
5. Drainage layer
6. Waterproofing layer
7. Thermal insulation
8. Vapour barrier
9. Concrete deck
10. Smooth gravel
11. Coping
12. Pipe / duct
13. Supply pipe
14. Rainwater outlet
15. Wall cladding
16. GRP planter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

cases, a small planter can be 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. Alternatively, larger versions of this planter can be used that are more 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 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.

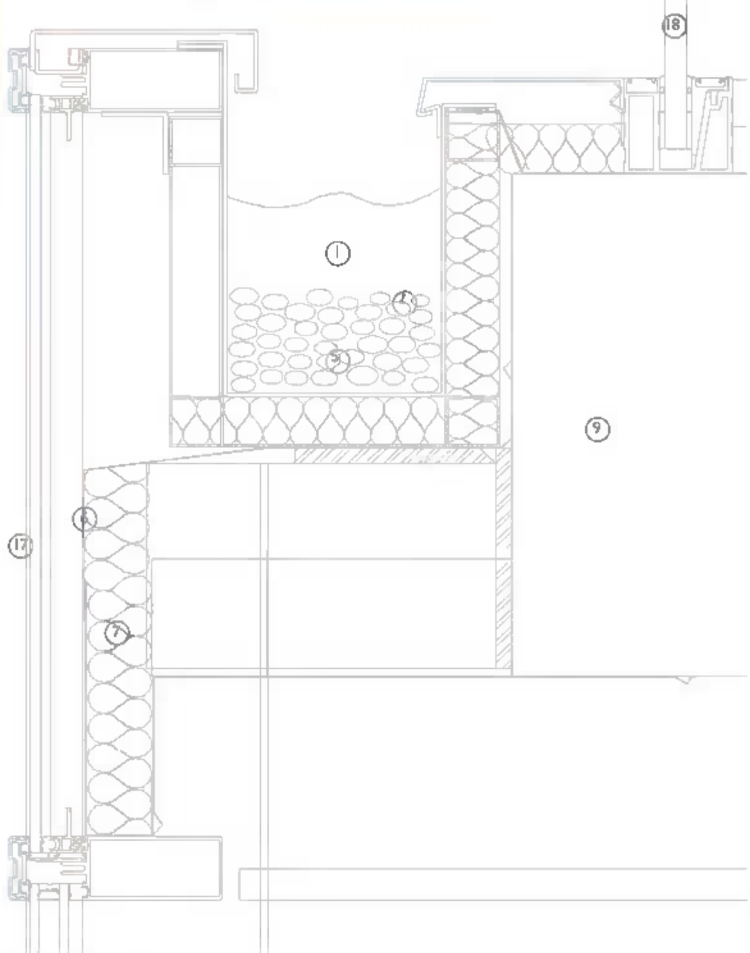
3-D view showing small balcony planter arrangement

3-D sectional view showing small balcony planter arrangement

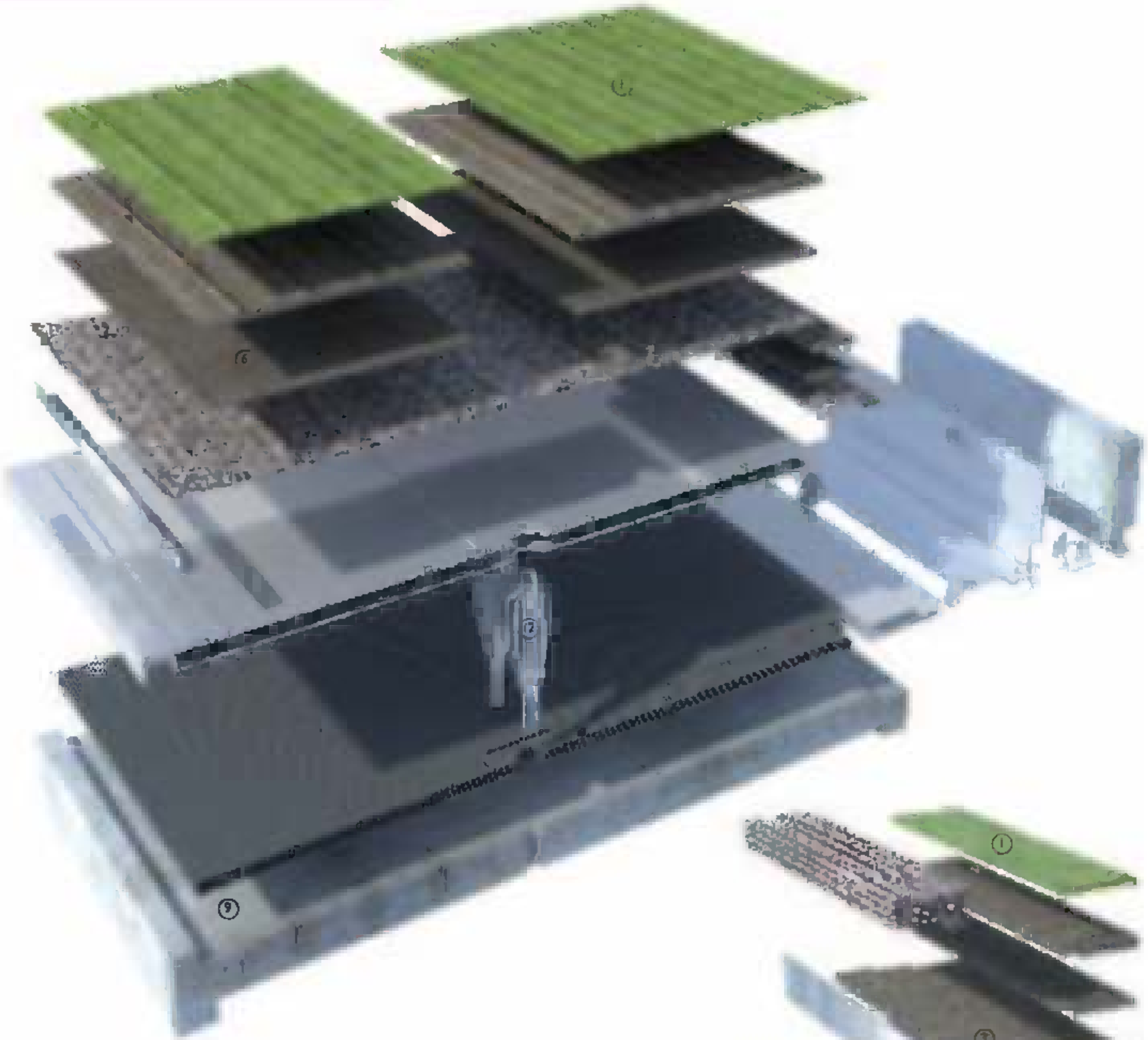




3-D detail view showing section through small balcony planter arrangement

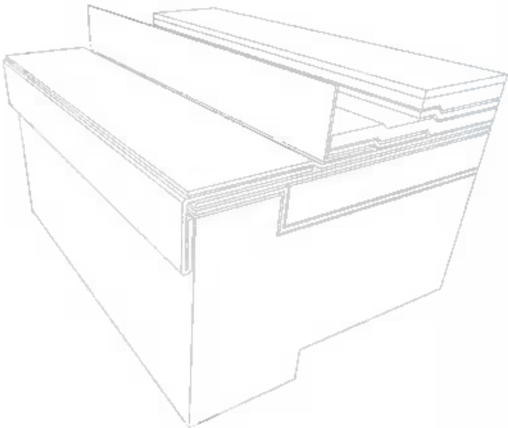


Vertical section 1:5 Small balcony planter



3-D exploded view showing lightly planted concrete roof assembly

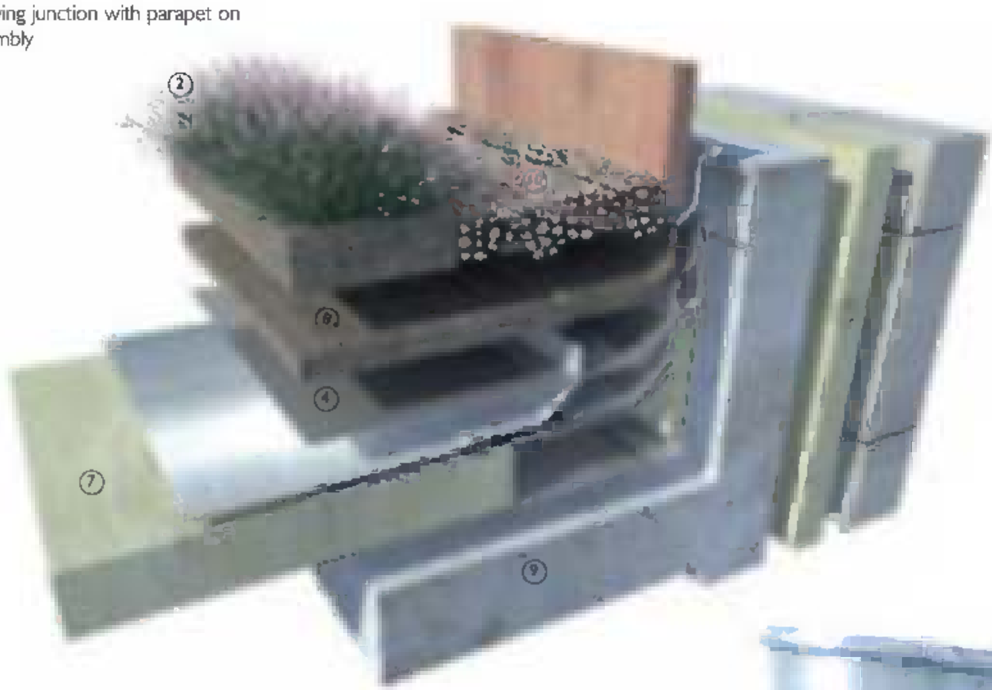
Details
1. Light vegetation
2. Heavy vegetation
3. Soil / growing medium
4. Filter sheet
5. Drainage layer
6. Waterproofing layer
7. Thermal insulation
8. Vapour barrier
9. Concrete deck
10. Smooth gravel
11. Coping
12. Pipe / duct
13. Supply pipe
14. Rainwater outlet
15. Wall cladding
16. GRP planter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

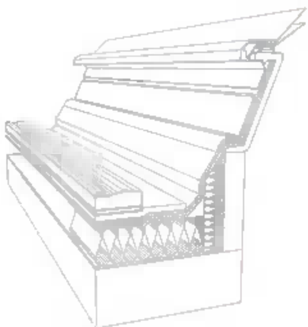


3-D view showing parapet condition on lightly planted roof assembly

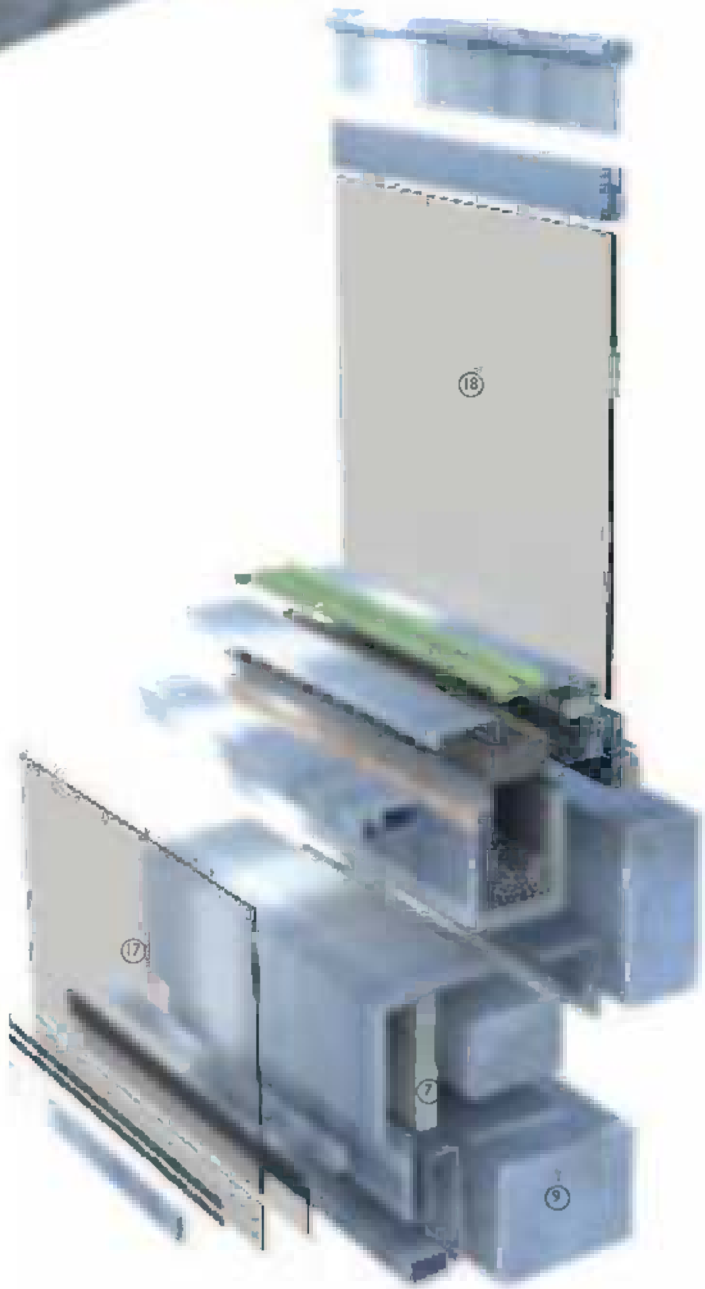
3-D exploded view showing parapet condition on lightly planted roof assembly

3-D exploded view showing junction with parapet on heavily planted roof assembly





3-D exploded view showing junction with rooflight on lightly planted roof assembly

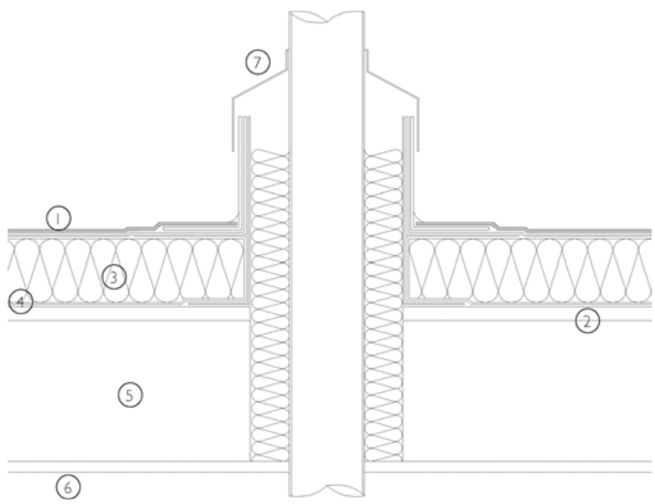


3-D exploded view showing junction with rooflight on lightly planted roof assembly

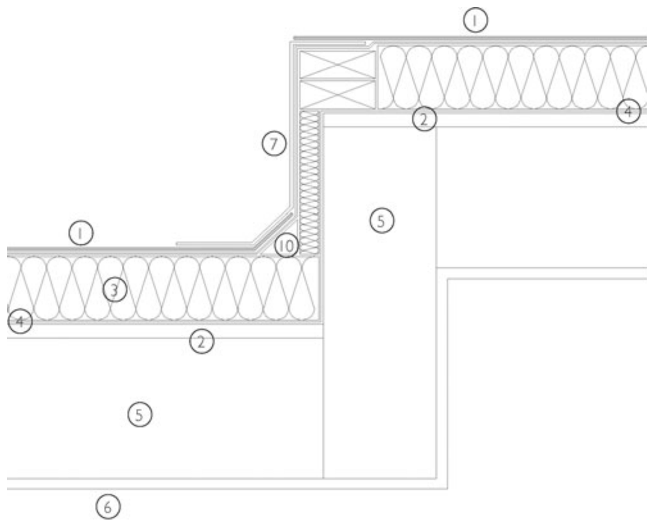
10

TIMBER ROOFS

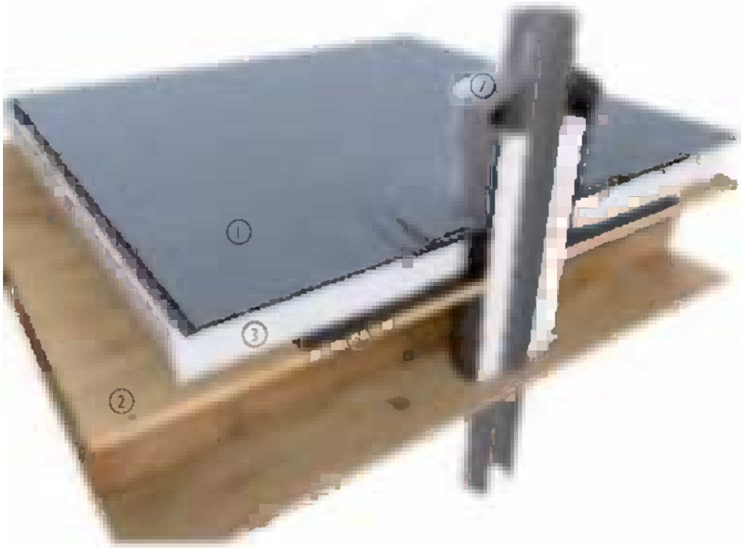
3-D view of flat timber roof with a bitumen-based sheet membrane, with pipe penetration and step in roof



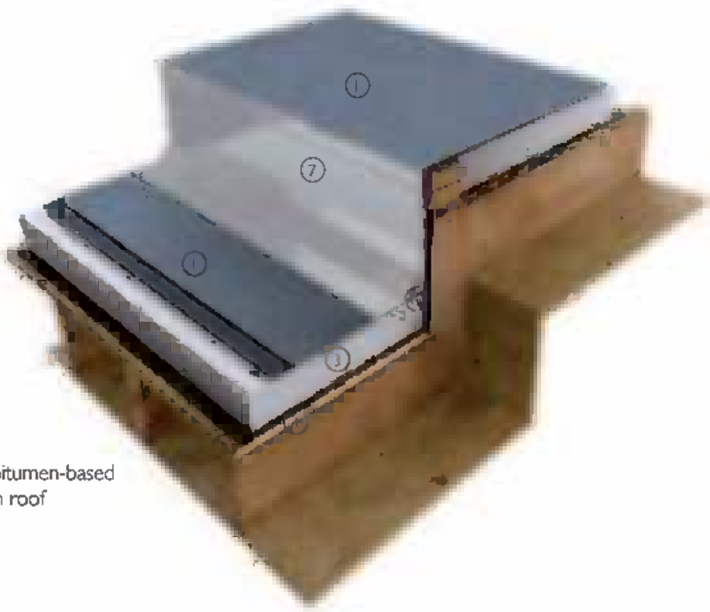
Vertical section 1:10. Pipe penetration



Vertical section 1:10. Step in roof



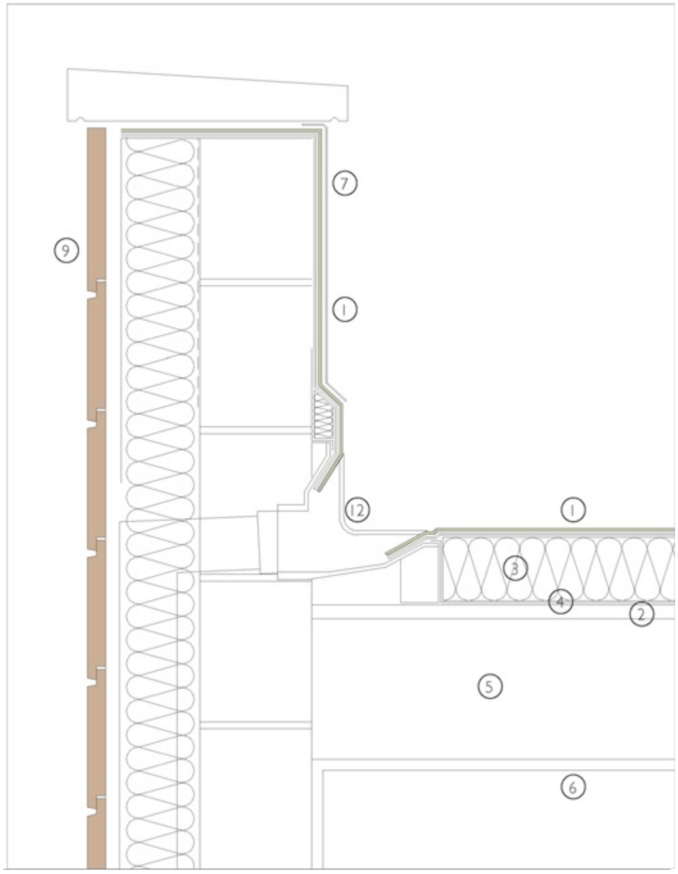
3-D view of flat roof with a bitumen-based sheet membrane, with pipe penetration



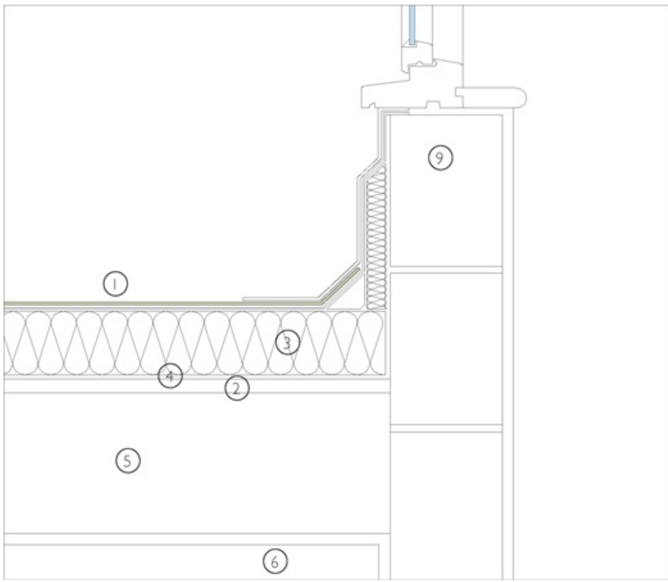
3-D view of flat roof with a bitumen-based sheet membrane, with step in roof

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



Vertical section 1:10. Two-way drain outlet



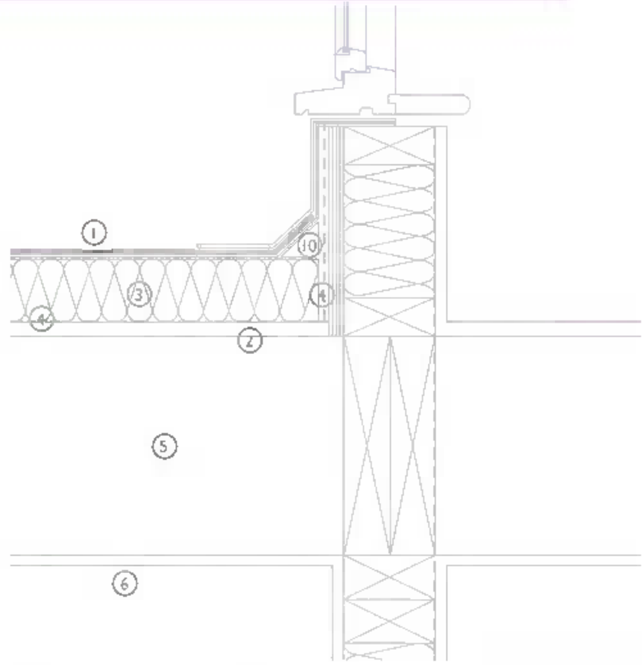
Vertical section 1:10. Door threshold

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. Membranes 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.

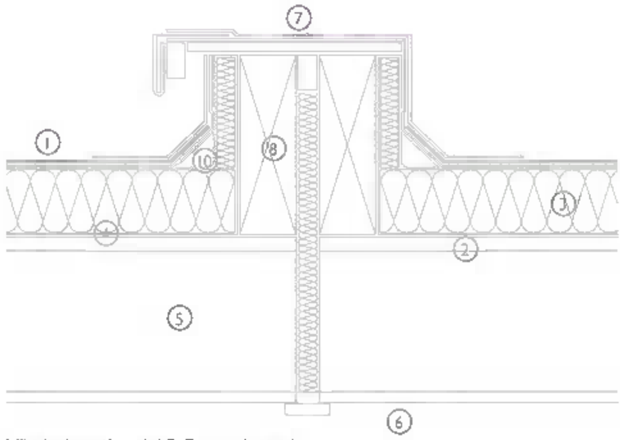
Bitumen sheet membranes are economic, and are often used with timber roof decks, which together provide an economic roof design for relatively small-scale applications, or designs with a complex geometry of low pitched roofs, as is often used in housing and in school buildings. Bitumen-based membranes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

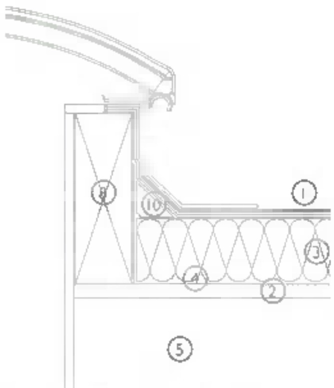
Bitumen-based sheet is manufactured in roll form in widths of around 1000mm, is black in colour, and is typically mixed with SBS (styrene-butadiene-styrene) polymers or with TPO (thermoplastic polyolefin) polymers. The addition of these polymers raises the melting point which ensures stability in hot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



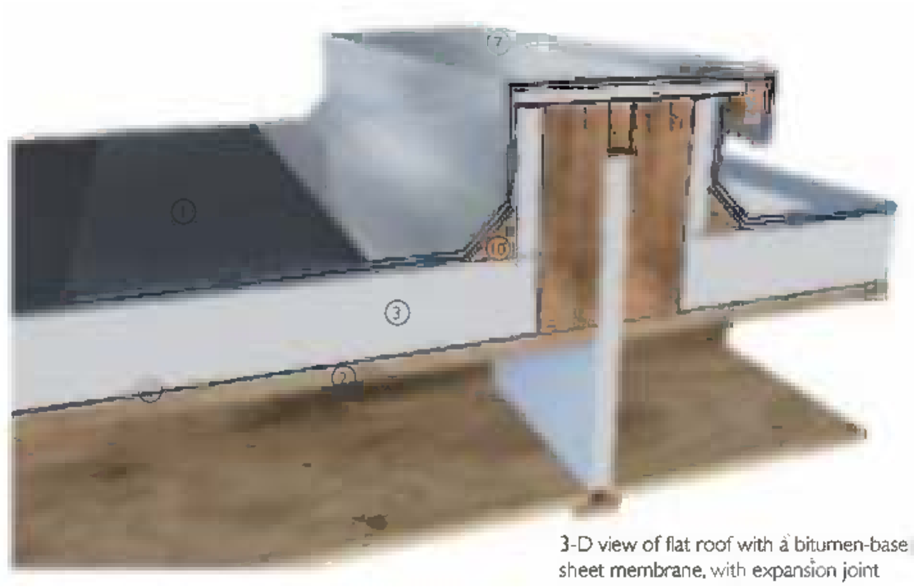
Vertical section 1:10. Low parapet wall



Vertical section 1:10. Expansion joint



Vertical section 1:10 Rooflight



3-D view of flat roof with a bitumen-base sheet membrane, with expansion joint

Details

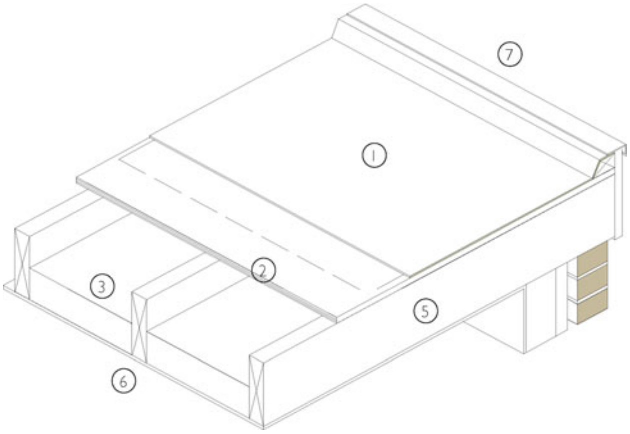
1. Bitumen-based sheet
2. Plywood sheet
3. Rigid thermal insulation
4. Vapour barrier
5. Softwood joists
6. Dry lining/drywall internal finish
7. Metal flashing
8. Timber upstand
9. External wall
10. Angle fillet
11. Proprietary skirt flashing
12. Rainwater outlet
13. Paving bonded to bitumen-based sheet

Roof build-up

Where plywood is used to form the structural deck of a timber roof, the joints 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, with 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.

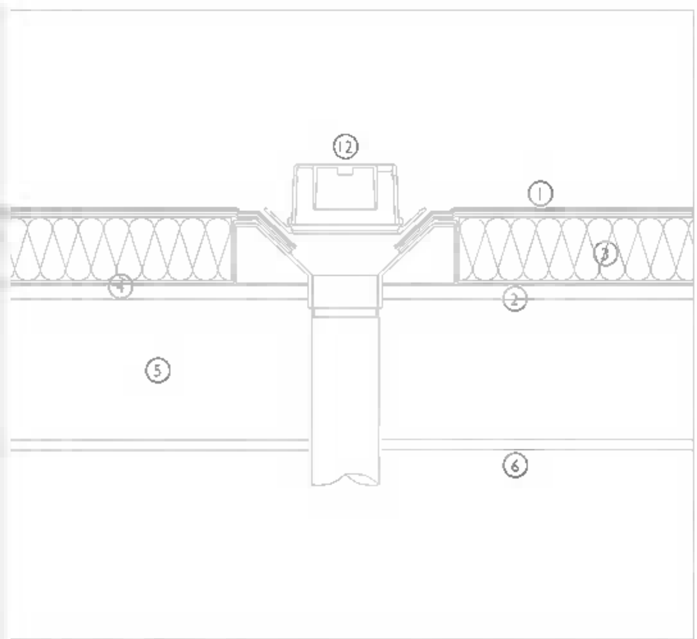
Solar protection

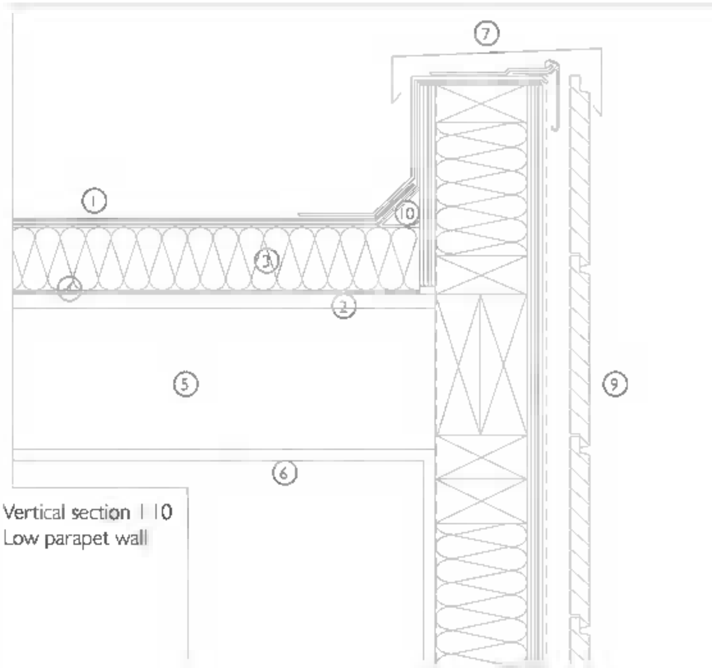
Resistance to UV radiation is provided by either a coating of fine stone chippings or by aluminium solar reflective paint applied to the visible surface of the bitumen-based sheet. As a result of providing this additional UV protection, these coatings have the additional benefit of reflecting heat, which 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



Isometric view of assembly

3-D view of flat roof with a bitumen-based sheet membrane, parapet detail





be provided with a solar protection layer during manufacture as part of a proprietary bitumen-based membrane system.

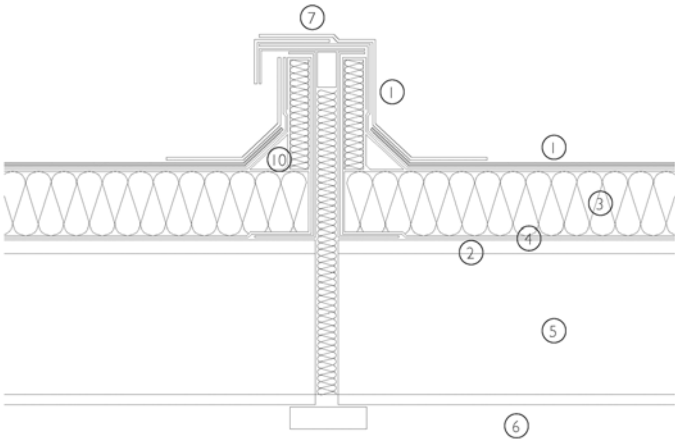
Fixing methods

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 watertight 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.

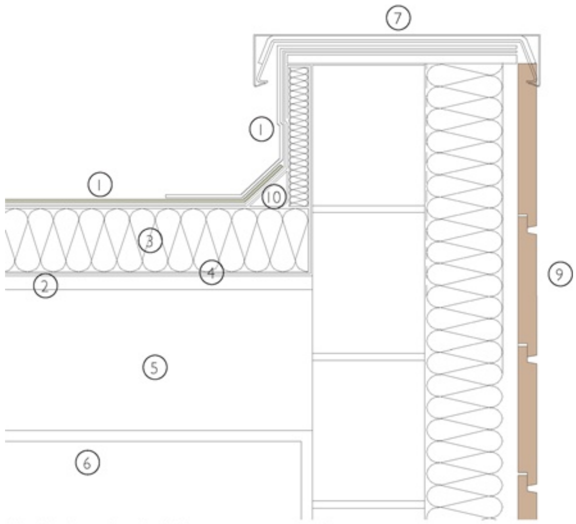
In the bonded method, the sheet is applied cold onto the substrate, the adhesive being either poured and spread in place or spray applied to the substrate / structural deck. Bitumen-based sheet is laid on top and is rolled into place. Laps are sealed with adhesive, but torching is sometimes used to seal 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 timber deck with disc-type fasteners. Laps

3-D view of flat roof with a bitumen-based sheet membrane, parapet detail



Vertical section 1:10. Expansion joint



Vertical section 1:10. Low parapet wall

Vertical section 1:10. Low parapet wall

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

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.

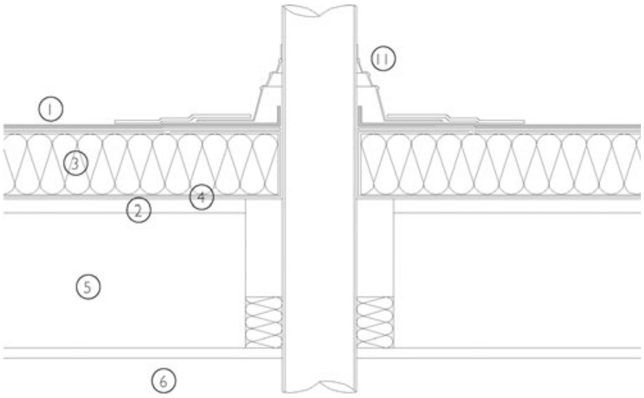
Parapet upstands

Upstands in bitumen-based sheets are formed by either fixing the sheet to the plywood face of a timber framed upstand, or to the face of the thermal insulation, depending on the configuration of the external wall. Where a timber roof deck meets a masonry wall, and 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 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 overhanging on both sides provides 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. 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 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.

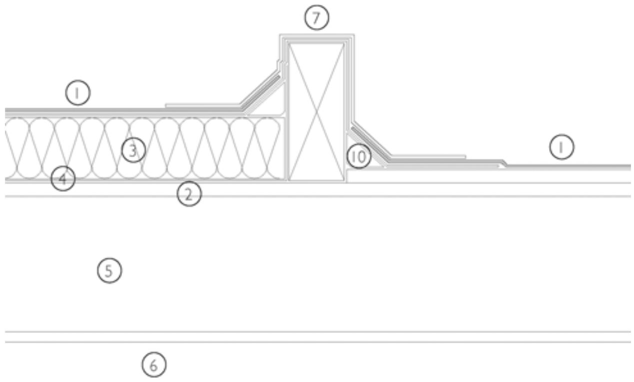
Upstands for perforations and movement joints are formed in the same way as other upstands, but the membrane continues over the top of the upstand. Where an expansion joint is formed, the membrane is separated on one side of the movement joint to open and close as a result of structural movement.

Junction with tiled roof

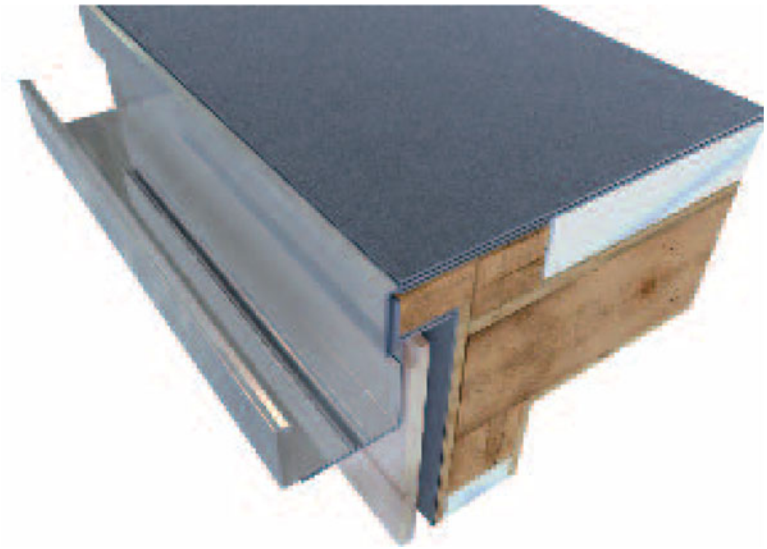
The junction of a flat roof and a tiled pitched roof is formed by extending the base layer and membrane up 150mm above the finished roof level, with an additional reinforcing layer to strengthen the junction. The roofing felt, or breather membrane, of the tiled pitched roof extends down over the top of this membrane to provide a complete weathertight seal across the roof. The bottom top row of tiles is 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



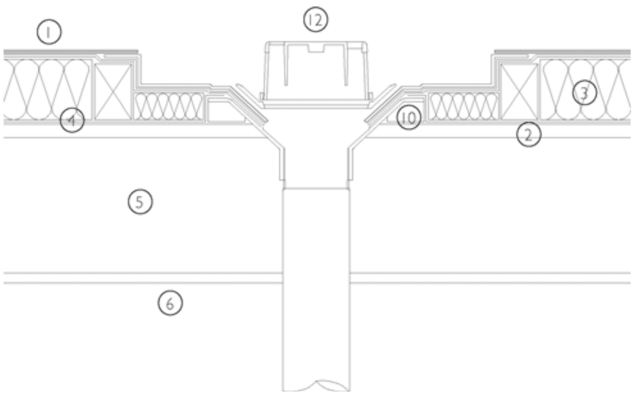
Vertical section 1:10. Pipe penetration



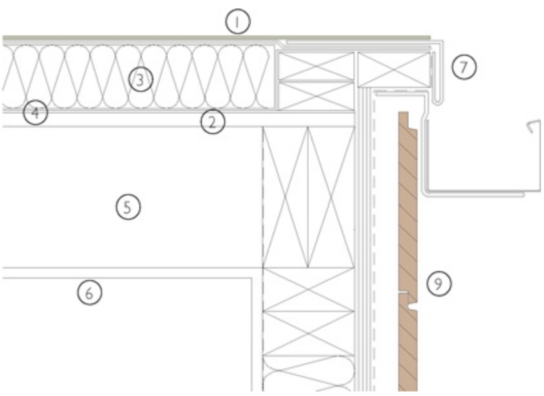
Vertical section 1:10. Step in roof



3-D view of flat roof with a bitumen-based sheet membrane, eaves detail



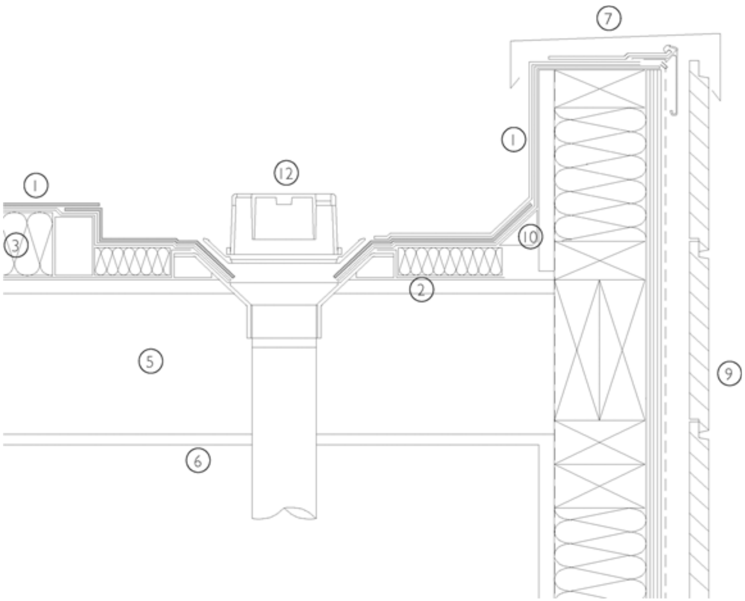
Vertical section 1:10. Rainwater outlet



Vertical section 1:10. Eaves

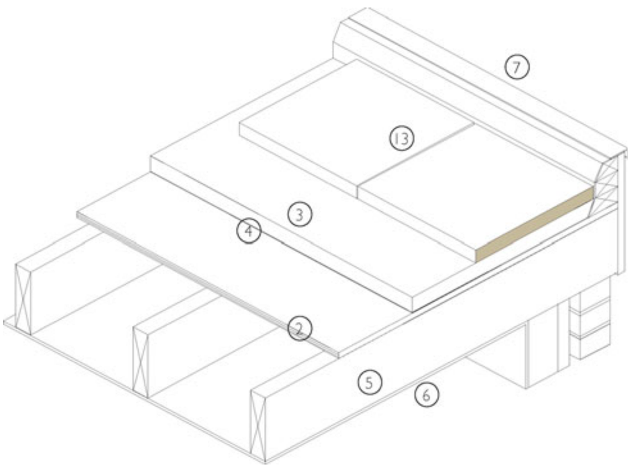
3-D view of flat roof with a bitumen-based sheet membrane, eaves detail

3-D view of flat roof with a bitumen-based sheet membrane, with low parapet wall and drain outlet

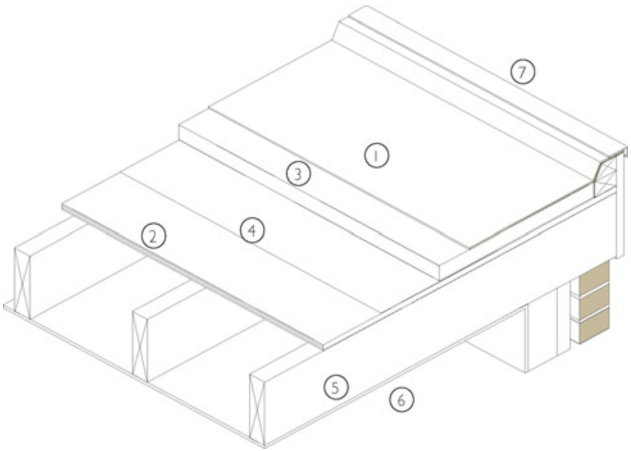


Vertical section 1:10. Low parapet wall with drain outlet

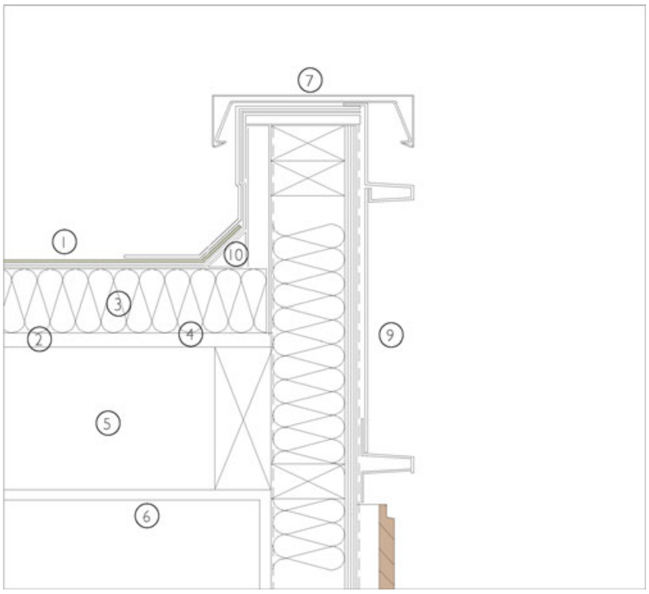
3-D view of flat roof with a bitumen-based sheet membrane, drain outlet detail



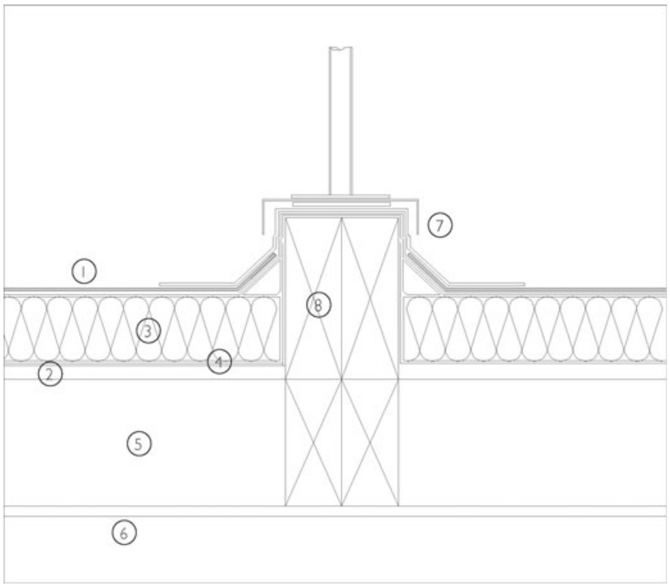
Isometric view of assembly



Isometric view of assembly



Vertical section 1:10. Low parapet wall



Vertical section 1:10. Balustrade

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

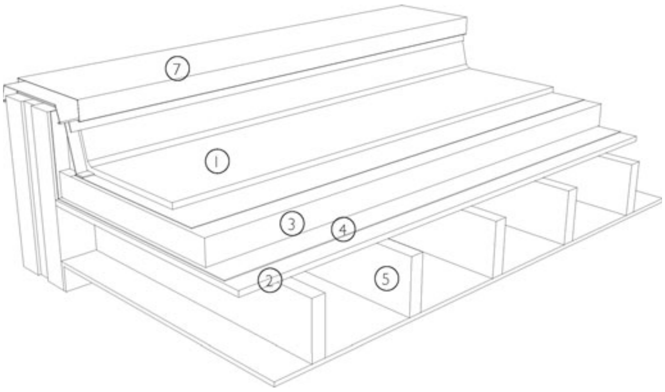
membrane forms a waterproof covering to an area of flat roof at the top of the pitched roof, the membrane is folded at the edge to form a drip, so that rainwater cannot track up into the roof construction. A metal drip is sometimes used to give a visually sharper edge to the roof. The vapour barrier 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 the bitumen-based membrane of 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 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

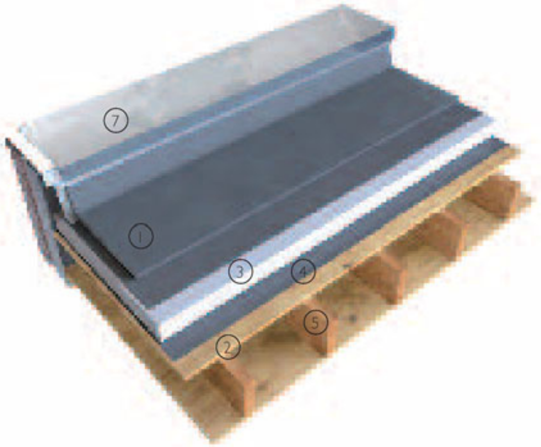
The eaves detail is formed with a folded drip formed in the same way as described for the junction with the top of a pitched roof. The gutter is tucked up behind the drip to ensure that all rainwater running off the edge of the eaves is collected by the gutter, and that no water is allowed to run behind 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 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.

Timber Roofs 01
Flat roof: Bitumen-based sheet membranes



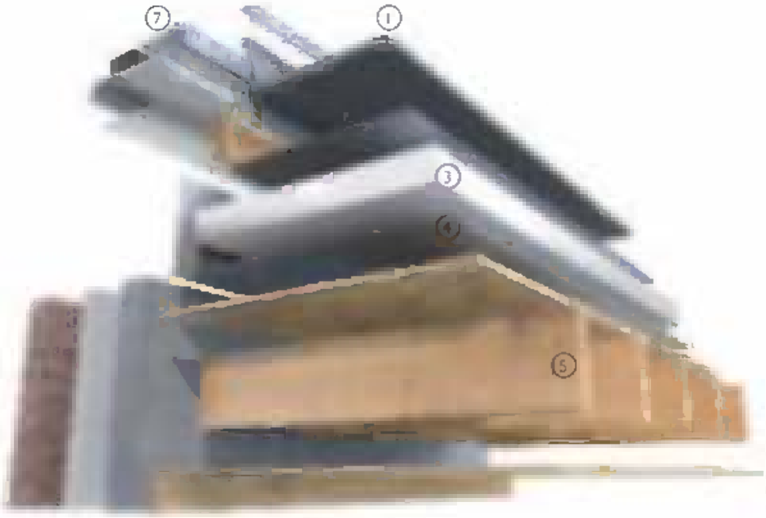
3-D line drawing of typical flat timber roof construction with rigid insulation above roof structure



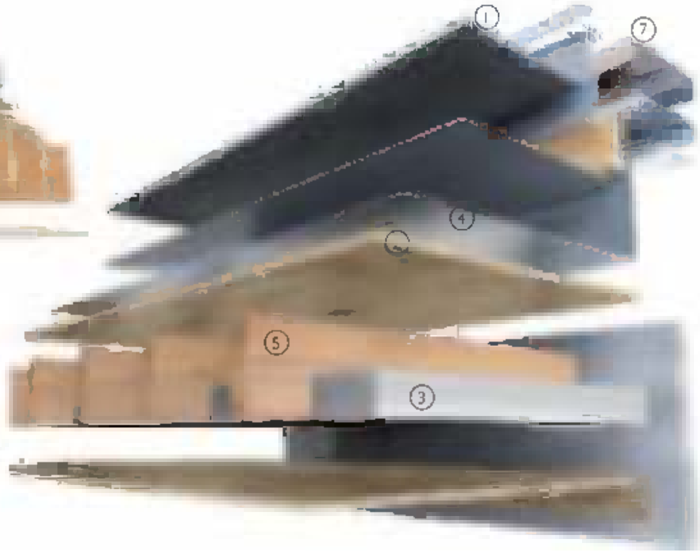
3-D view of typical flat timber roof construction with rigid insulation above roof structure

Details

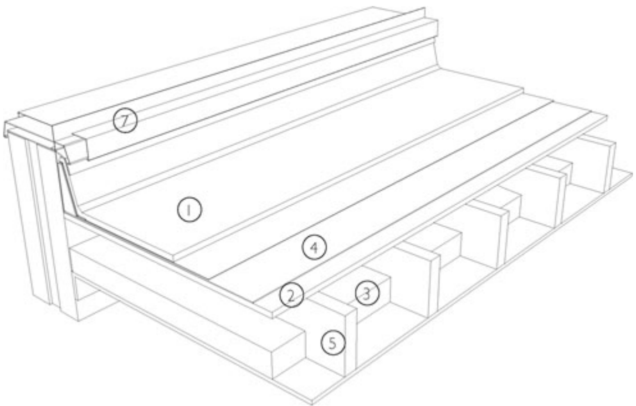
1. Bitumen-based sheet
2. Plywood sheet
3. Rigid thermal insulation
4. Vapour barrier
5. Softwood joists
6. Dry lining/drywall internal finish
7. [illegible]
8. Timber upstand
9. External wall
10. Angle fillet
11. Proprietary skirt flashing
12. Rainwater outlet
13. Paving bonded to bitumen-based sheet



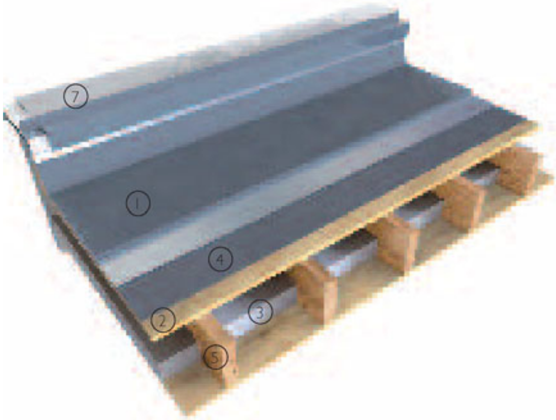
3-D exploded view of typical flat timber roof construction with rigid insulation above roof structure



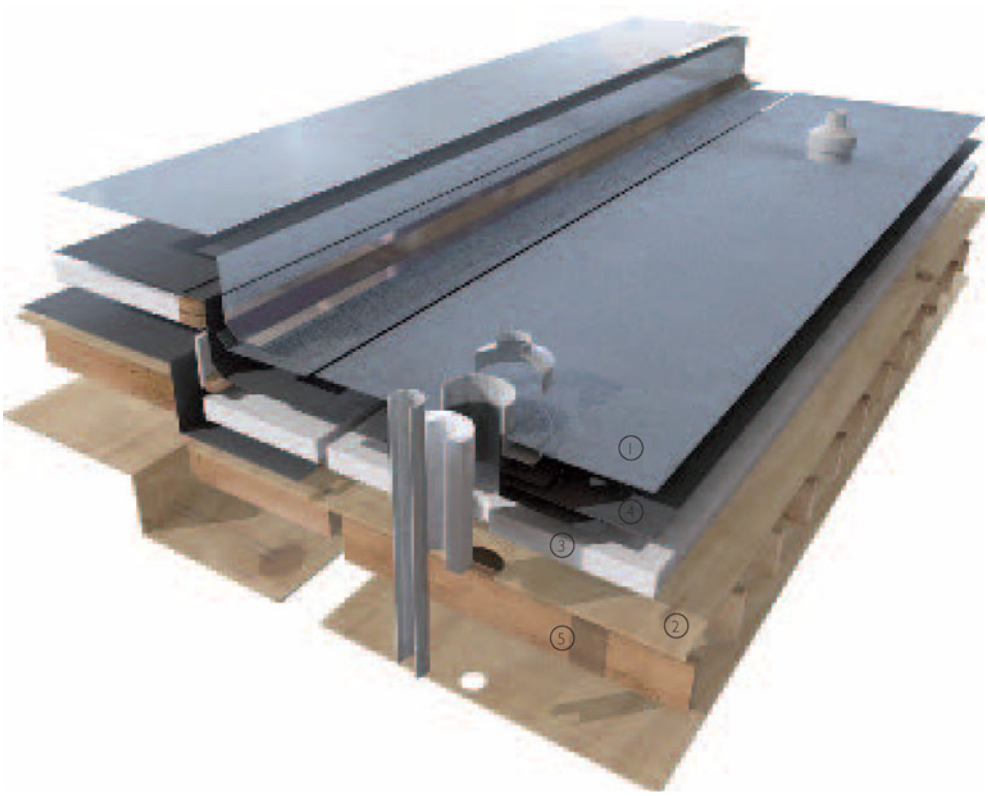
3-D exploded view of typical flat timber roof construction with insulation between roof joists



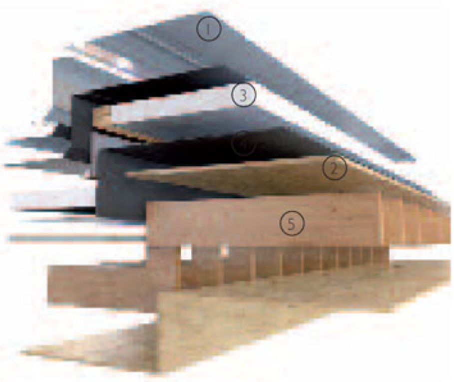
3-D line drawing of typical flat timber roof construction with insulation between roof joists



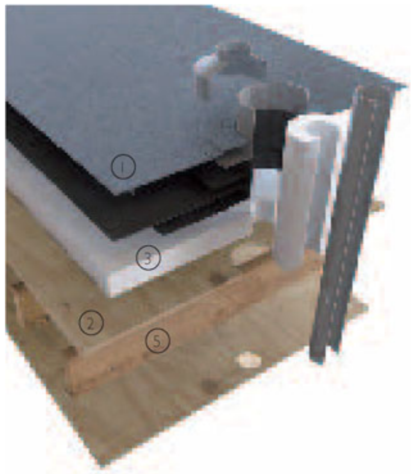
3-D view of typical flat timber roof construction with insulation between roof joists



3-D exploded view of flat roof with a bitumen-based sheet membrane, with pipe penetration and step in roof

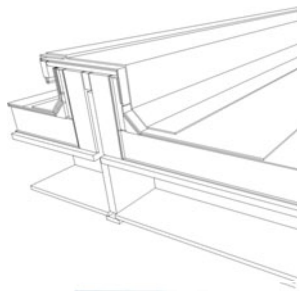


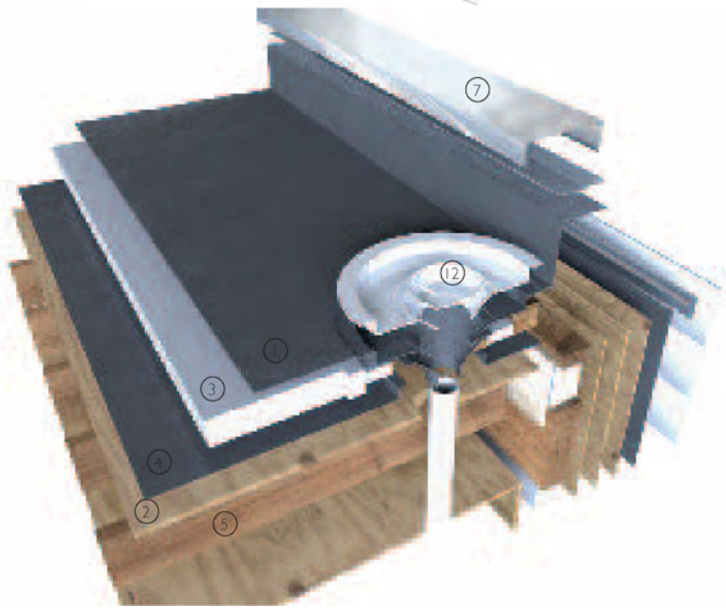
3-D exploded view of flat roof with a bitumen-based sheet membrane, with step in roof



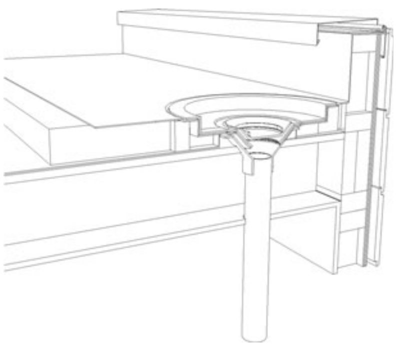
3-D exploded view of flat roof with a bitumen-based sheet membrane, with pipe penetration

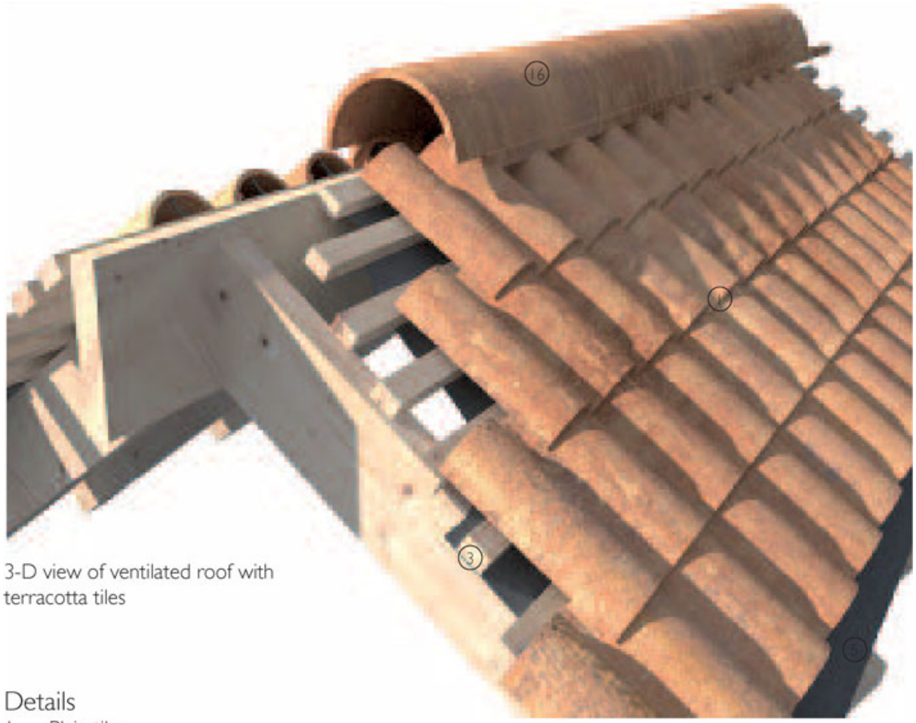
3-D exploded view of expansion joint in a flat roof with a bitumen-based sheet membrane



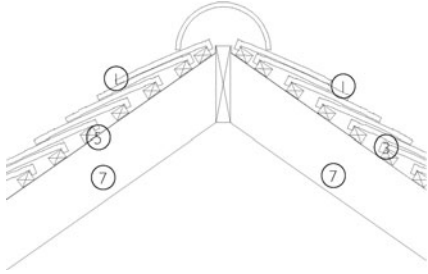


3-D exploded view of drain outlet in a flat roof with a bitumen-based sheet membrane

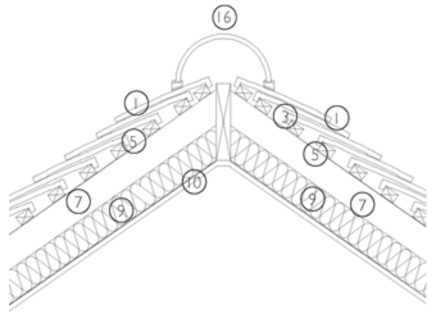




3-D view of ventilated roof with terracotta tiles



Vertical section 1:20. Unventilated roof



Vertical section 1:20. Ventilated roof

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
17. Inner cavity leaf

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 traditional 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.

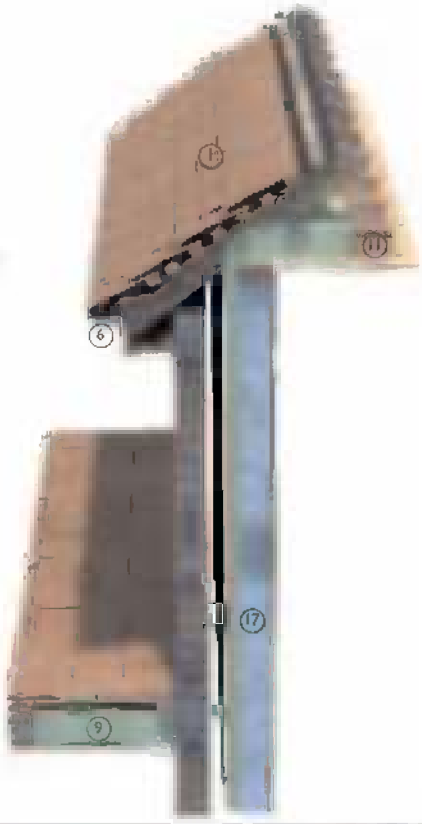
Both tile types are fixed to timber battens set horizontally, that is, at right angles to the direction of the slope. The battens are fixed onto roofing felt, which forms a second line of defence and full weathertight barrier to the roof. The roofing felt is set on timber rafters (sloping timbers) or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

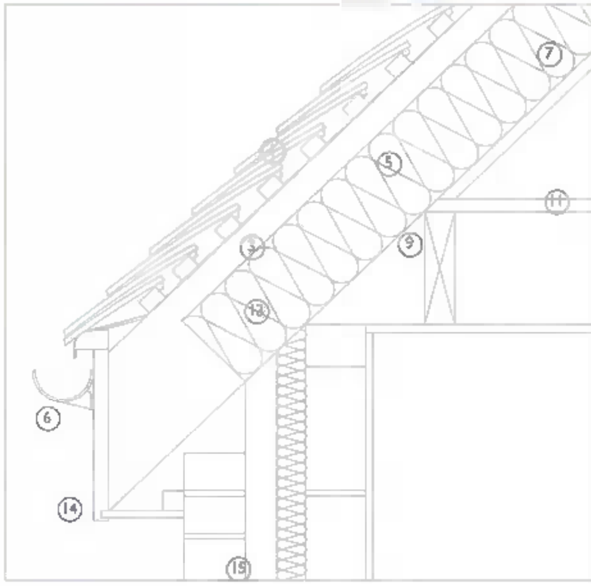
Plain tiles

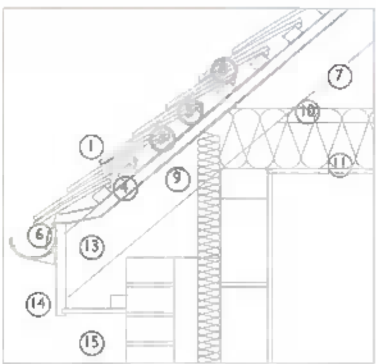
Plain tiles are made in a variety of sizes, the most common being around 260mm x 160mm. Tiles are lapped by a minimum of around 35mm on their top edge, called the 'head lap', when hung vertically, and are head lapped by a minimum of around 65mm when hung on any slope down to 35° above the horizontal. The maximum head lap for all conditions is around 90mm, so that tiles are always lapped with three tiles set over one another. 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.

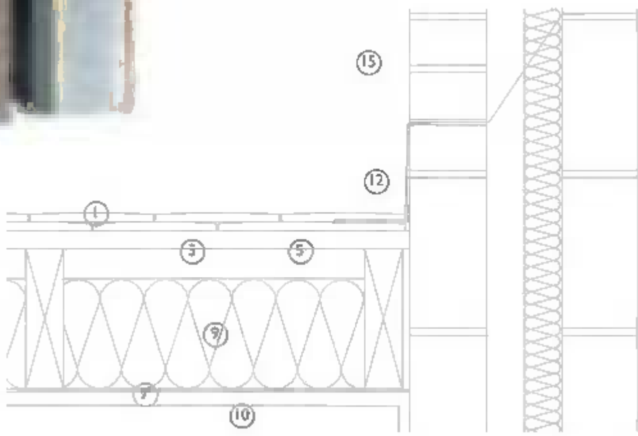
Interlocking tiles

Interlocking tiles in both clay and concrete are also made in different profiles and sizes, 3-D views showing timber tiled roof eaves and abutment using plain tiles



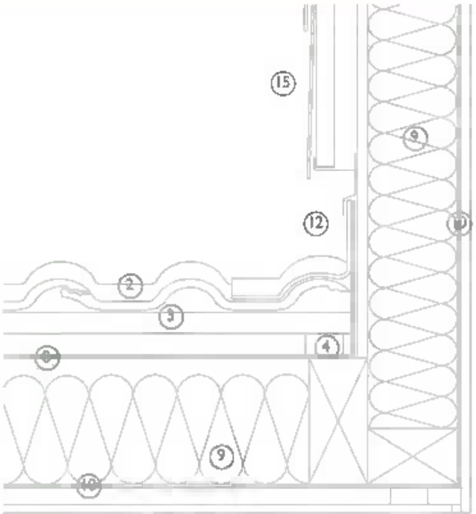




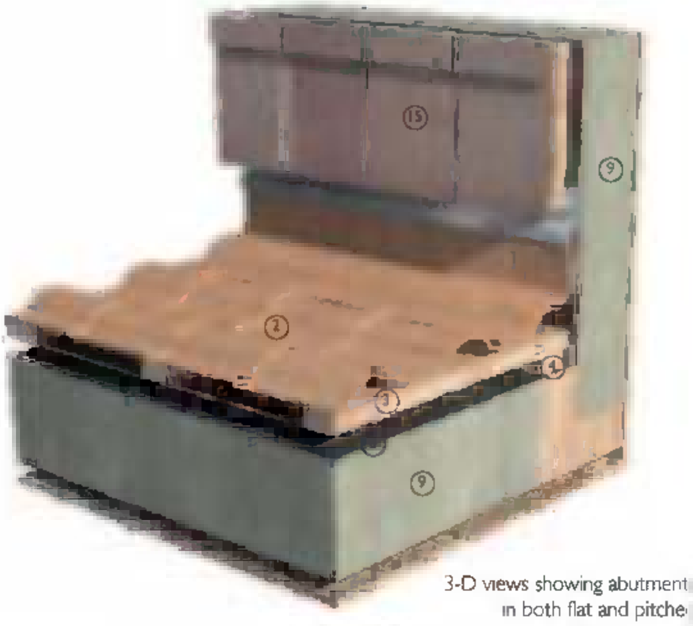


Vertical section 1:20. Plain tiles. Eaves

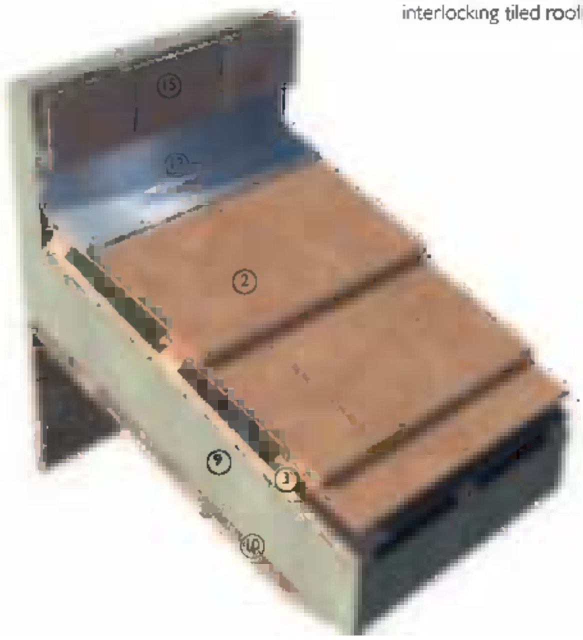
Vertical section 1:10. Plain tiles. Eaves and abutment

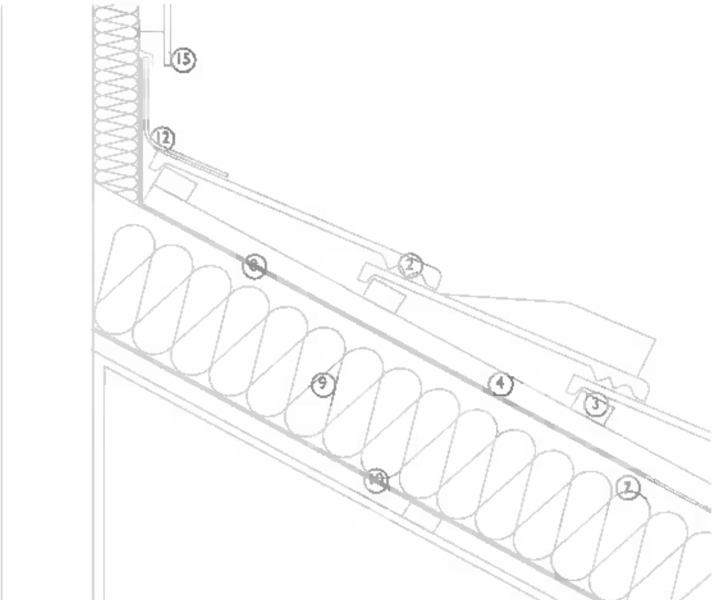


Vertical section 1:10. Interlocking tiles. Abutment



3-D views showing abutment in both flat and pitche interlocking tiled roof





Vertical section 1:10. Interlocking tiles. Abutment

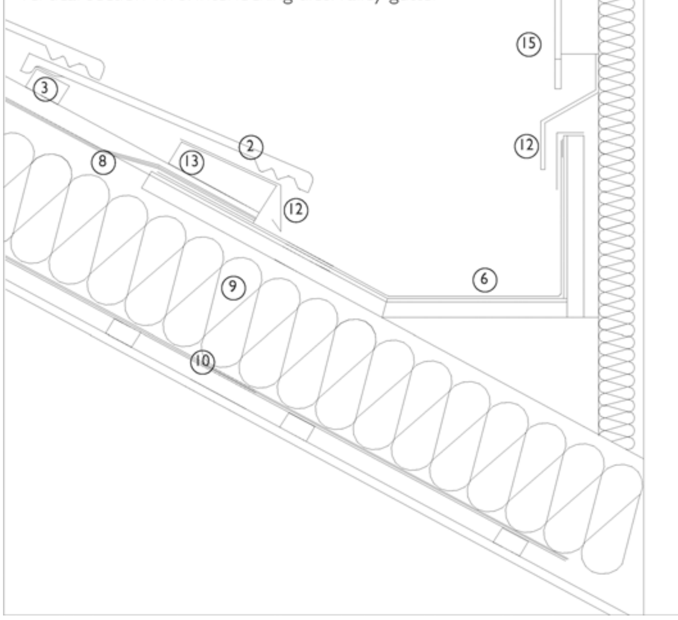
Details
1. Plain tile
2. Interlocking tile
3. Softwood battens
4. Softwood counter battens
5. Roofing felt
6. Gutter
7. Softwood rafter
8. Vapour permeable membrane
9. Thermal insulation
10. Vapour barrier
11. Softwood joist
12. Metal flashing
13. Ventilator
14. Fascia board
15. External wall
16. Ridge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

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 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.

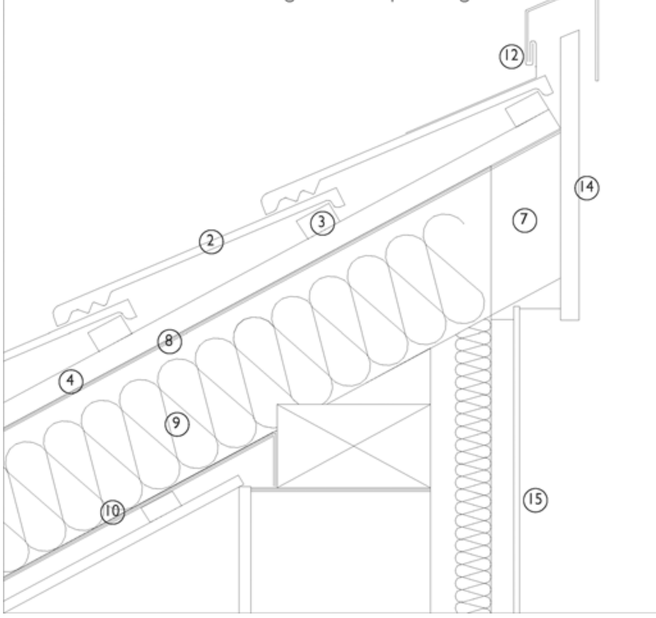
Ventilation

Like flat roofs, pitched roofs are formed as either warm roofs or cold roofs. In the cold roof, horizontal joints are insulated, and the void is ventilated to ensure that any conden-

Vertical section 1:10. Interlocking tiles. Valley gutter



Vertical section 1:10. Interlocking tiles. Monopitch ridge

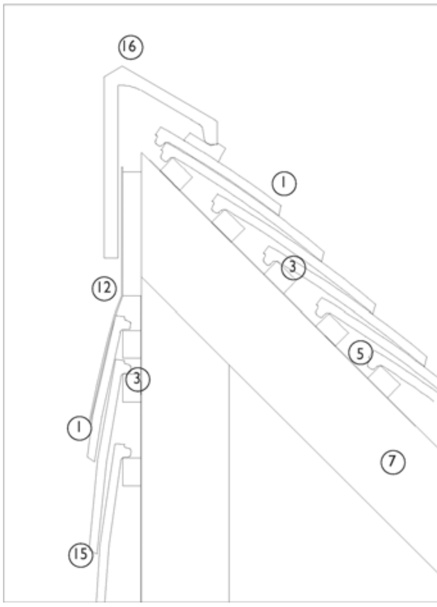


3-D view of plain tiles on monopitch roof

3-D view of plain tiles on monopitch roof

sation 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' membrane as the underlayer to the tiling 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 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 and roof spaces which are divided.

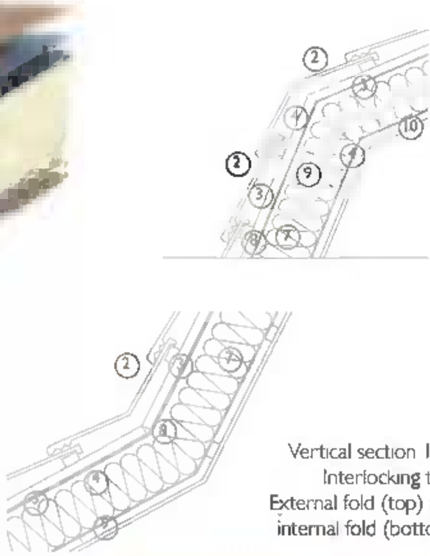
In the warm roof, the sloping rafters are filled with thermal insulation in order to allow the internal space of the roof void to be used. As with the cold roof, a vapour barrier is set between the thermal insulation and the internal dry wall lining. A vapour permeable membrane is set on the outside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



Vertical section 1:10. Plain 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
17. Ridge capping

3-D view showing internal fold on interlocking tiled timber roof



Vertical section 1:1(
Interlocking tile:
External fold (top) an
internal fold (bottom

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.

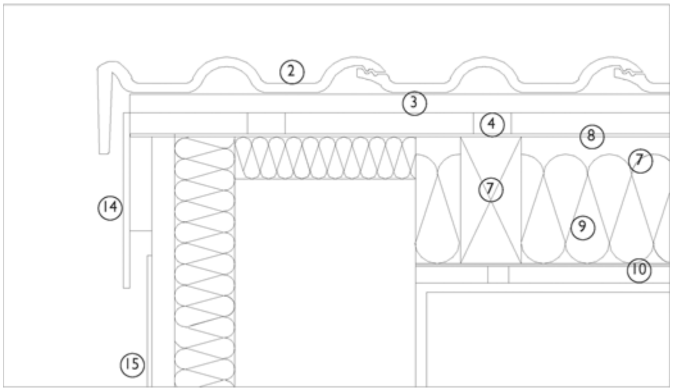
Eaves

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.

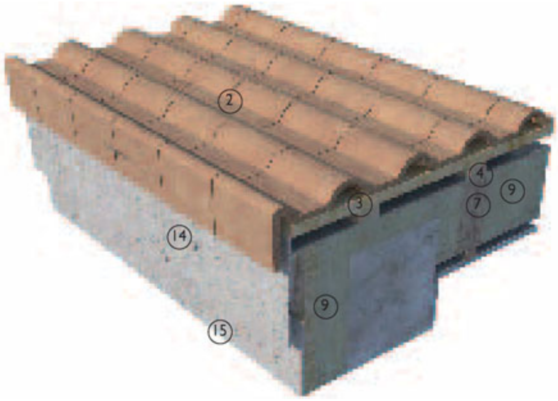
In the cold roof version the proprietary ventilator is set beneath the underlayer. Fresh air is allowed to flow into the ventilator set beneath the bottom tile and is released into the roof void without affecting the thermal insulation of the roof at ceiling level, which is continuous between wall and 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 to form a continuity with the wall insulation, or alternatively the wall insulation continues vertically until it reaches the sloping 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

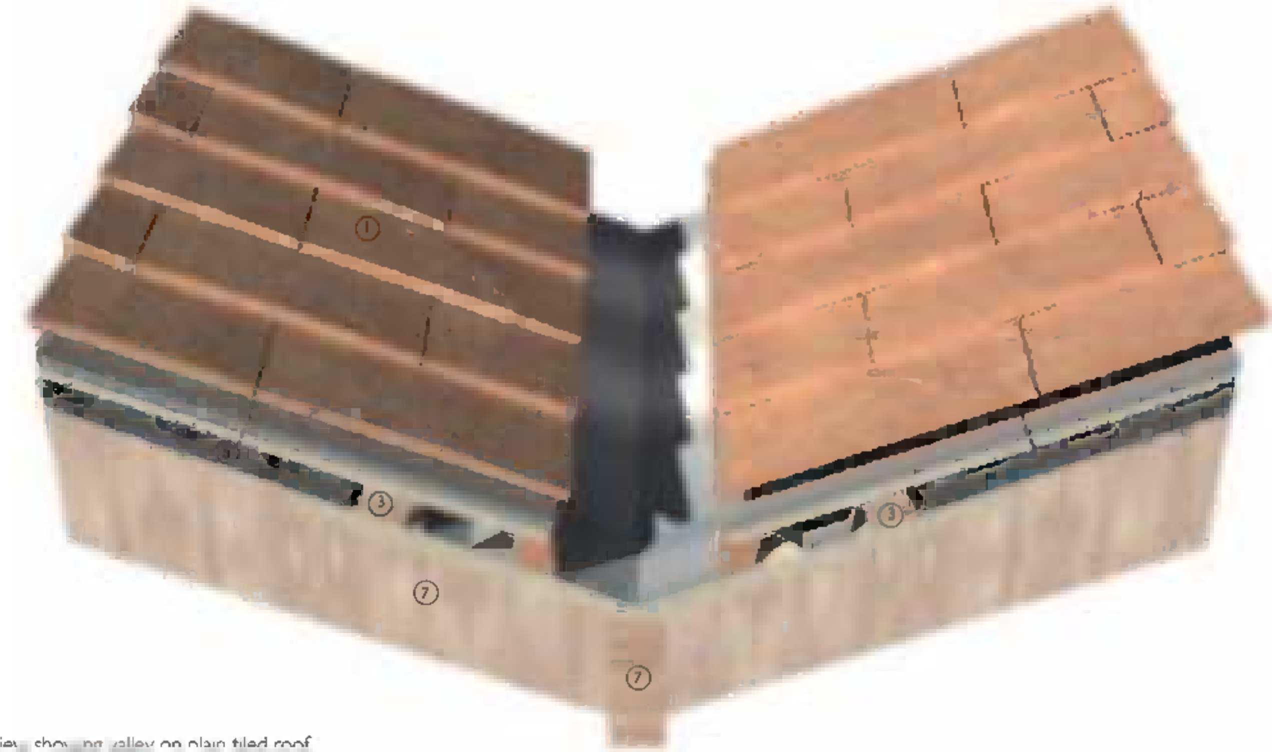
Where a sealed ridge is required, ridge tiles are either bedded in a sand cement mortar, or are dry fixed with metal screws, typically stainless steel, where a rapid installation is required. For ventilated ridges, proprietary fixings usually made in PVC-U with ventilation slots are used to ventilate 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



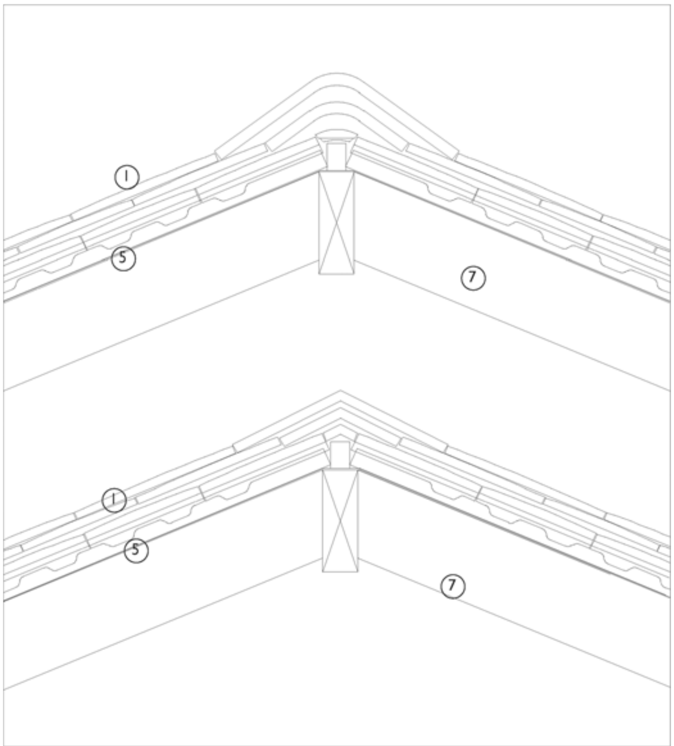
Vertical section 1:10. Interlocking tiles. Verge



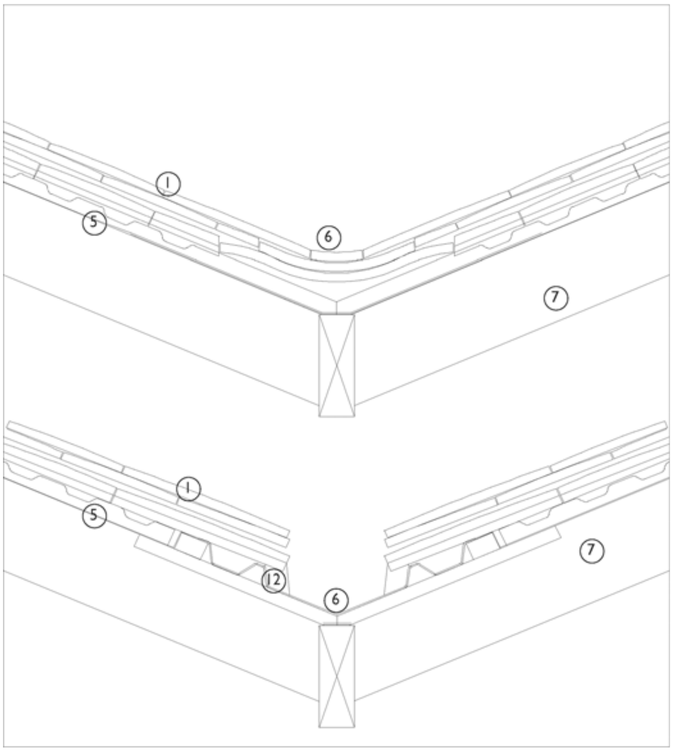
3-D view showing verge detail on interlocking tiled roof



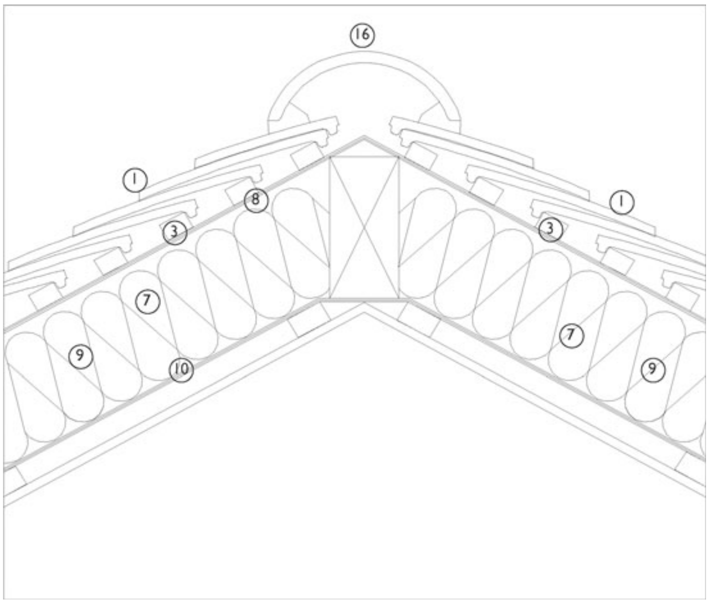
3-D view showing valley on plain tiled roof



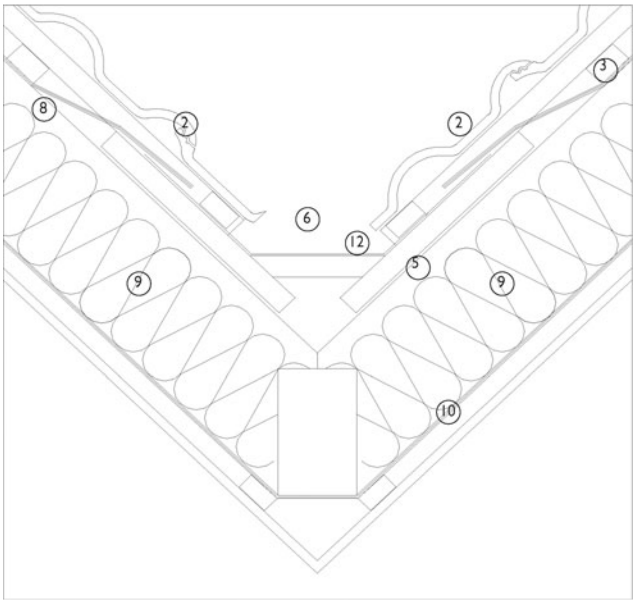
Vertical sections 1:10. Plain tiles. Hips



Vertical sections 1:10. Plain tiles. Valleys

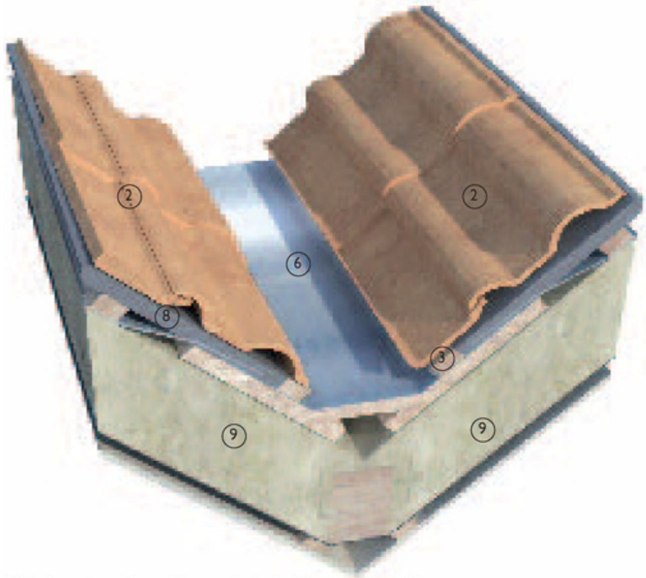


Vertical section 1:10. Plain tiles. Ridge

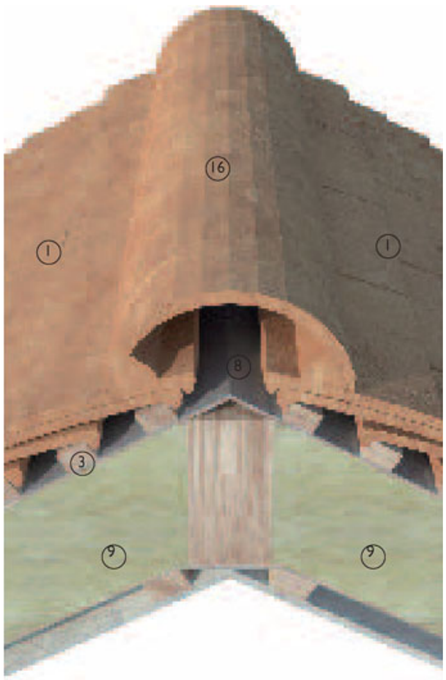


Vertical section 1:10. Interlocking tiles. Valley gutter

3D view showing ridge on plain tiled roof



3D view showing valley on interlocking tiled roof



3D detail view of ridge on plain tiled roof

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.

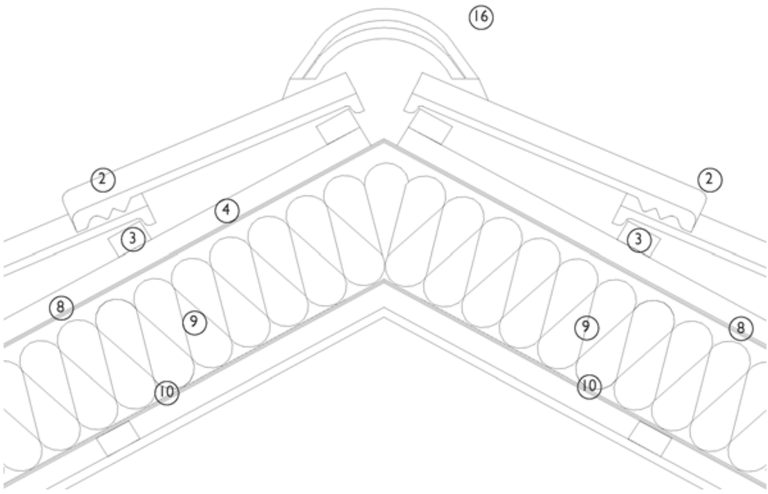
Verges

Verges, or gable ends, are closed with a sand cement mortar seal between the underside of the tiles and the fascia board beneath. Metal clips, usually in stainless steel, are used to restrain the edge tile. Proprietary systems of interlocking tiles often have special verge tiles. 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 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.

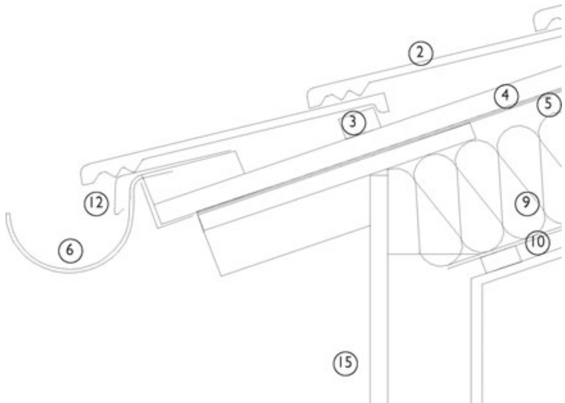
Hips and valleys

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 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. 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.

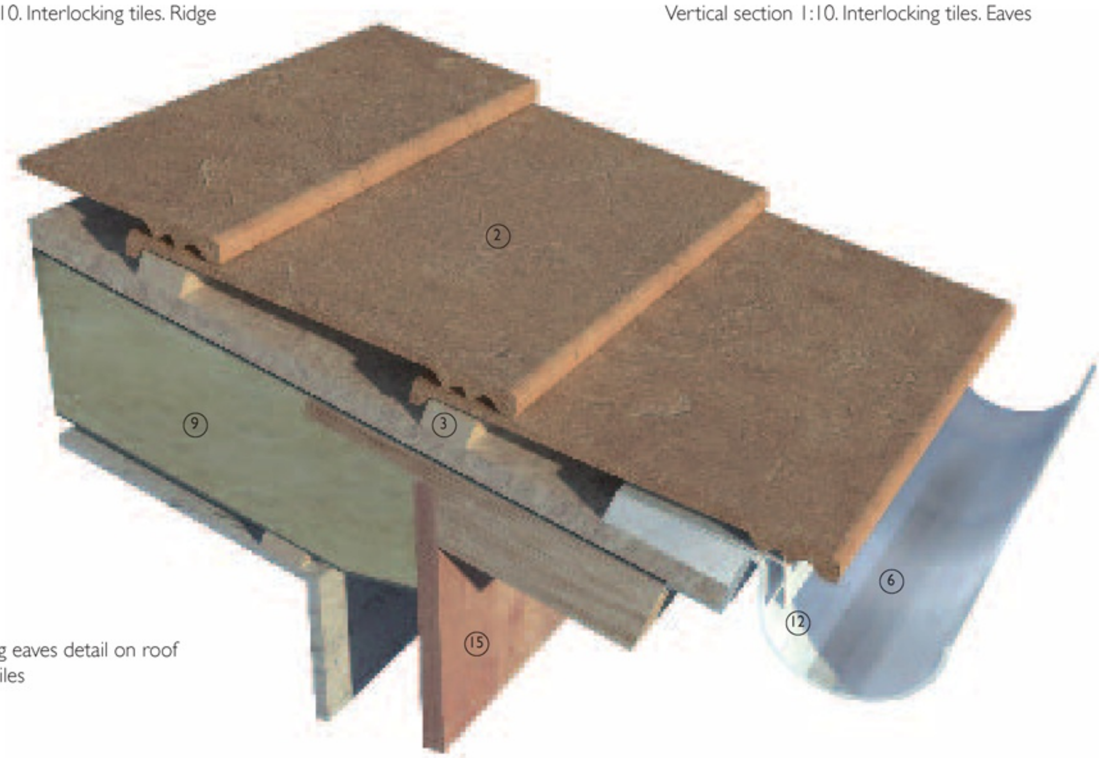
Valleys are formed in the same way, with



Vertical section 1:10. Interlocking tiles. Ridge



Vertical section 1:10. Interlocking tiles. Eaves



3-D detail showing eaves detail on roof
with interlocking tiles

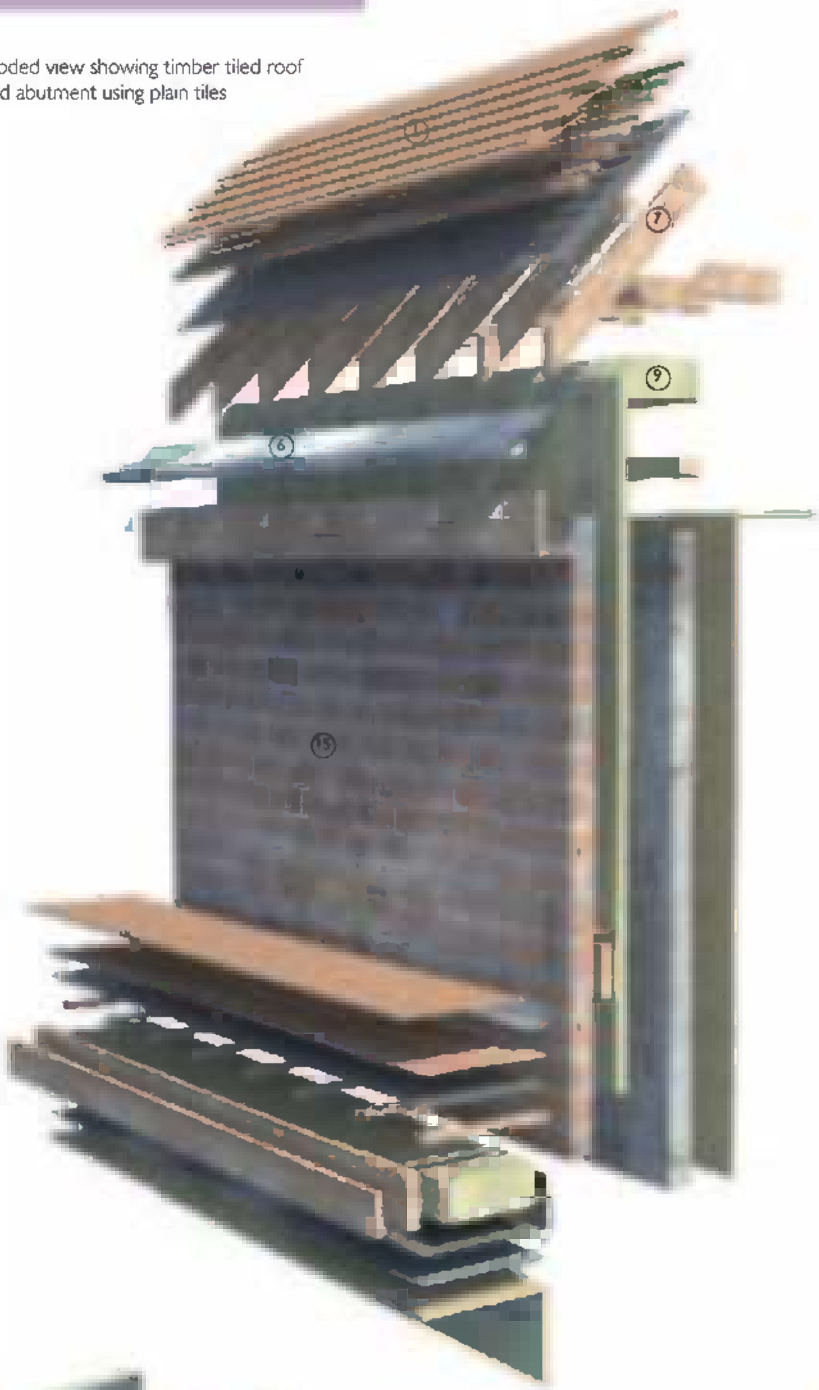
either folded tiles or mitred tiles. When a large amount of rainwater is collected in the valley, a full gutter can be formed by introducing a metal or GRP strip. The edges of the gutter are folded up the adjacent battens and are made continuous with the felt underlay. The gutter is usually supported by timber boards or plywood sheet set between the rafters as shown. 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, 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 or is formed into the slope of the interlocking tile.

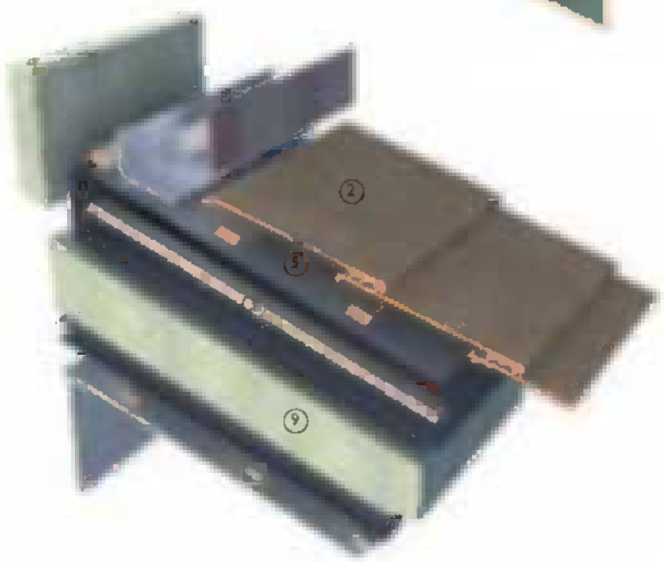
Details
1. Plain tile
2. Interlocking tile
3. Softwood battens
4. Softwood counter battens
5. Roofing felt
6. Gutter
7. Softwood rafter
8. Vapour permeable membrane
9. Thermal insulation
10. Vapour barrier
11. Softwood joist
12. Metal flashing
13. Ventilator
14. Fascia board
15. External wall
16. Ridge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

3D exploded view showing timber tiled roof eaves and abutment using plain tiles

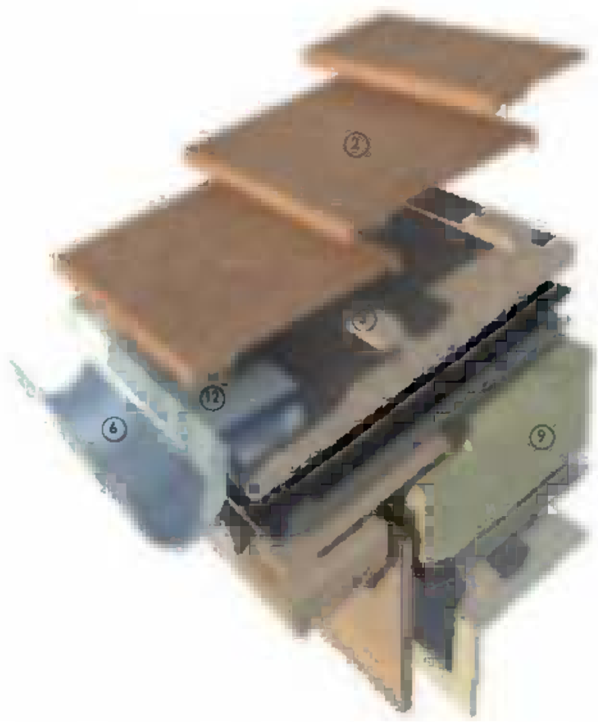


Details

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

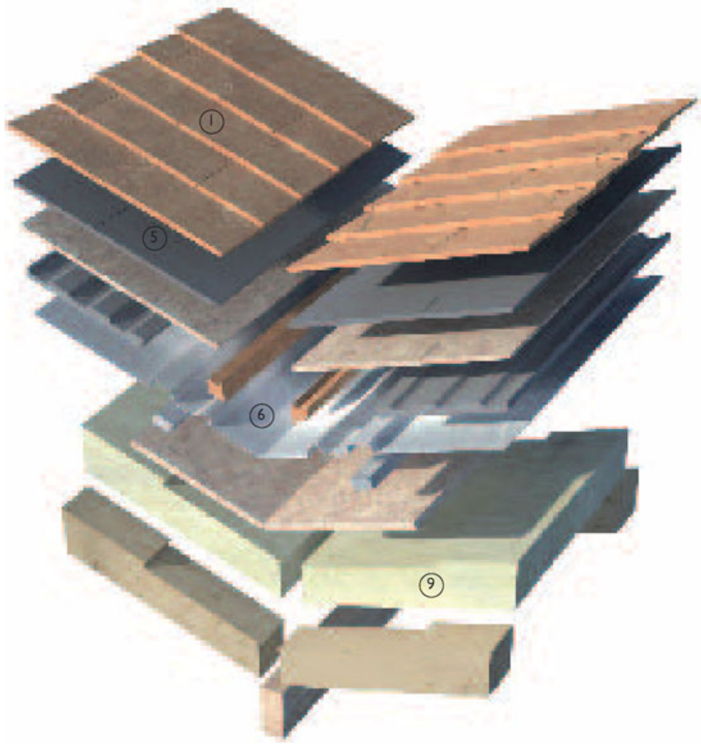


3D exploded view showing tiled roof abutment condition

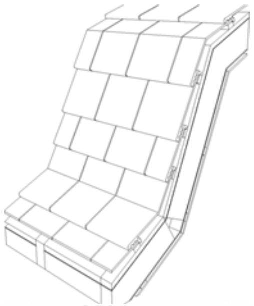


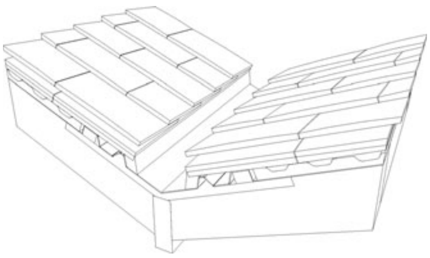
3D exploded view showing eaves condition on roof with interlocking tiles

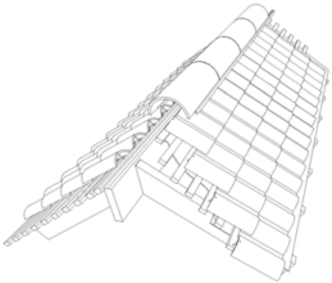
3D exploded view showing internal fold on roof using interlocking tiles

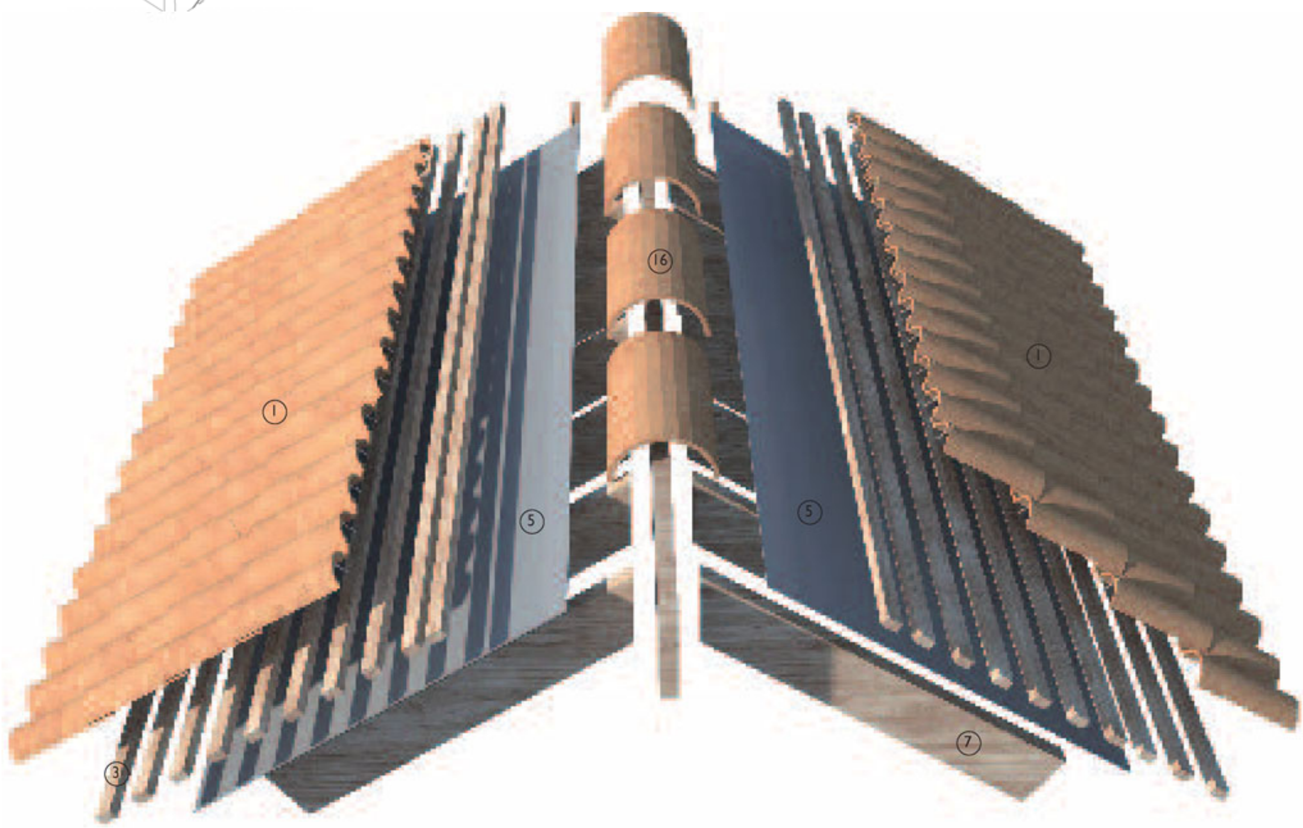


3D exploded view showing valley condition on roof using plain tiles

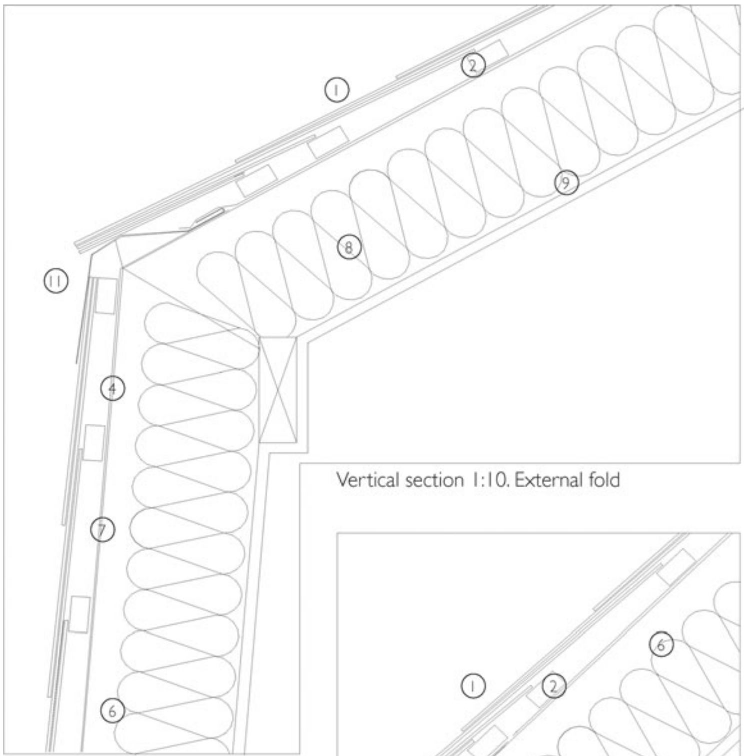




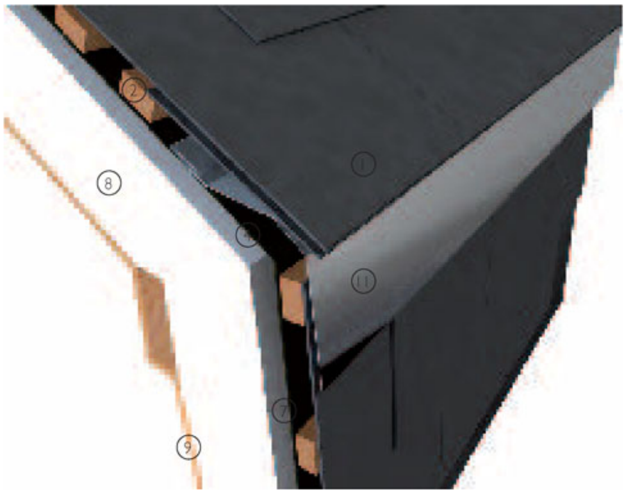




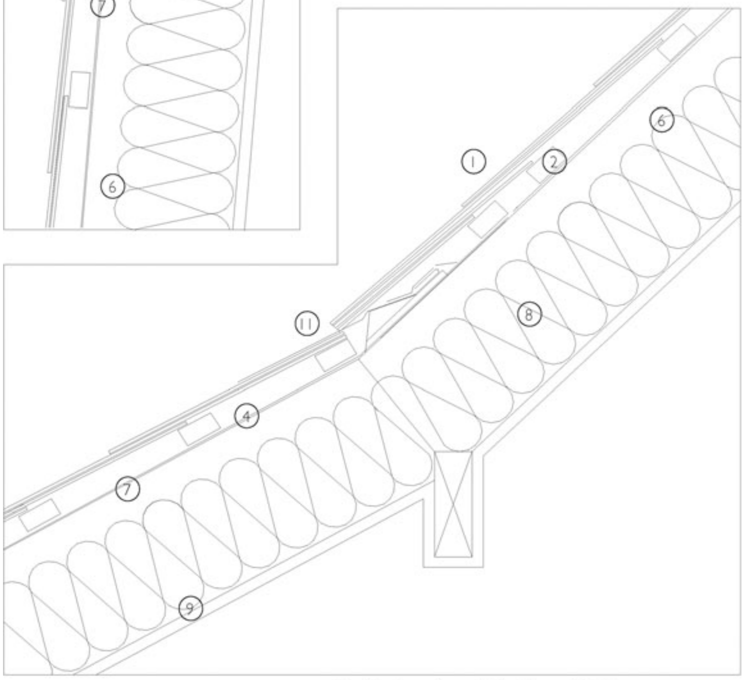
3D exploded view showing condition of roof using curved terracotta tiles



Vertical section 1:10. External fold



3-D view of external fold detail in timber pitched roof construction with roofing slates



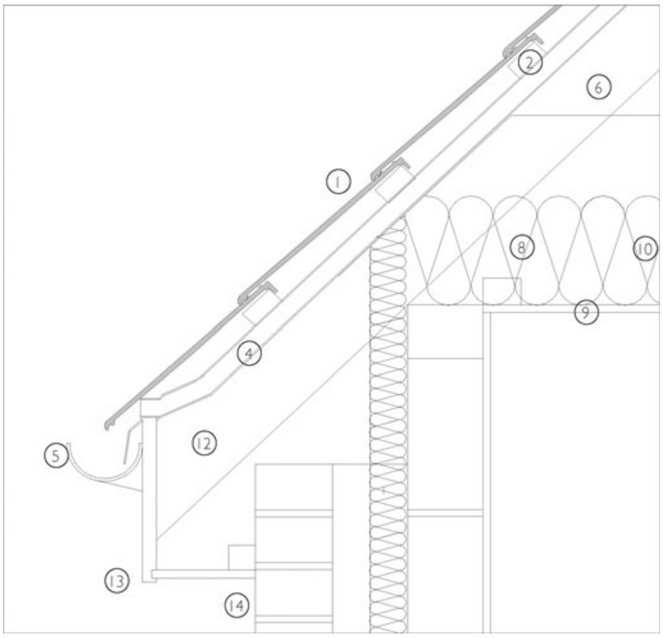
Vertical section 1:10. Internal fold

3-D view of internal fold detail in timber pitched roof construction with roofing slates

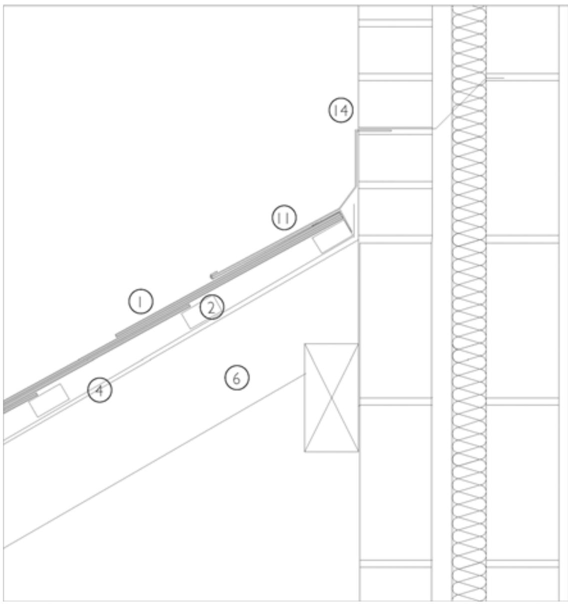
Details
1. Slate
2. Softwood battens
3. Softwood counter battens
4. Roofing felt
5. Gutter
6. Softwood rafter
7. Vapour permeable membrane
8. Thermal insulation
9. Vapour barrier
10. Softwood joist
11. Metal flashing
12. Ventilator
13. Fascia board
14. External wall
15. Ridge capping
16. Flexible pipe

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 slates 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.

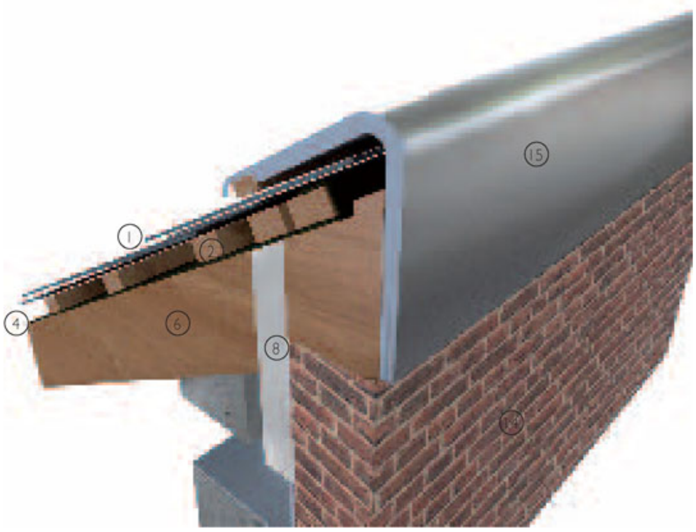
All these slate types can be used in roof pitches from vertically hung to usually 22.5° above the horizontal. All slate types require a head lap (discussed in the previous section on tiles) ranging from 60mm to around 120mm depending on the roof pitch. Both natural slate and fibre cement types are laid 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.



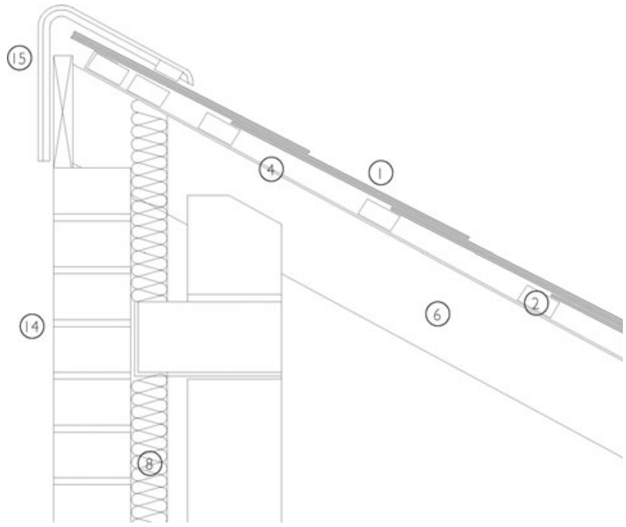
Vertical section 1:10. Eaves



Vertical section 1:10. Abutment



3-D view of timber monopitched roof construction with roofing slates



Vertical section 1:10. Monopitch ridge

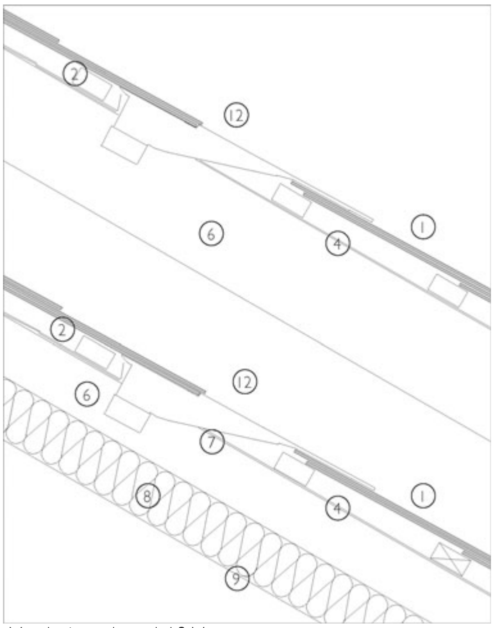
Natural slate is sorted into at least three groups on site, based on the material thickness, which varies in the splitting of the natural material. When fixed, slates used on any course (row of slates) are of similar thickness. The thickest slates are used at the base of the roof, and the thinnest are 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 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 outlined in the section on tiled roofs.

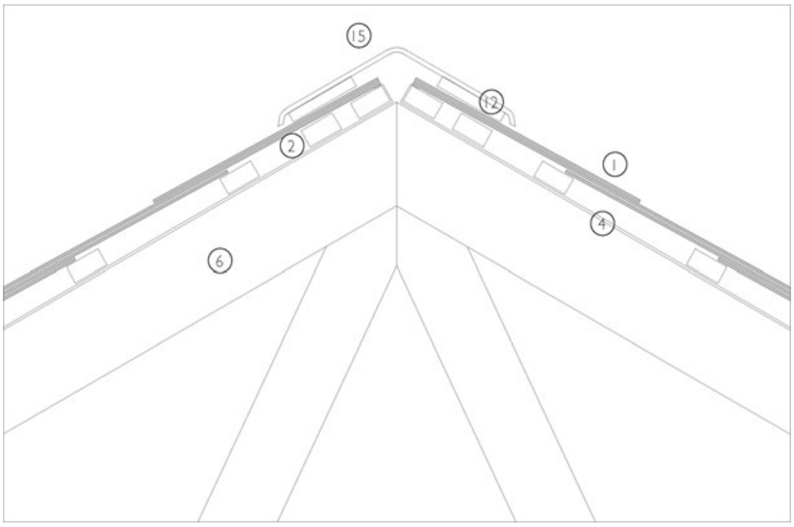
Roof folds

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. When the roof pitch forms an internal fold, 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. An 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 with an internal fold.

3-D view of timber monopitched roof construction with roofing slates

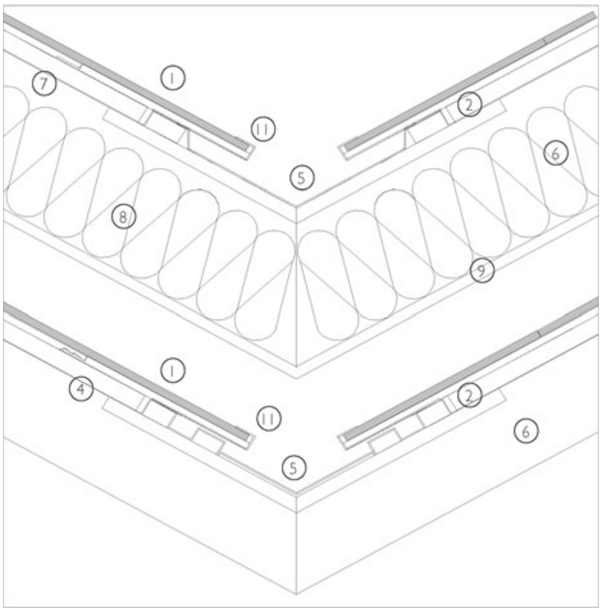


Vertical sections 1:10. Verges



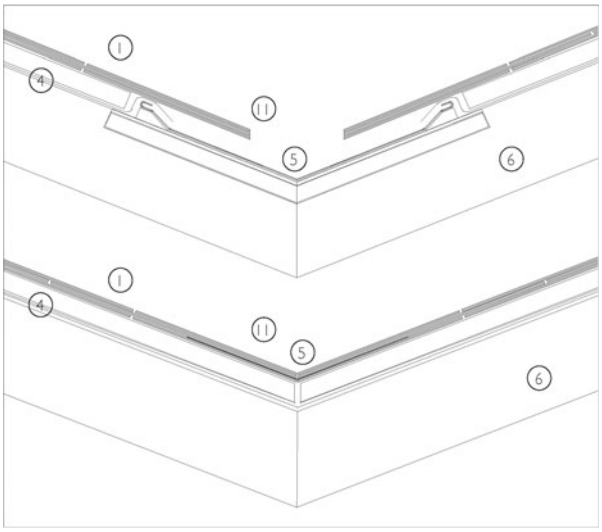
Vertical section 1:10. Ridge

3-D view of valley detail in timber pitched roof construction with roofing slates

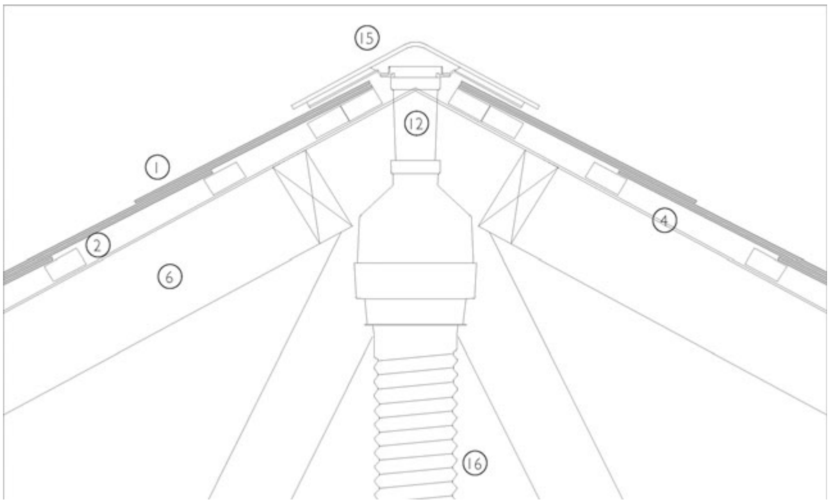


Vertical sections 1:10. Valleys

3-D view of valley detail in timber pitched roof construction with roofing slates



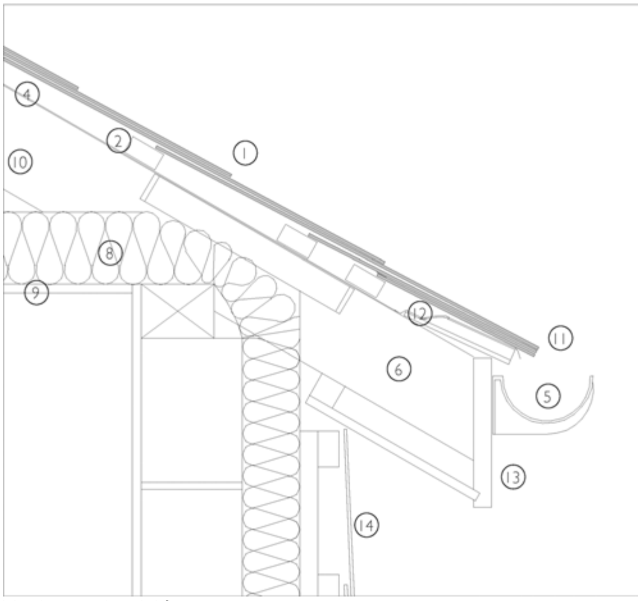
Vertical sections 1:10. Valleys



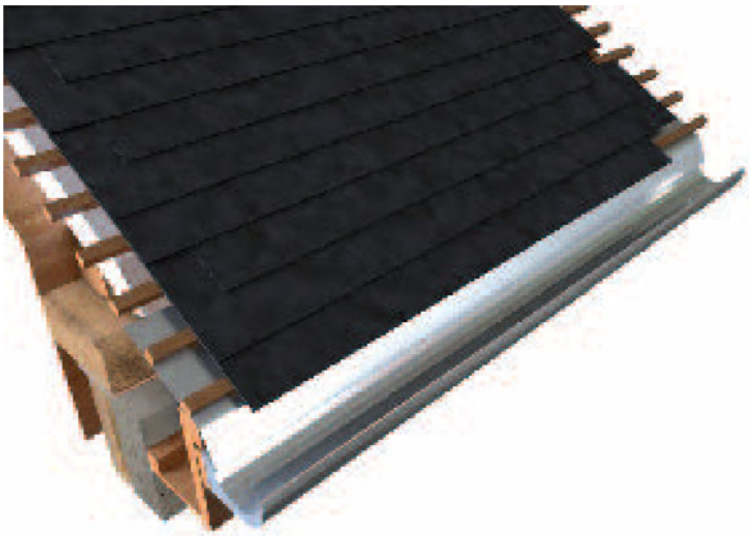
Vertical section 1:10. Ridge with vent extract

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

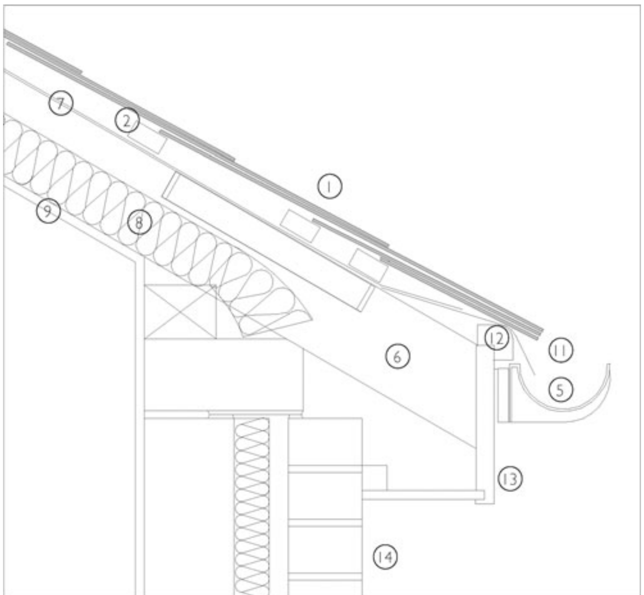


Vertical section 1:10. Eaves

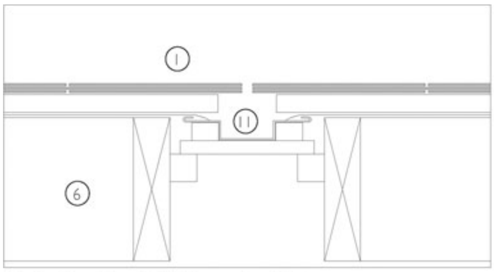


3-D view of timber pitched roof construction with roofing slates with gutter at eaves

3-D view of timber pitched roof construction with roofing slates with gutter at eaves

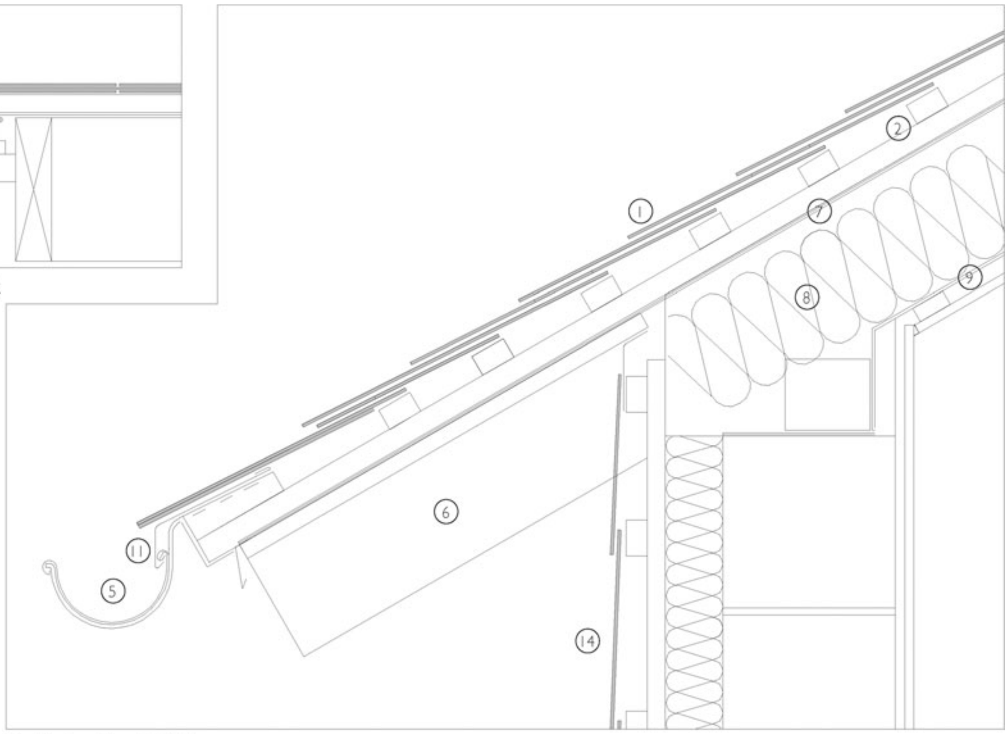


Vertical section 1:10. Eaves



Vertical section 1:10. Expansion joint

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



Vertical section 1:10. Eaves

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. A ridge vent 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 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.

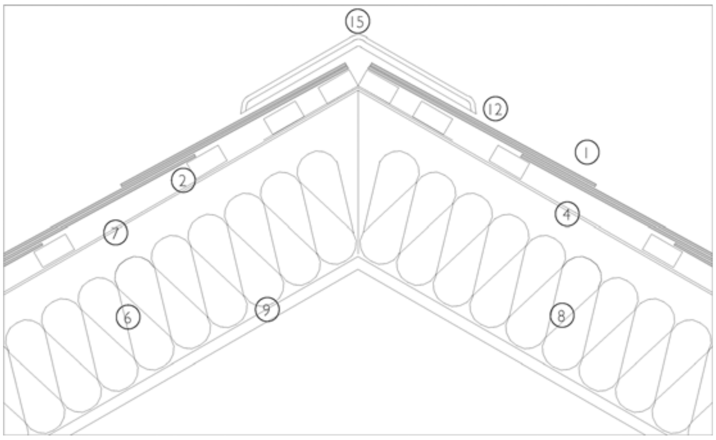
Dormer windows

For slate cladding on the vertical faces, or cheeks, of a dormer window 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 the slates, 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. At the corners of the vertically-hung slates, 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.

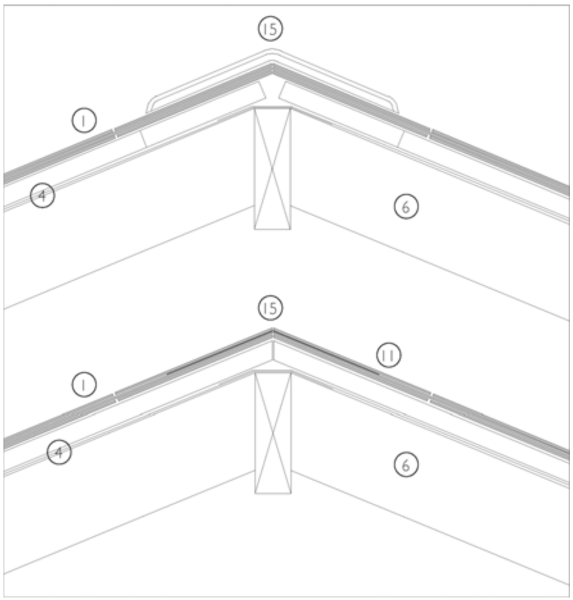
Abutments

Abutments at the side of a pitched roof, and at a monopitch ridge condition, 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 the flashing is returned into a joint between brick courses.

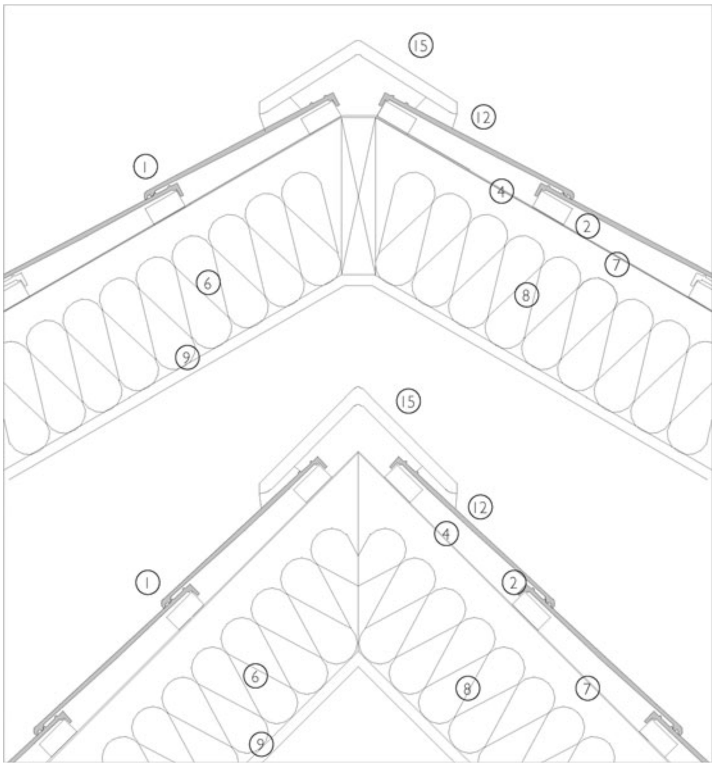
Valley gutters are formed in the same way, with a metal tray folded up the underside of the slate, as described in the section on tiled roofs. The vertical face of the gutter where it meets the adjacent wall is sealed with a flashing set over the top of the gutter to provide a complete weathertight seal.



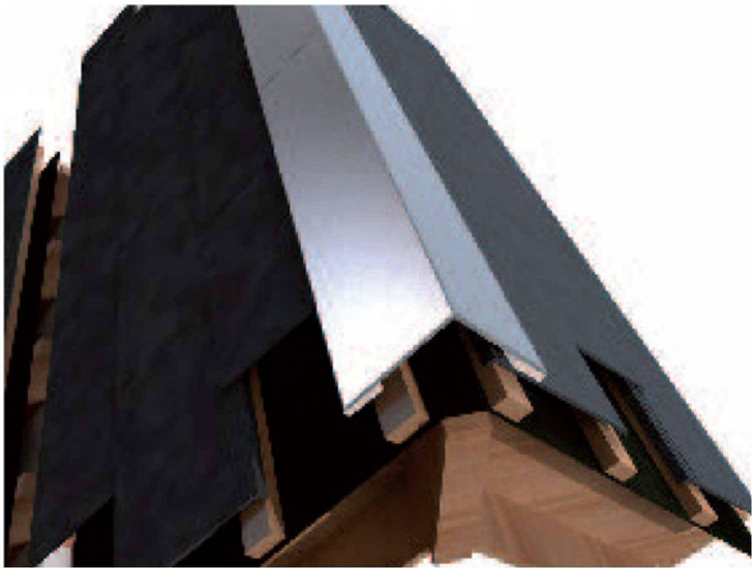
Vertical section 1:10. Ridges



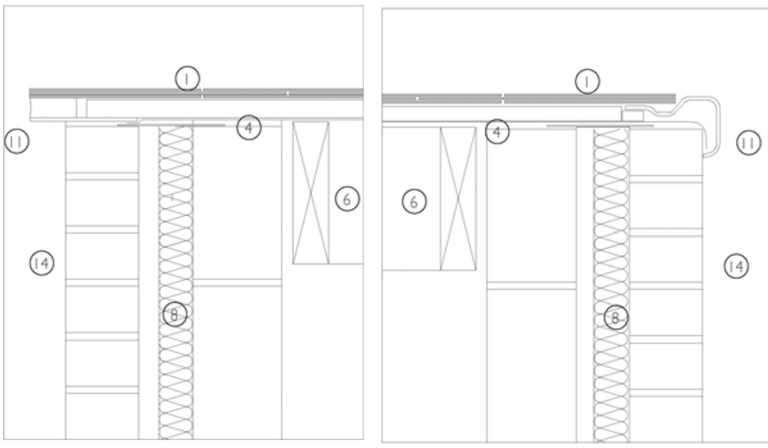
Vertical sections 1:10. Hips



Vertical sections 1:10. Ridges

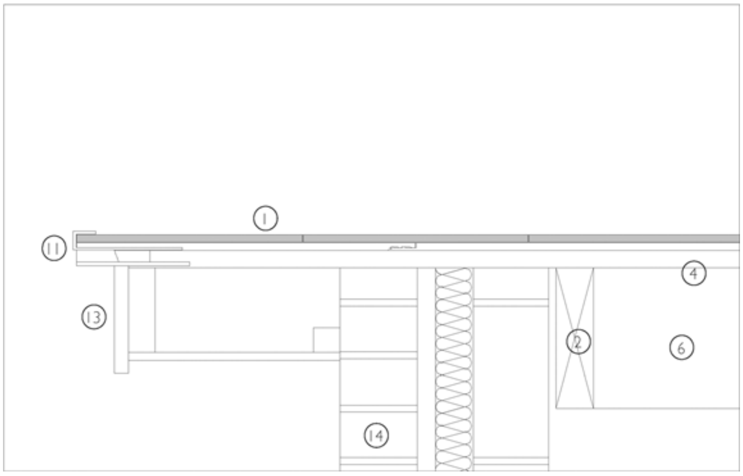


3-D view of ridge detail of timber pitched roof construction with roofing slates

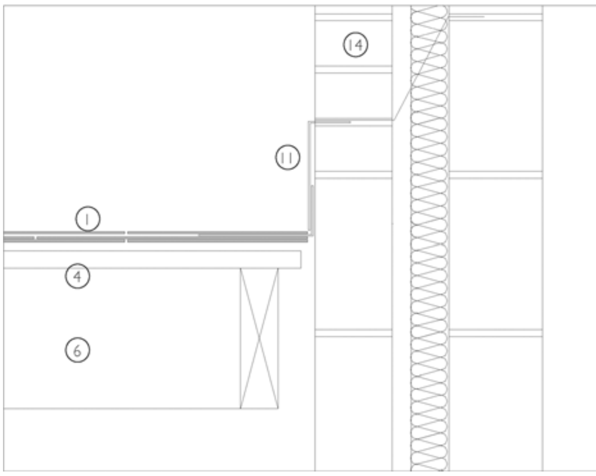


Vertical section 1:10. Ventilators

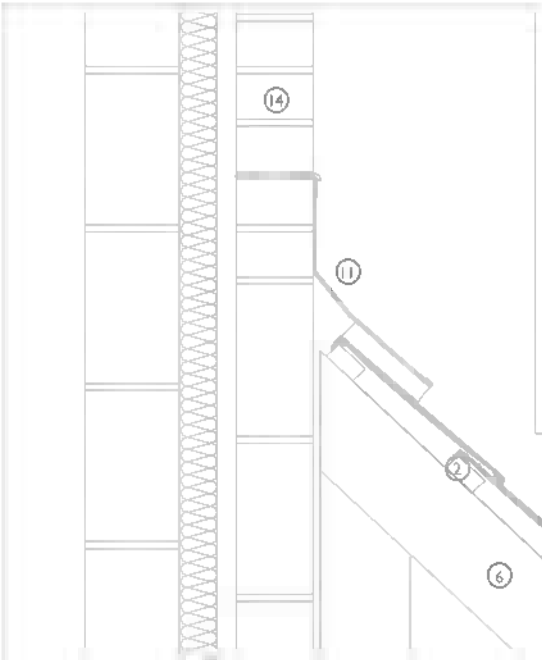
3-D view of ridge detail of timber pitched roof construction with roofing slates



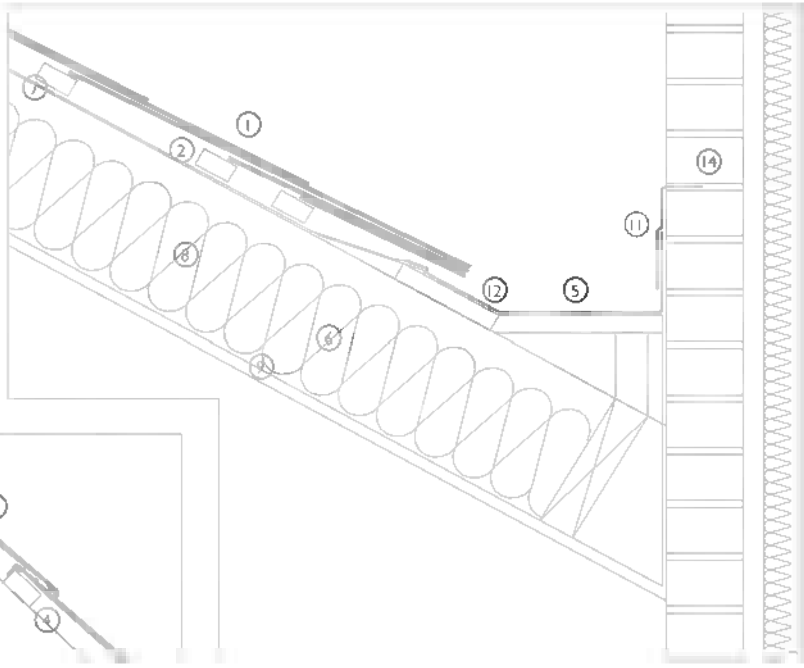
Vertical section 1:10. Verge



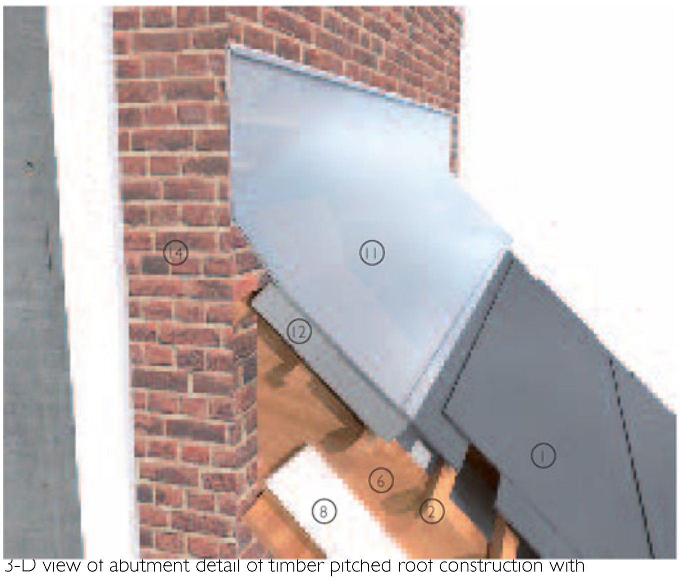
Vertical section 1:10. Abutment



Vertical section 1:10. Abutment

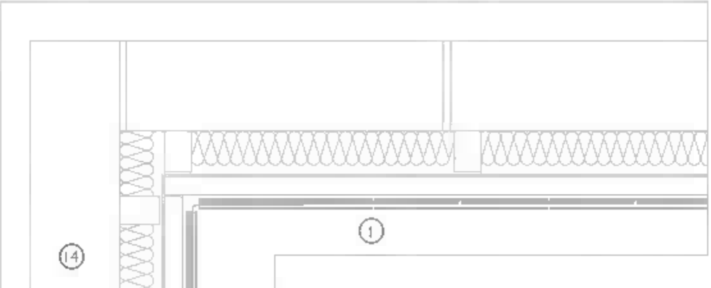
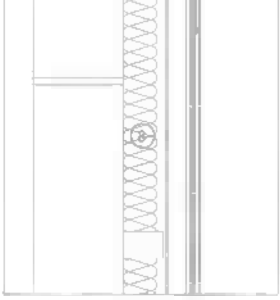


Vertical section 1:10. Valley gutter

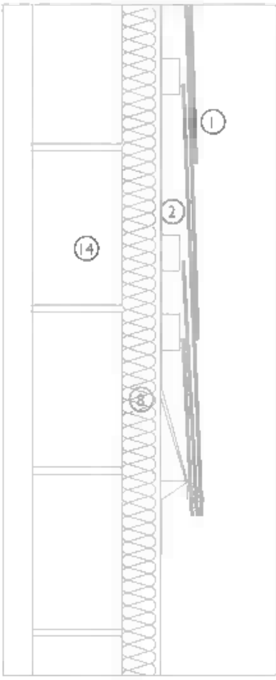


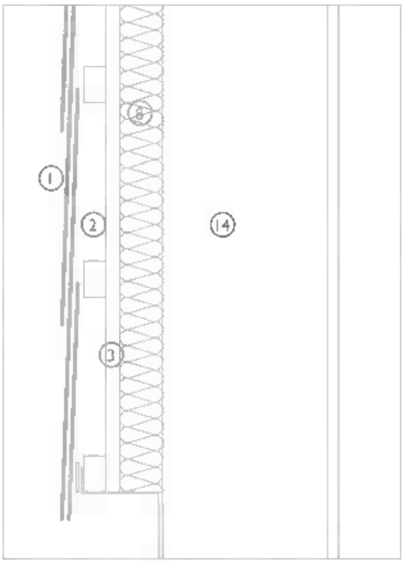
3-D view of abutment detail of timber pitched roof construction with roofing slates

3-D view of abutment detail of timber pitched roof construction with roofing slates

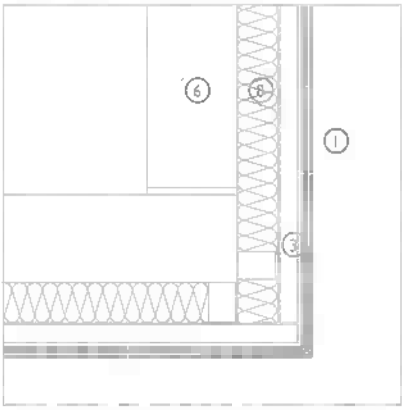



Horizontal sections 1:10. Vertically hung slates at internal corner

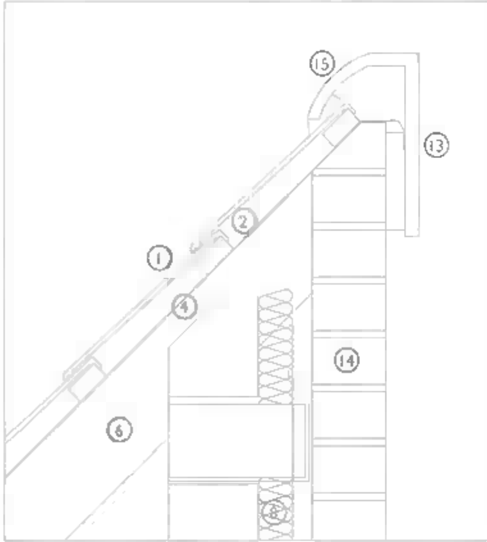




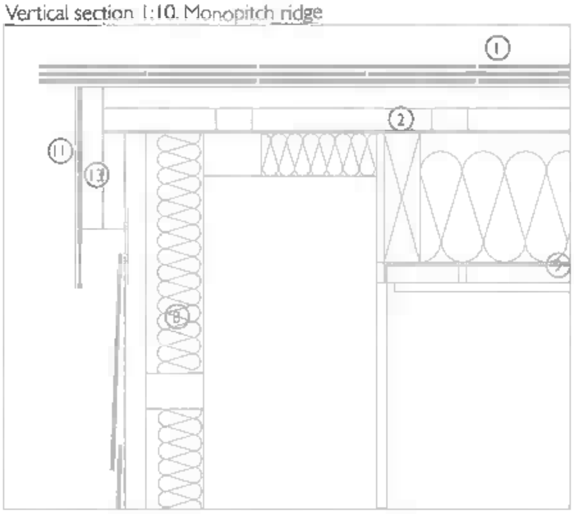
Vertical section 1:10. Base of wall



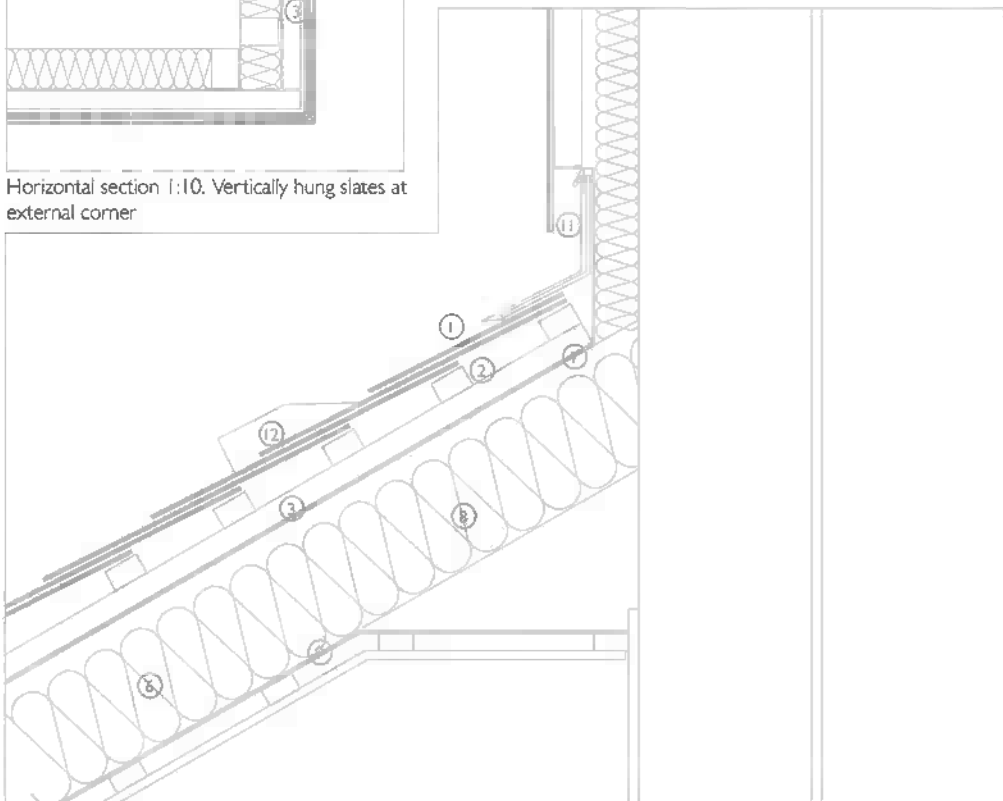
Horizontal section 1:10. Vertically hung slates at external corner



Vertical section 1:10. Monopitch ridge



Vertical section 1:10. Vertically hung slates at external corner



Vertical section 1:10. Dormer window

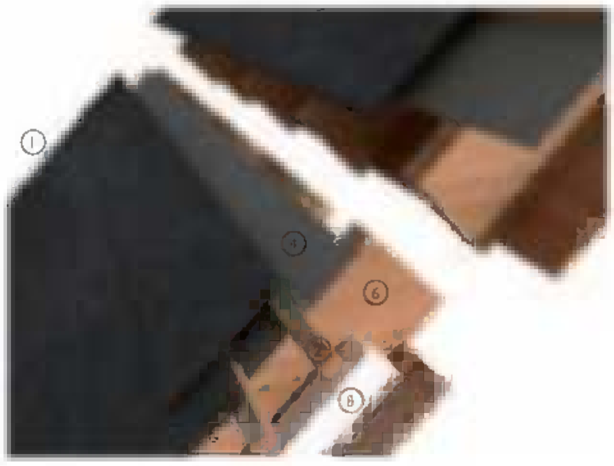
Details

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

3-D overview of timber pitched roof construction with roofing slates

Details

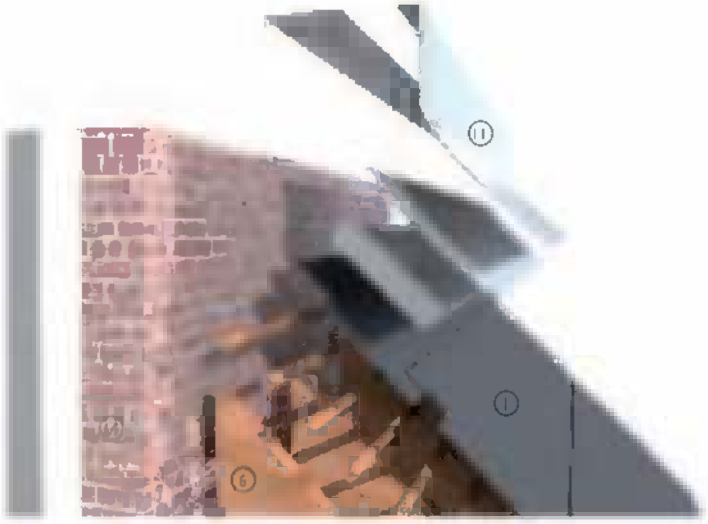
1. Slate
2. Softwood battens
3. Softwood counter battens
4. Roofing felt
5. Gutter
6. Softwood rafter
7. Vapour permeable membrane
8. Thermal insulation
9. Vapour barrier
10. Softwood joist
11. Metal flashing
12. Ventilator
13. Fascia board
14. External wall
15. Ridge capping
16. Flexible pipe



3-D detail view of timber pitched roof construction with roofing slates

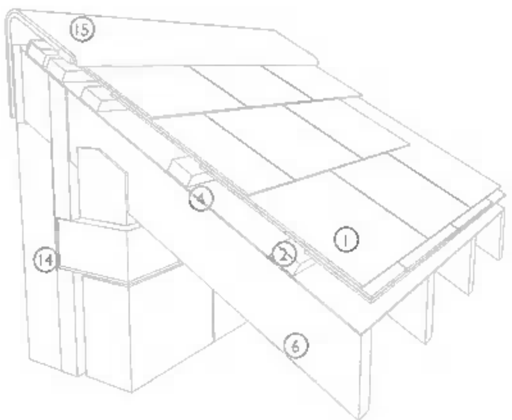
3-D exploded view of timber pitched roof construction with roofing slates

3-D exploded view of timber pitched roof construction with roofing slates

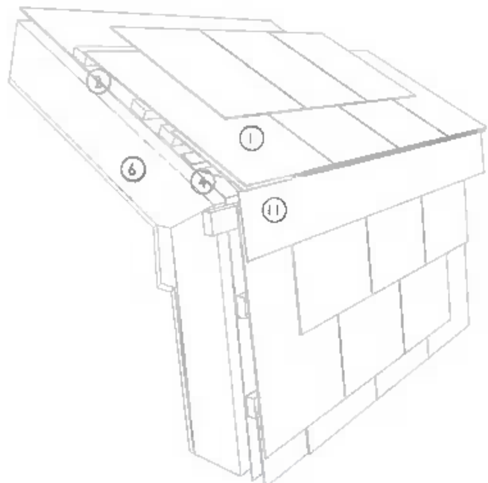


3-D exploded view of abutment detail of timber pitched roof construction with roofir

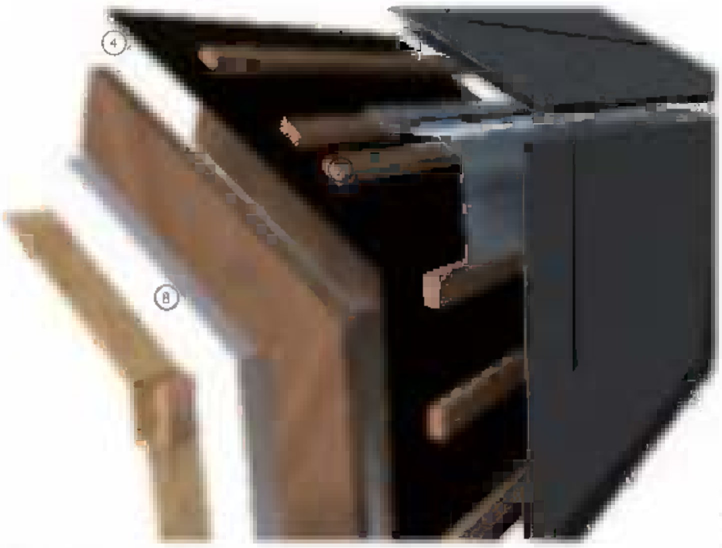
3-D exploded view of timber monopitched roof construction with roofing slates



3-D line drawing of timber monopitched roof construction with roofing slates

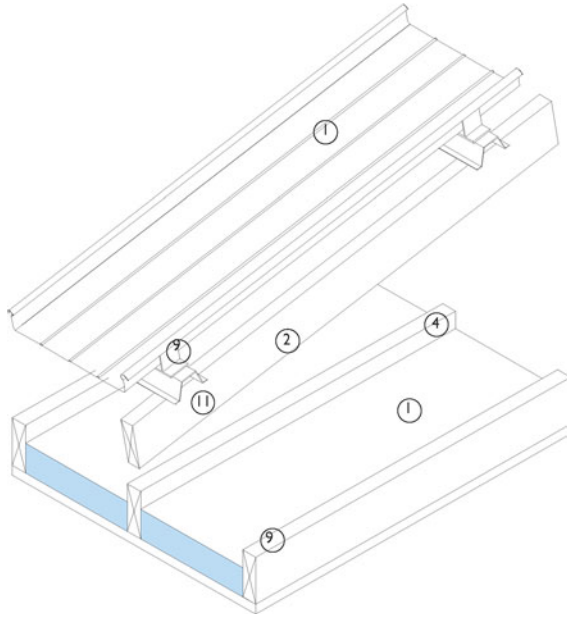


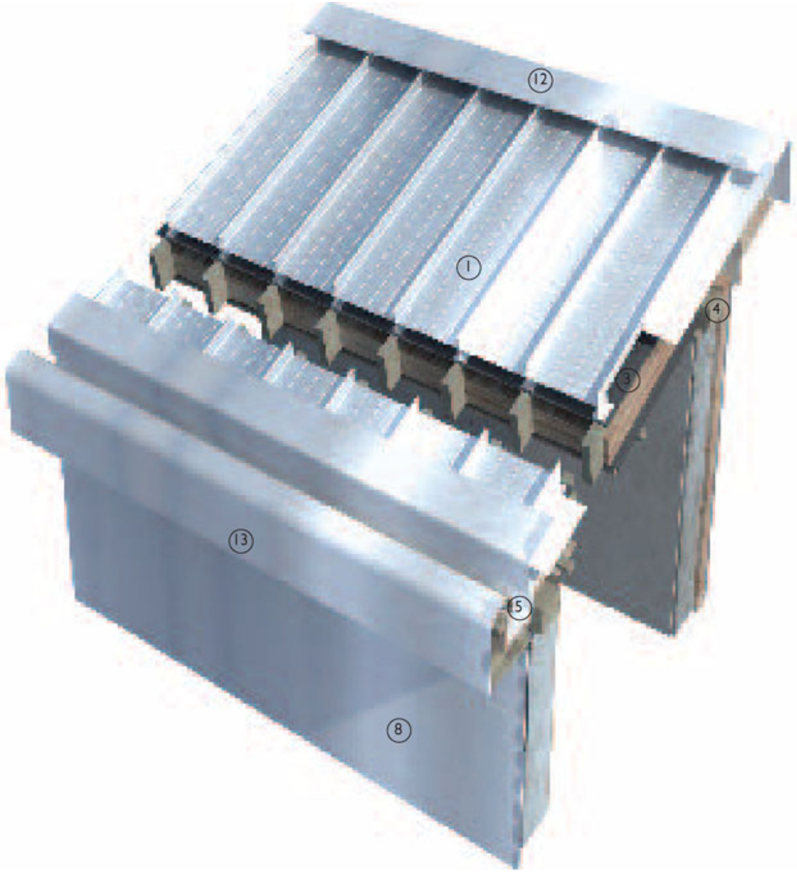
3-D line drawing of timber pitched roof construction with roofing slates, external fold detail



3-D exploded view of timber pitched roof construction with roofing slates, external fold detail

3-D exploded view of timber pitched roof construction with roofing slates, eaves detail





Isometric view of assembly

3-D view showing metal standing seam pitched roof with timber structure

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

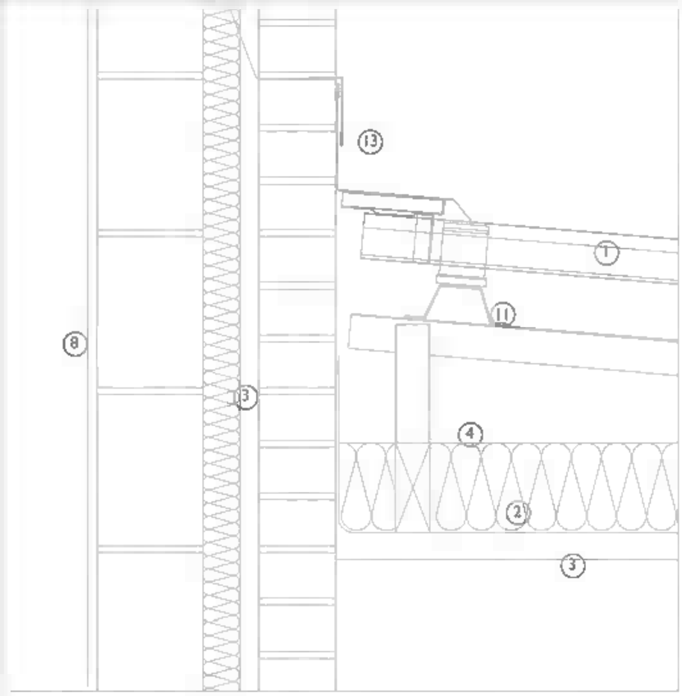
Eaves are ventilated by leaving a gap between the top of the fascia board supporting the gutter and the underside of the standing seam roof sheet. A metal angle is fixed in front of the opening to avoid rainwater being blown through the opening into the roof void. Valley gutters are formed in a similar 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

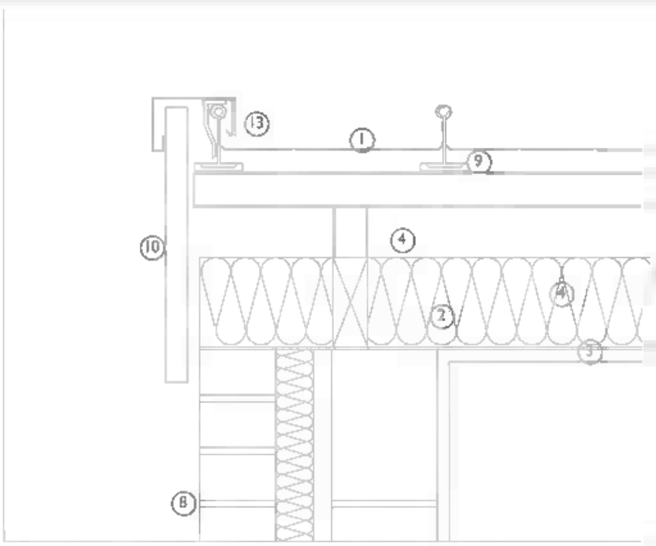
Ridges are formed by creating a gap, typically 100mm between the metal sheets. The gap at the ridge is covered with a folded metal ridge capping which is fixed to the sheets beneath. A narrow gap is maintained between the ridge sheet and the standing seam sheet in order to provide constant ventilation 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 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, 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. In some examples, 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.

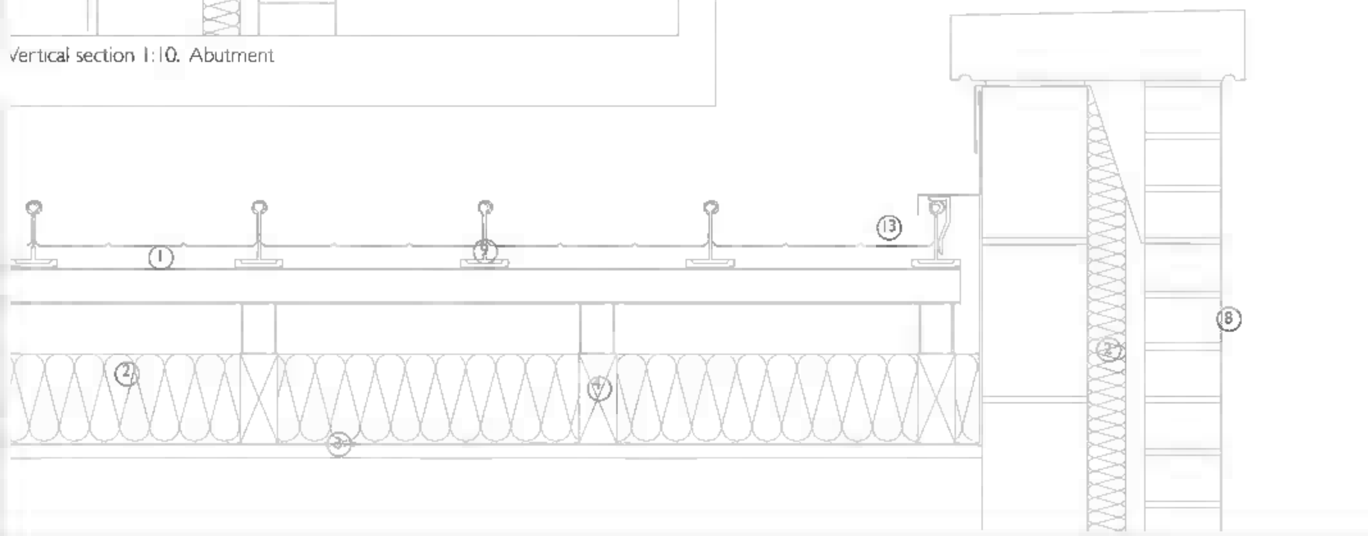


Vertical section 1:10. Abutment



Vertical section 1:10. Verge

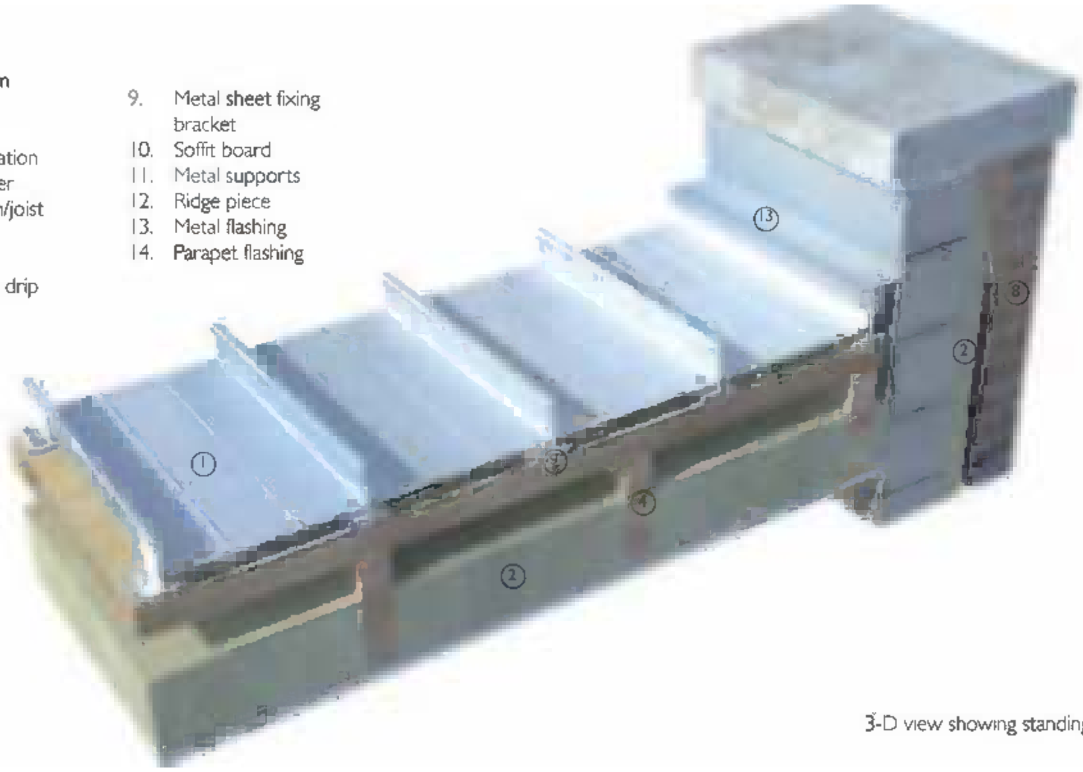
Vertical section 1 10. Parapet verge



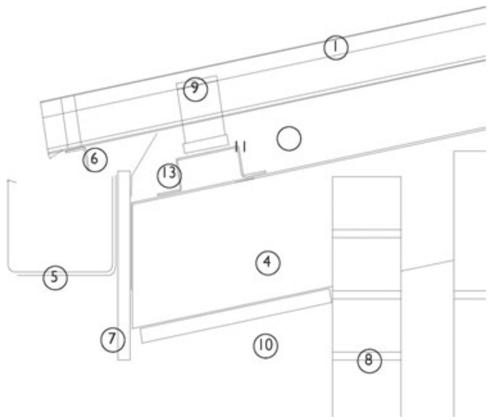
Details

- Standing seam sheet
- Fibre quilt thermal insulation
- Vapour barrier
- Timber beam/joist
- Folded metal gutter
- Folded metal drip
- Fascia board
- External wall

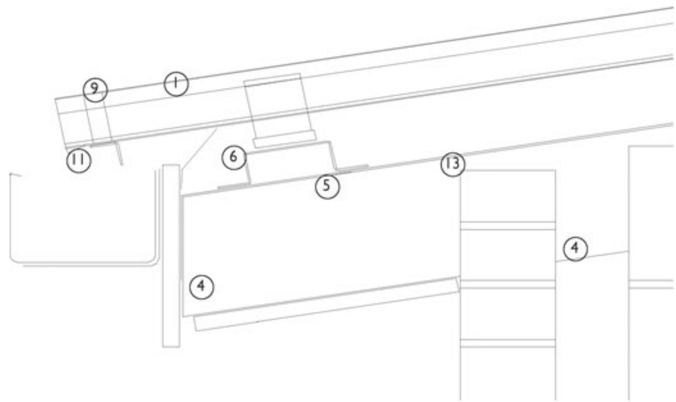
9. Metal sheet fixing bracket
10. Soffit board
11. Metal supports
12. Ridge piece
13. Metal flashing
14. Parapet flashing



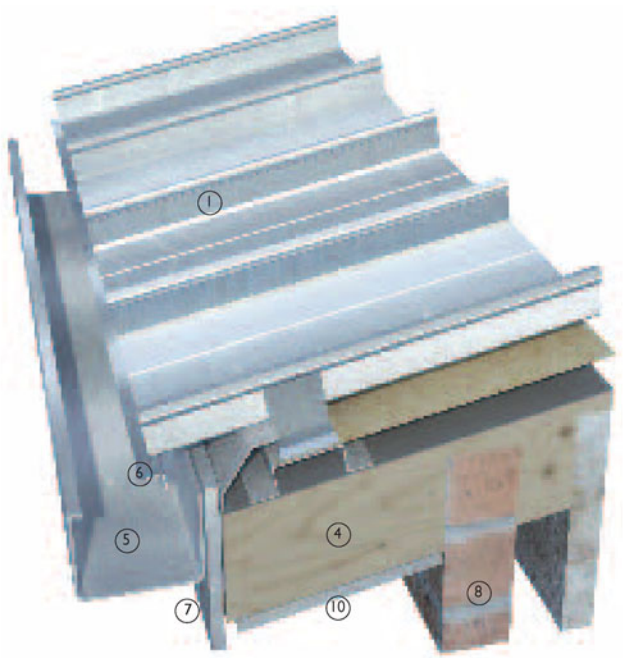
3-D view showing standing seam cold roof configuration



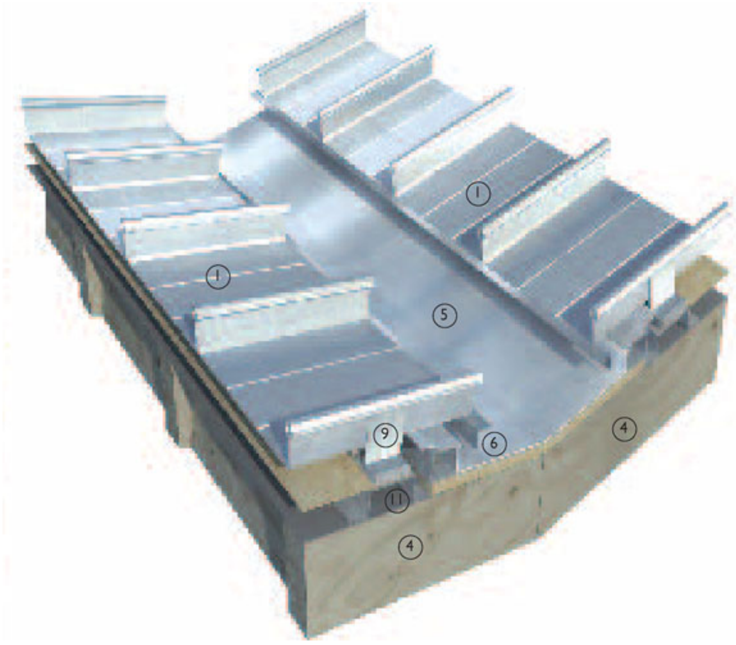
Vertical section 1:10. Eaves



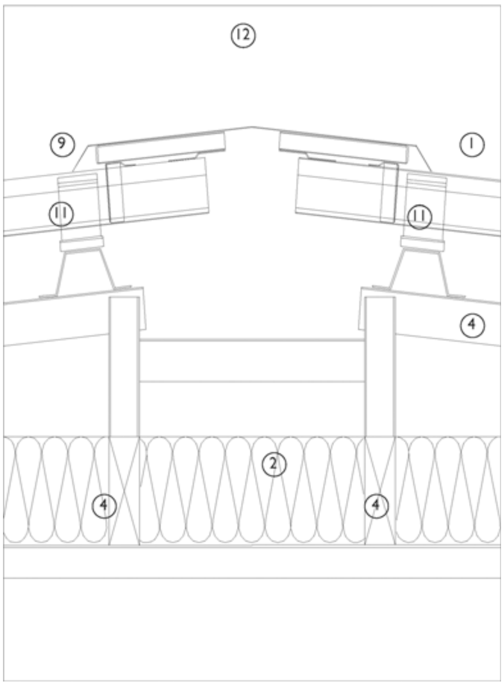
Vertical section 1:10. Valley gutter



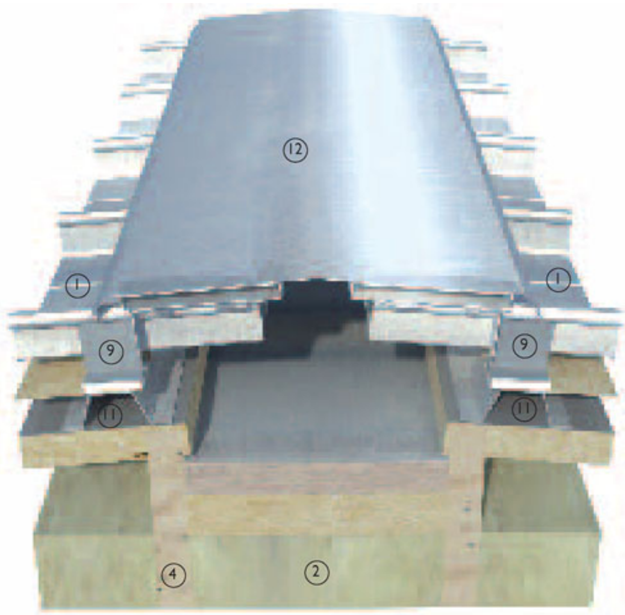
3-D view showing eaves and gutter detail on metal pitched roof



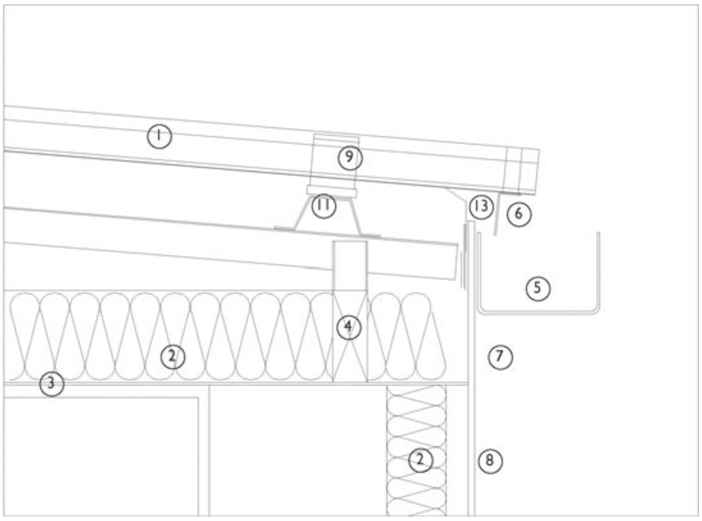
3-D view showing valley gutter detail on metal pitched roof



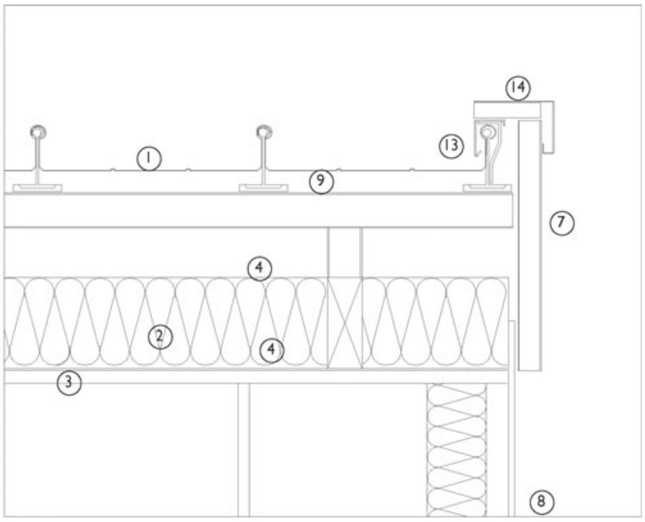
Vertical section 1:10. Ridge



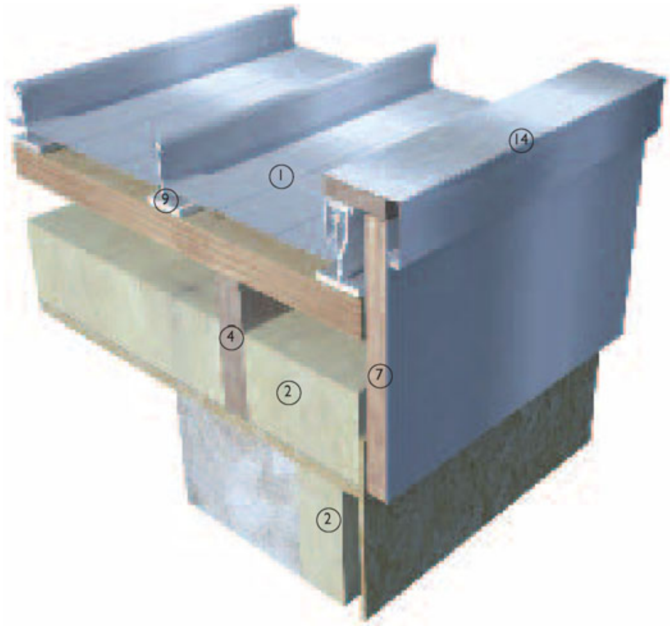
3-D view showing ridge detail fragment



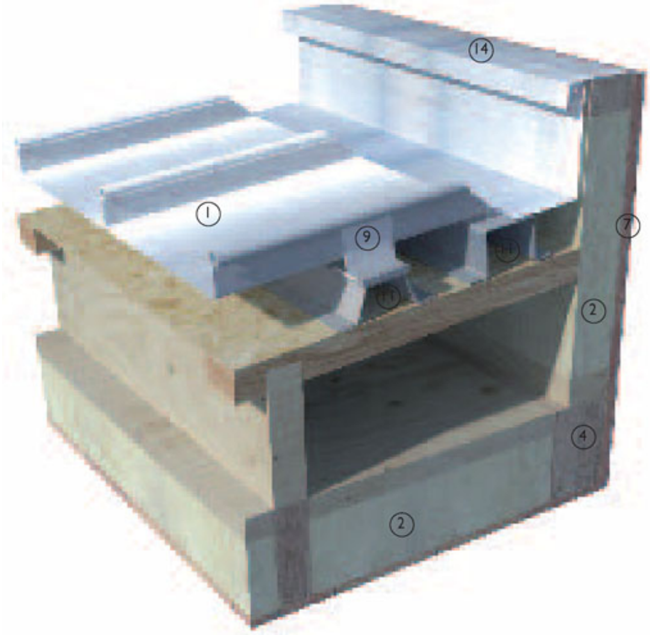
Vertical section 1:10. Eaves



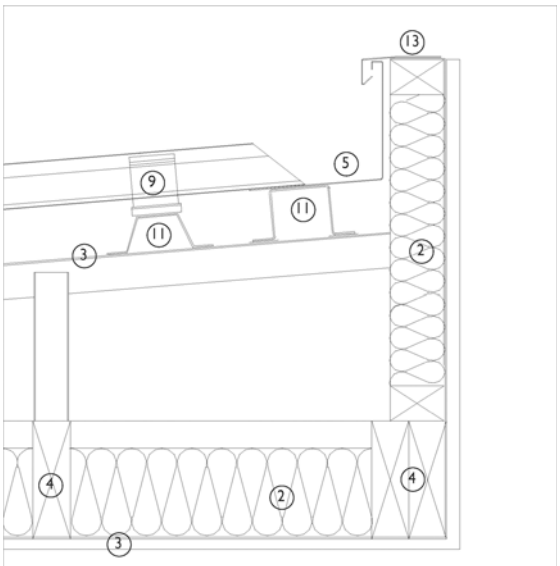
Vertical section 1:10. Verge



3-D view showing verge on metal standing seam cold roof

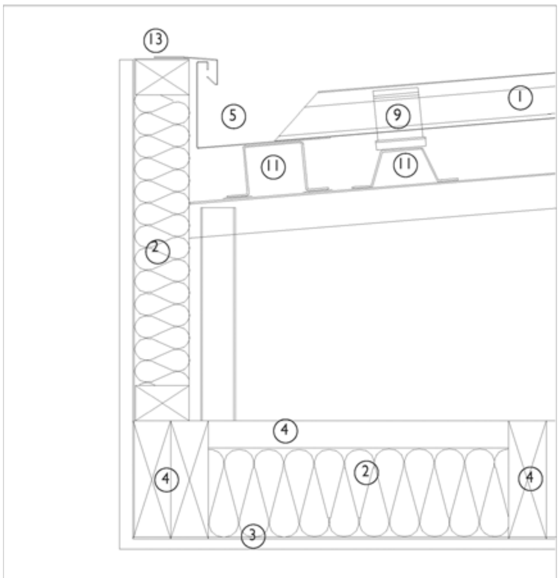


3-D view showing edge condition on metal standing seam cold roof



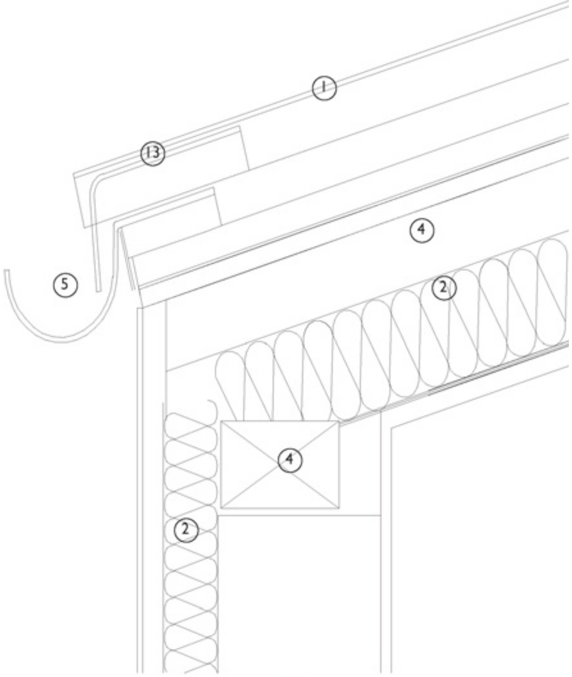
Details

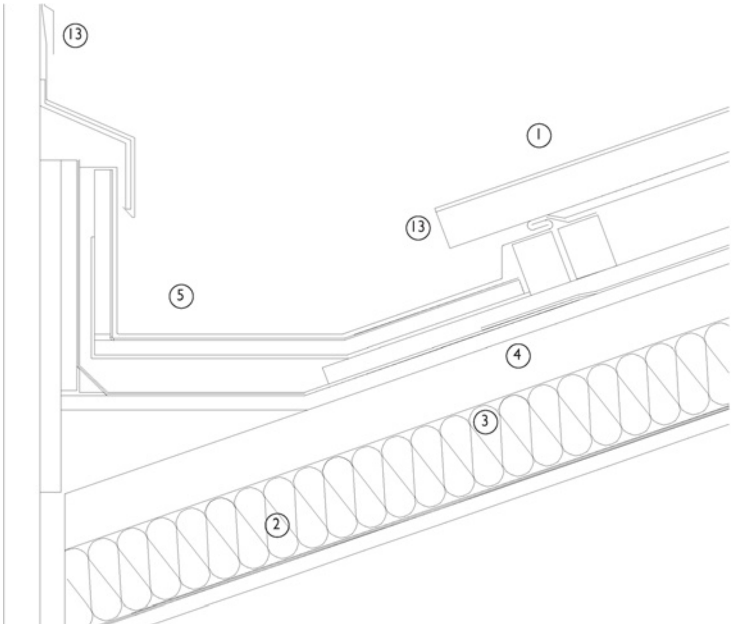
1. Standing seam sheet
2. Fibre quilt thermal insulation
3. Vapour barrier
4. Timber beam/joist
5. Folded metal gutter
6. Folded metal drip
7. Fascia board
8. External wall
9. Metal sheet fixing bracket
10. Soffit board
11. Metal supports
12. Ridge piece
13. Metal flashing
14. Parapet flashing



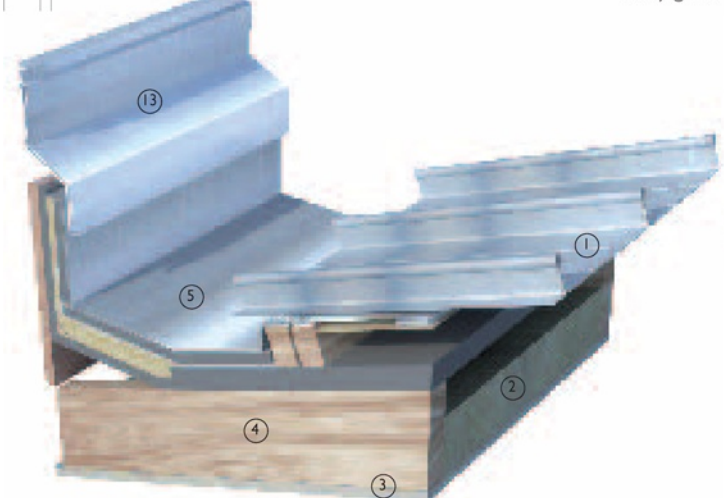
Vertical section 1:10. Penetration

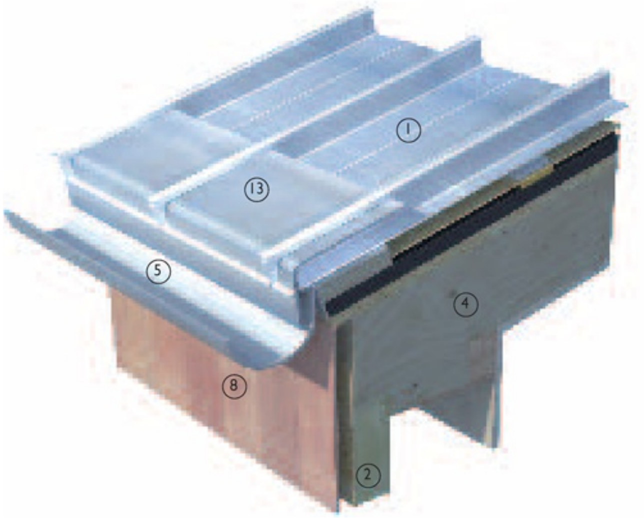
Vertical section 1:10. Standing seam roof. Eaves





Vertical section 1:10. Standing seam roof. Valley gutter





3-D views showing valley gutter and eaves gutter details on standing seam roof

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

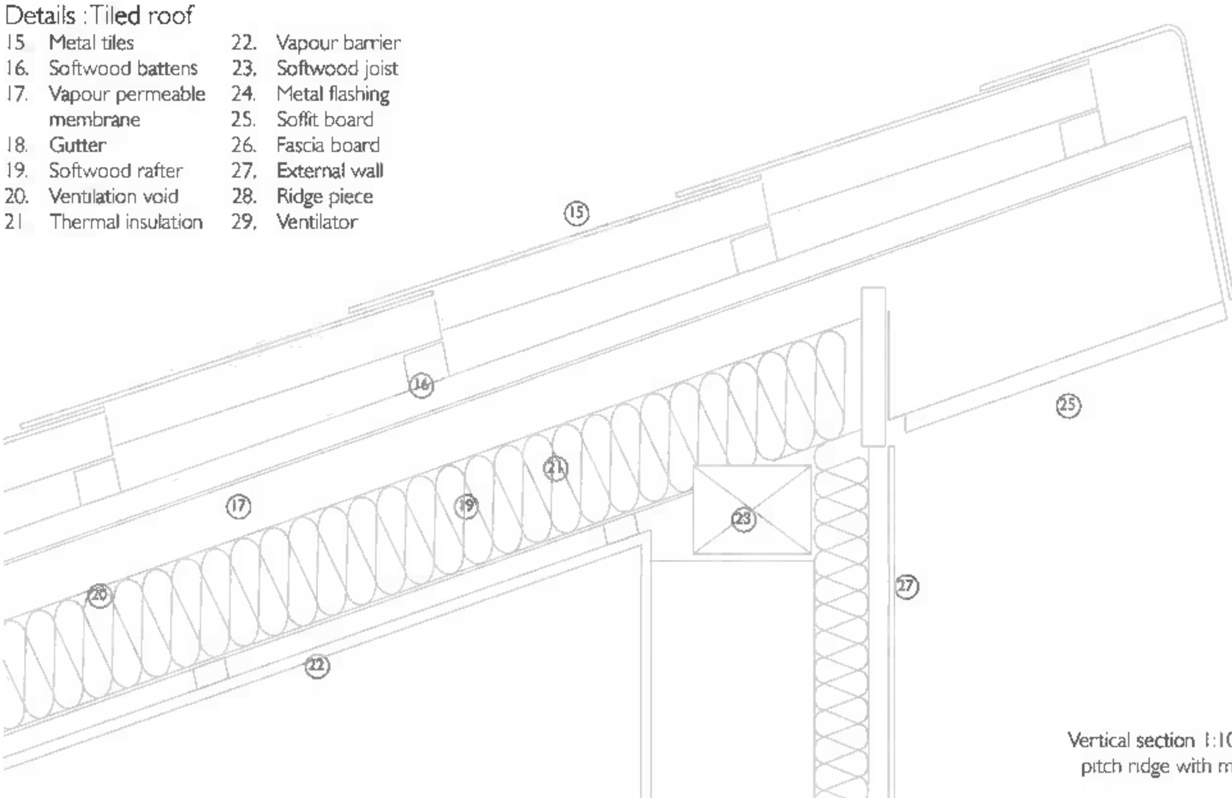
Metal tiled roofs

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 appearance 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.

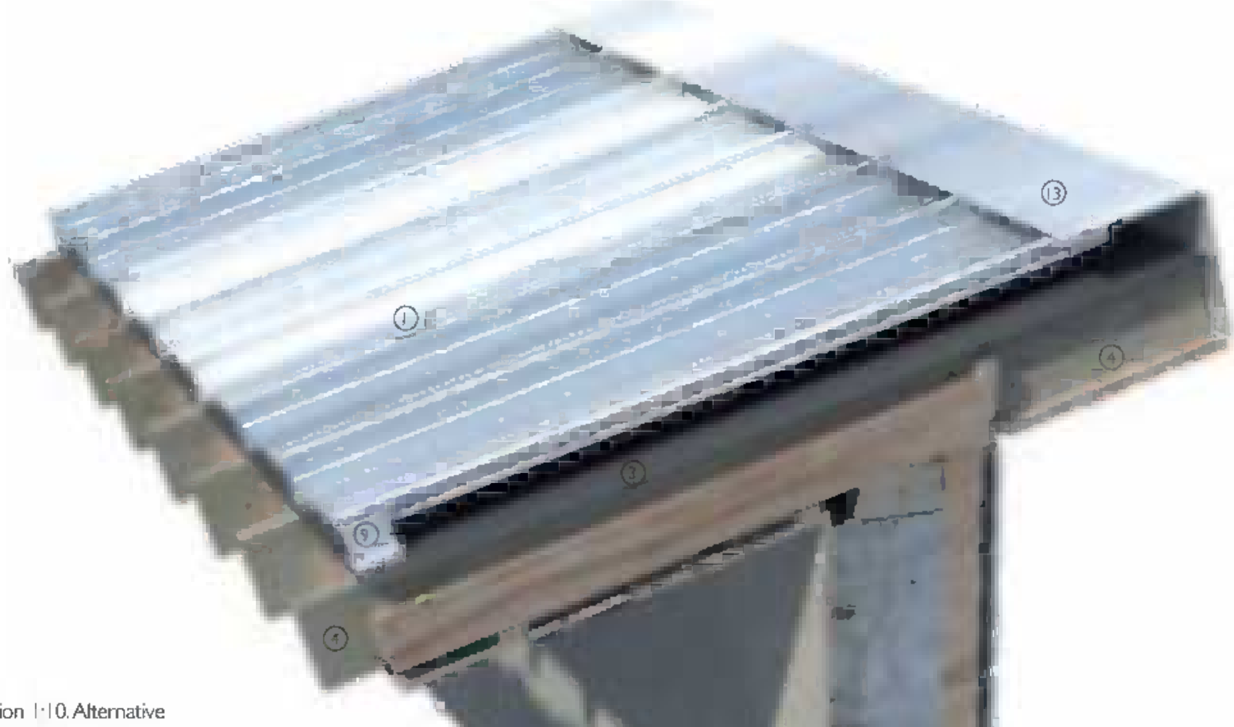
Ridges and verges are usually made from folded metal sheet and are individually designed and fabricated for a building project. An advantage of metal sheet tiles over clay tiles is that tiles and edging pieces can be individually designed for each project while remaining economic, since metal can be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

Details : Tiled roof

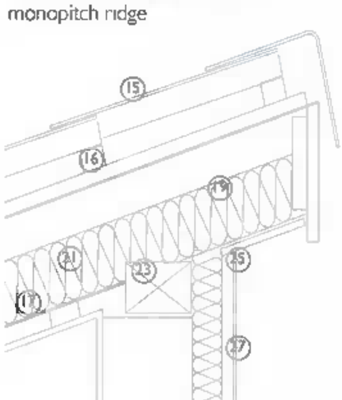
15. Metal tiles
16. Softwood battens
17. Vapour permeable membrane
18. Gutter
19. Softwood rafter
20. Ventilation void
21. Thermal insulation
22. Vapour barrier
23. Softwood joist
24. Metal flashing
25. Soffit board
26. Fascia board
27. External wall
28. Ridge piece
29. Ventilator



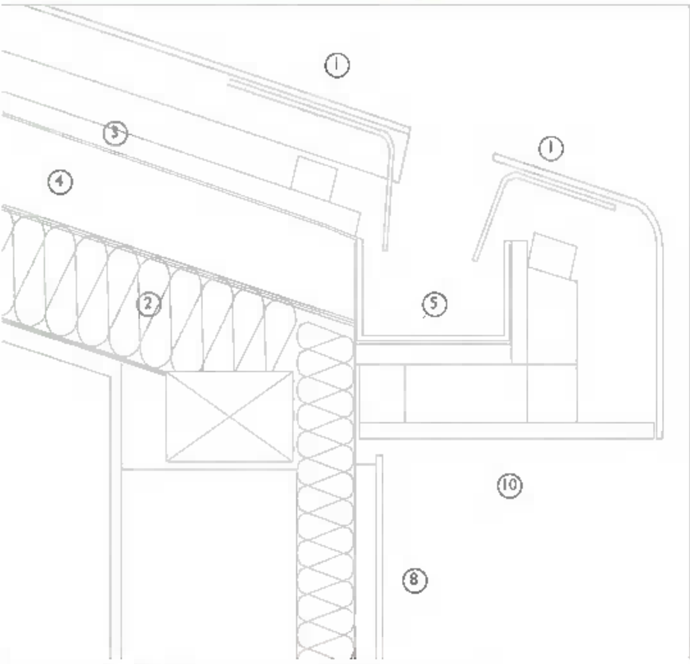
Vertical section 1:10. Mono-pitch ridge with metal tiles



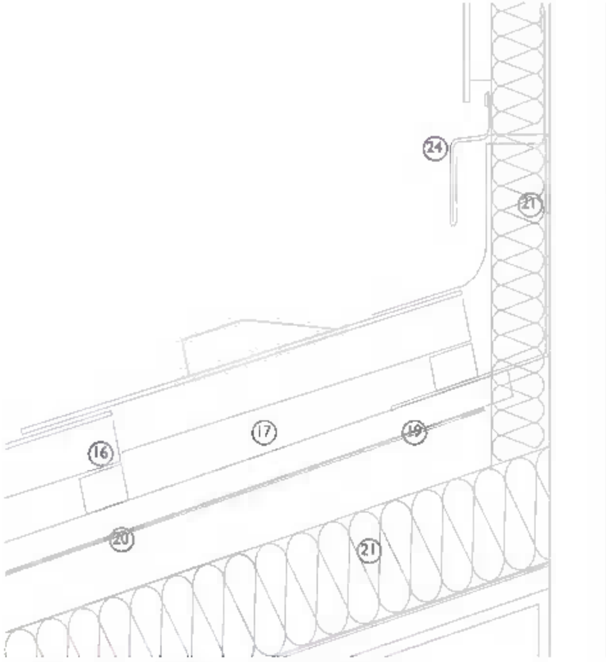
Vertical section 1:10. Alternative monopitch ridge



3-D view showing standing seam roof on timber structure



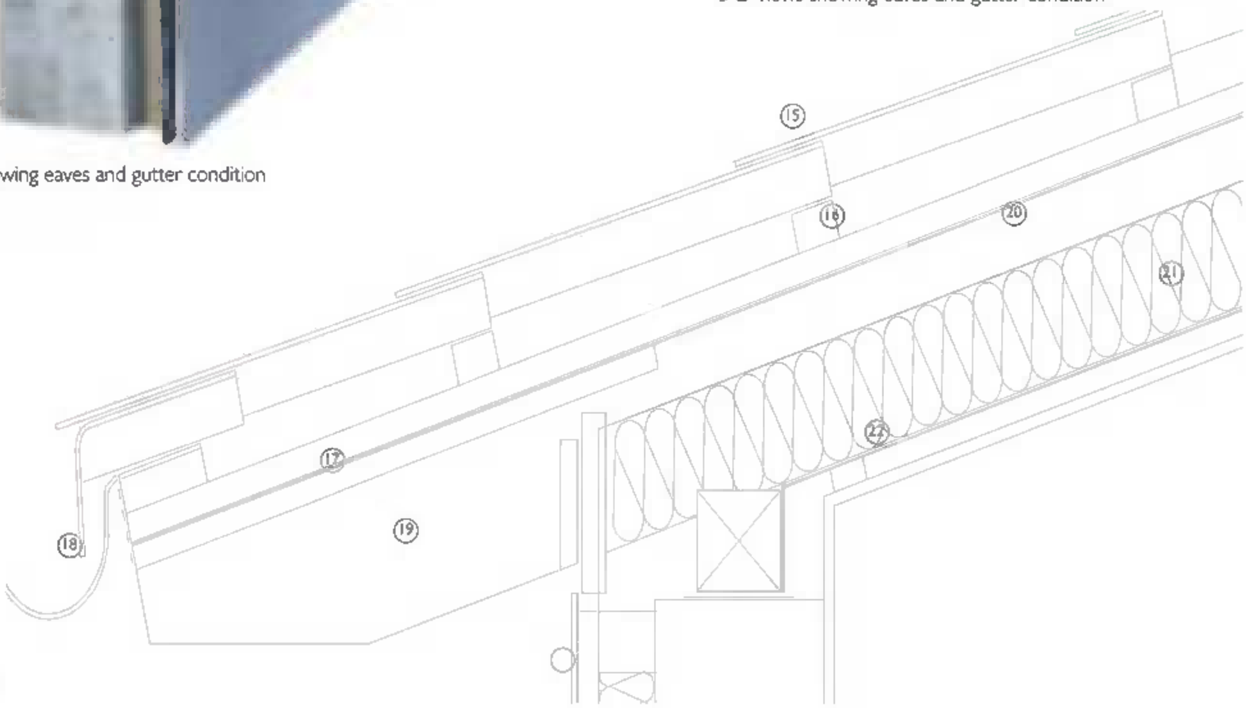
Vertical section 1:10. Standing seam roof. Eaves and gutter



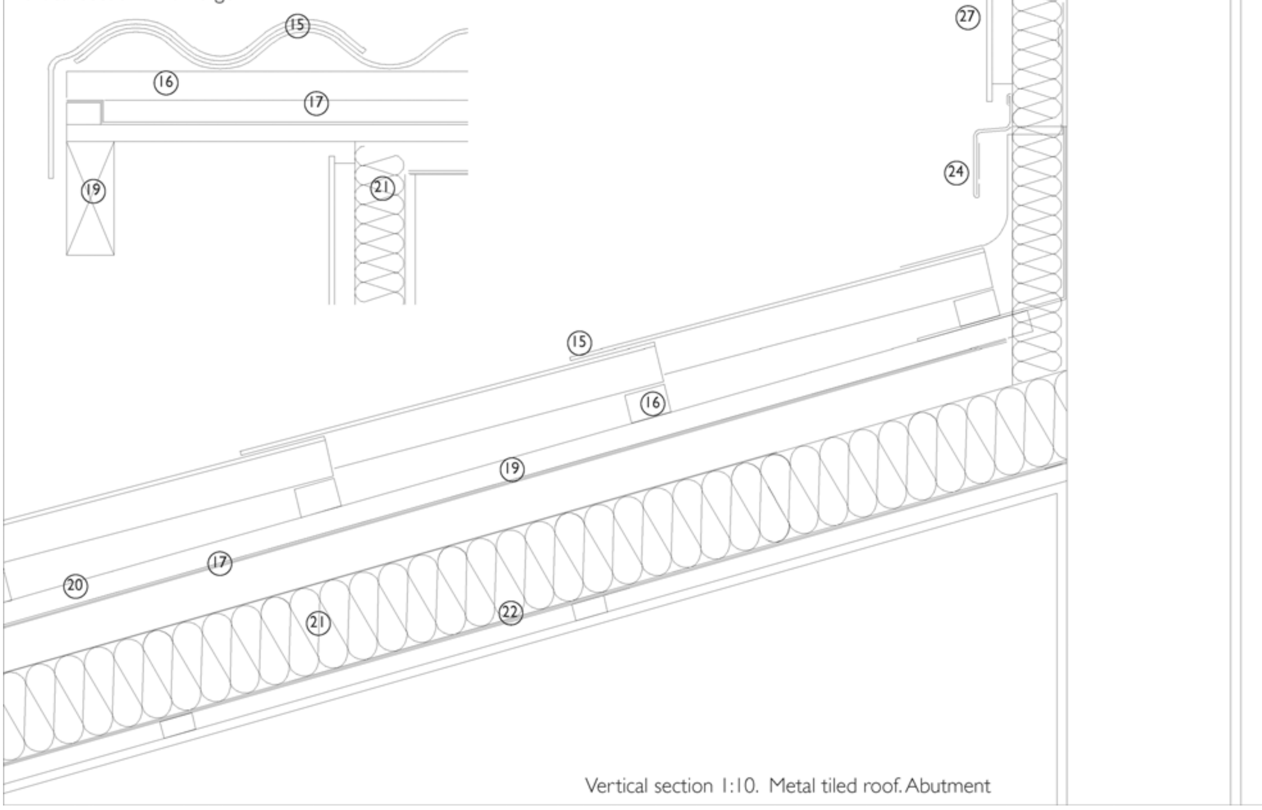
Vertical section 1:10. Metal tiled roof. Abutment


3-D views showing eaves and gutter condition


3-D views showing eaves and gutter condition

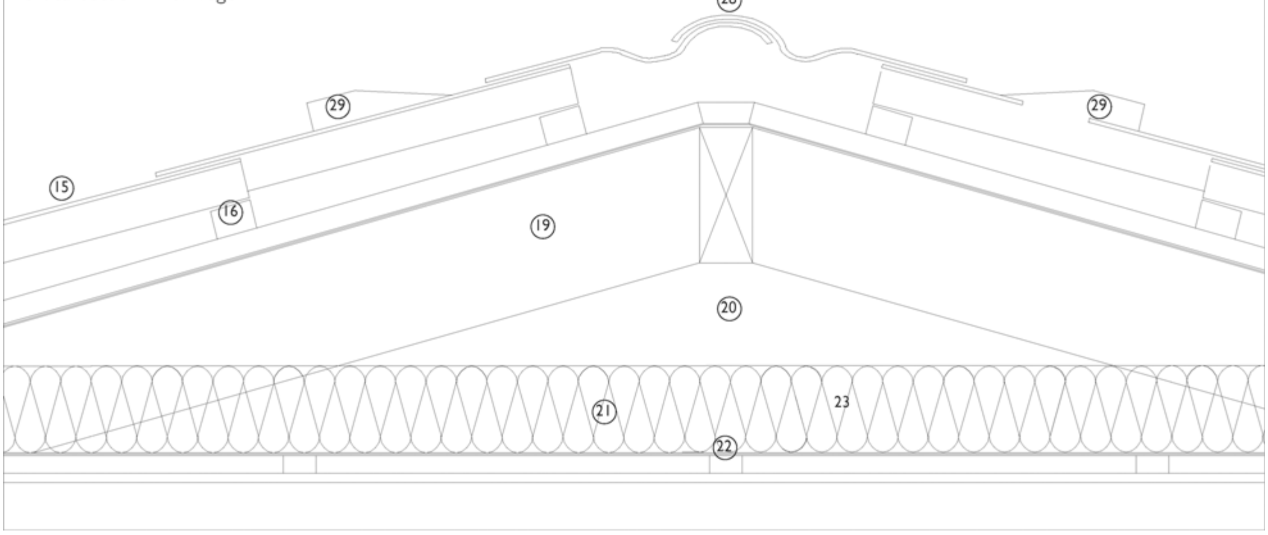


Vertical section



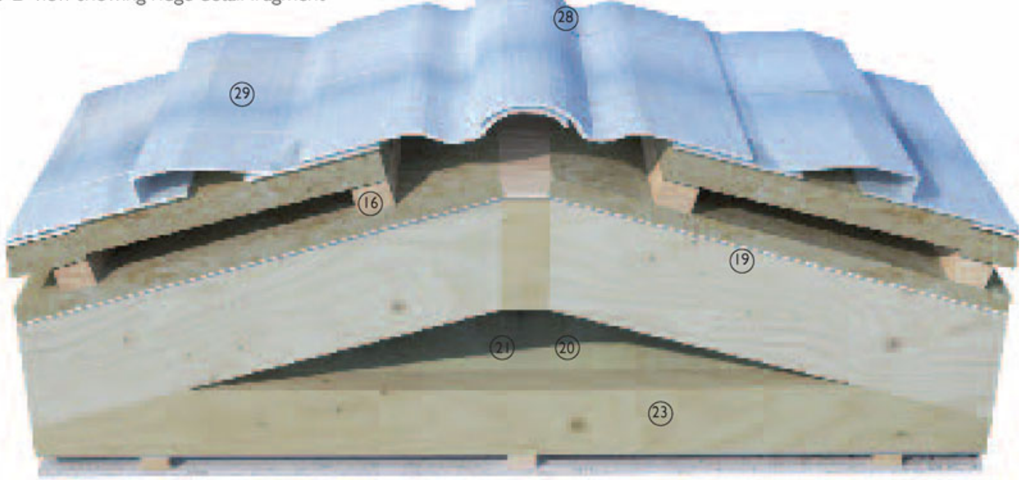
Vertical section 1:10.Verge

Vertical section 1:10. Metal tiled roof. Abutment



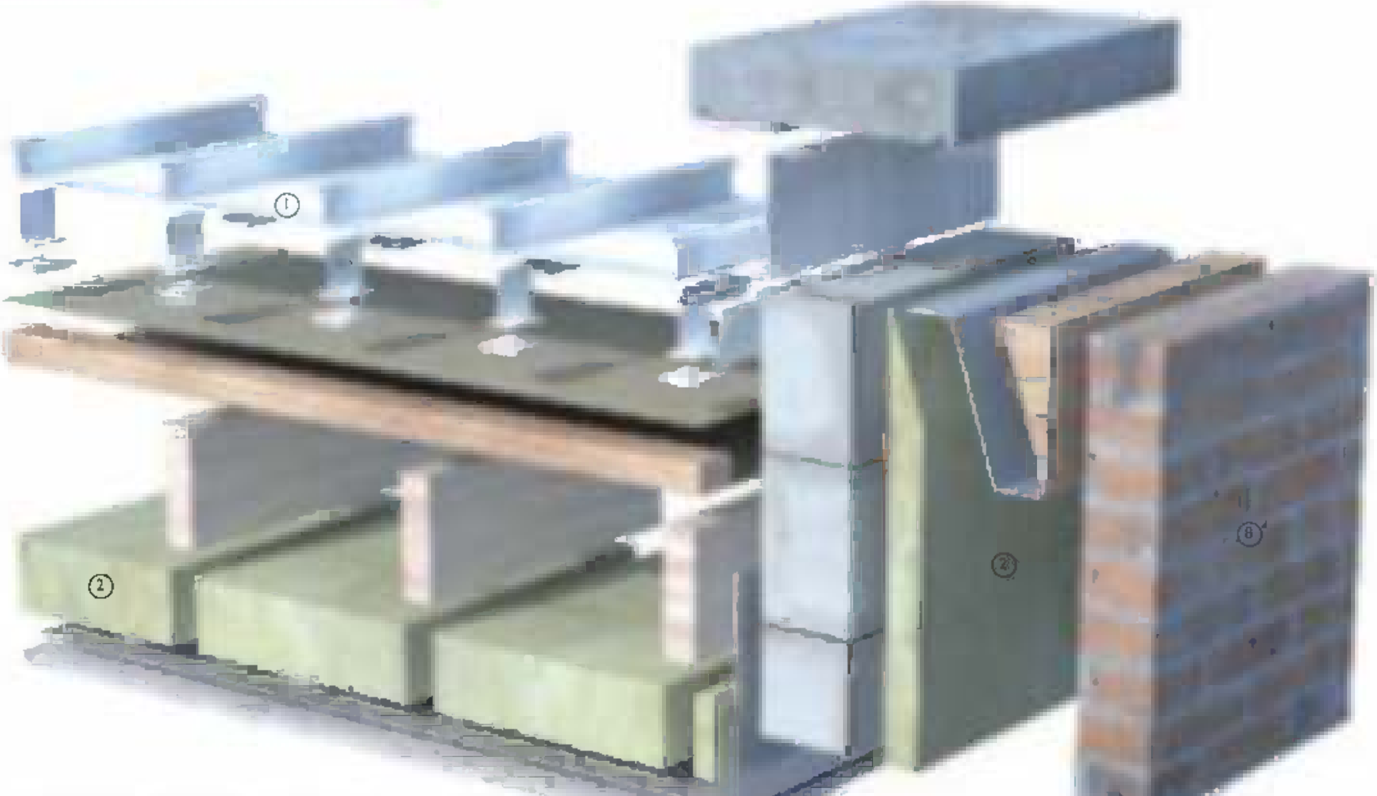
Vertical section 1:10. Ridge

3-D view showing ridge detail fragment

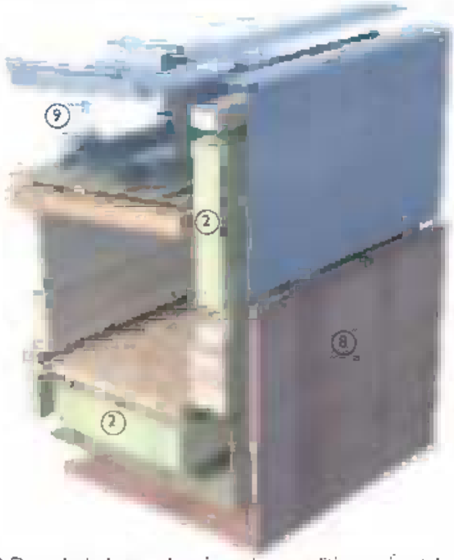


Details: Tiled roof

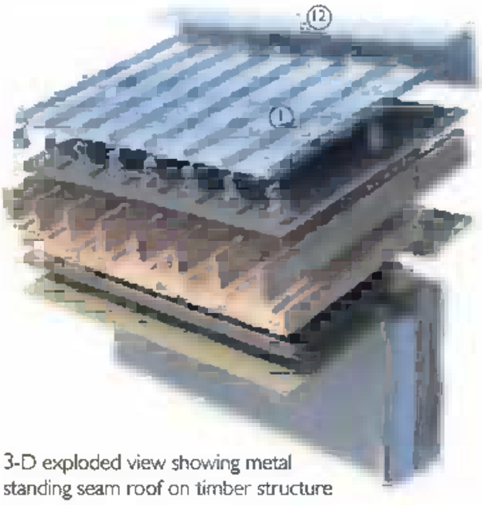
15. Metal tiles
16. Softwood battens
17. Vapour permeable membrane
18. Gutter
19. Softwood rafter
20. Ventilation void
21. Thermal insulation
22. Vapour barrier
23. Softwood joist
24. Metal flashing
25. Soffit board
26. Fascia board
27. External wall
28. Ridge piece
29. Ventilator



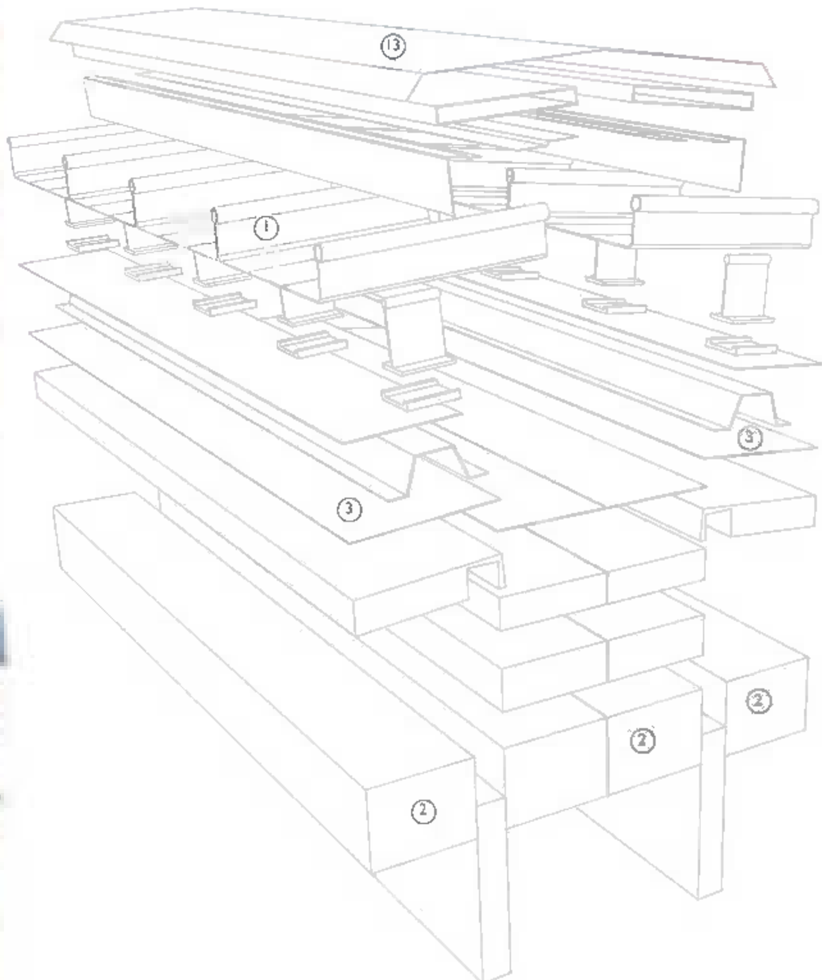
3-D exploded view showing metal standing seam cold roof configuration



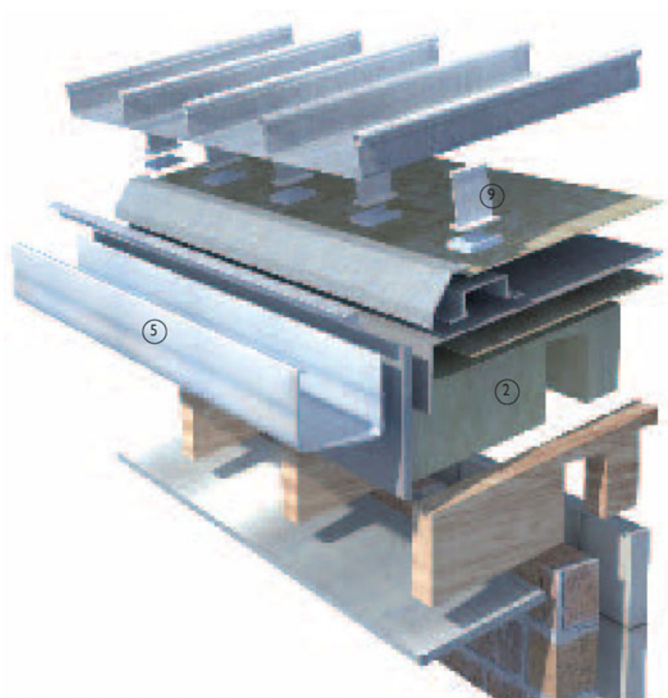
3-D exploded view showing edge condition on metal standing seam cold roof



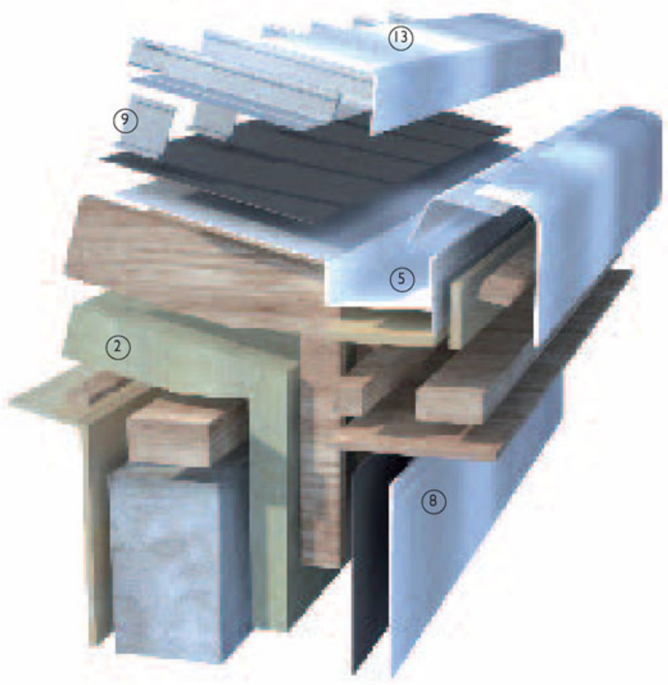
3-D exploded view showing metal standing seam roof on timber structure



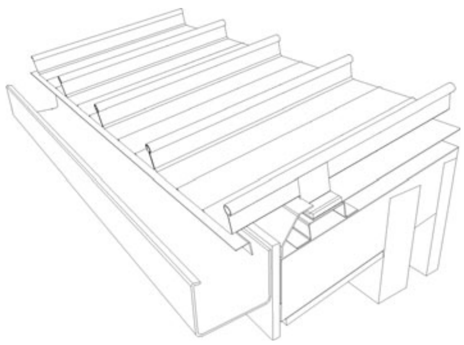
3-D exploded view showing ridge configuration on metal standing seam roof on timber structure

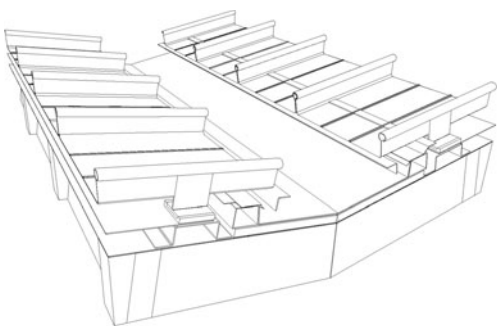


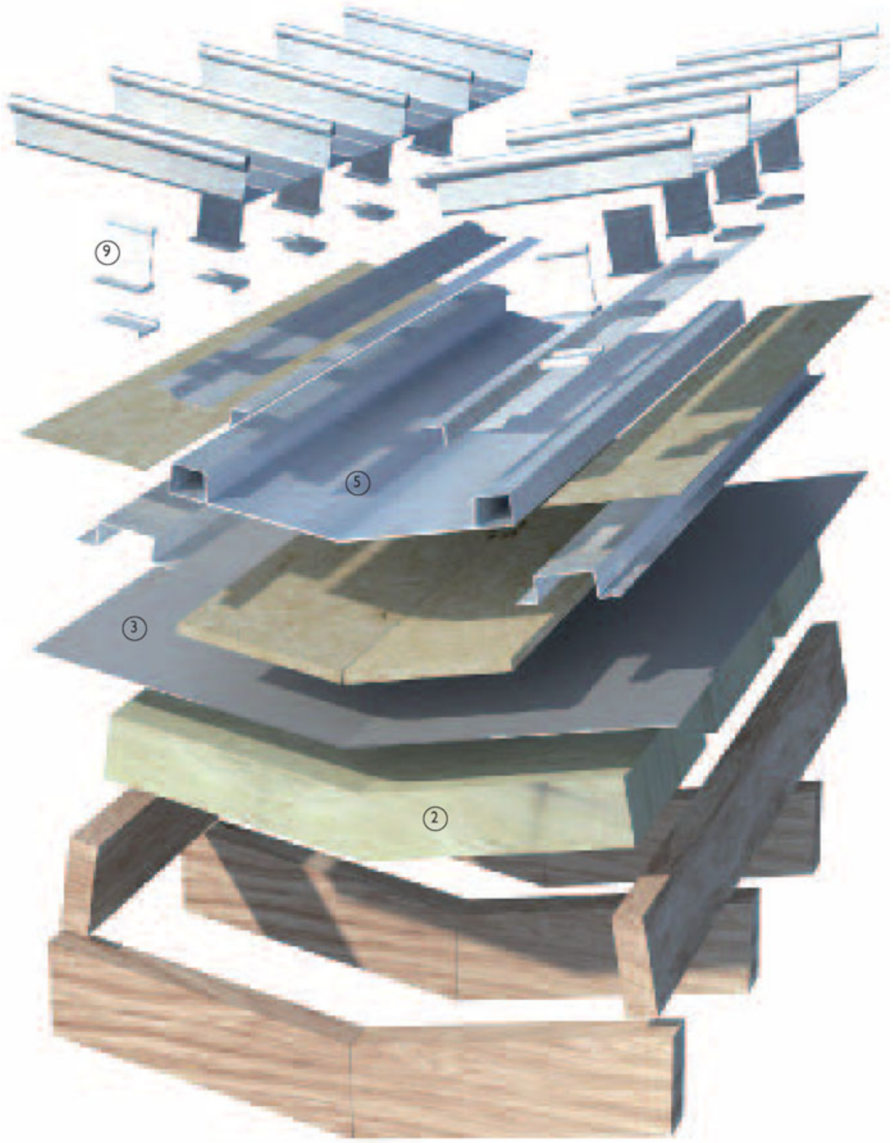
3-D exploded view showing ridge configuration on metal standing seam roof on timber structure



3-D exploded view showing eaves and gutter assembly on metal standing seam roof on timber structure







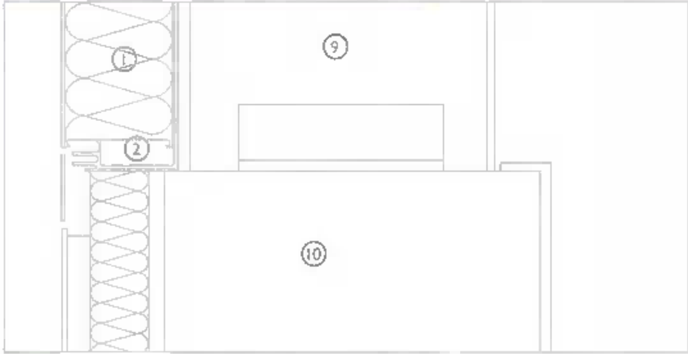
Details : Standing seam roof

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

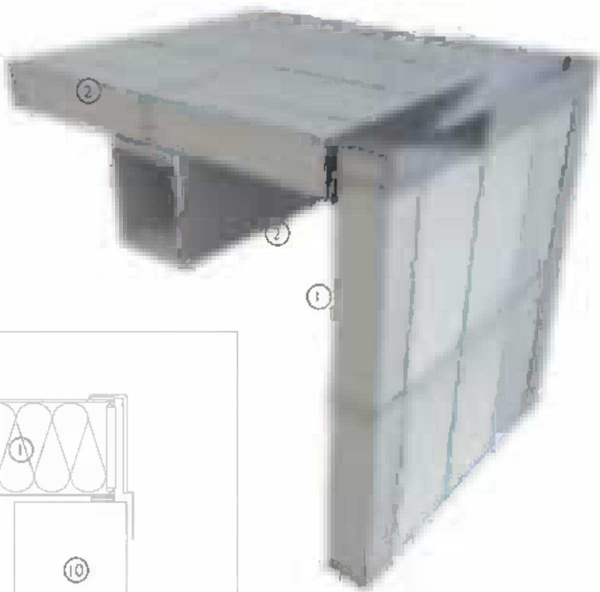
3-D exploded view showing valley gutter configuration on metal standing seam roof on timber structure

11

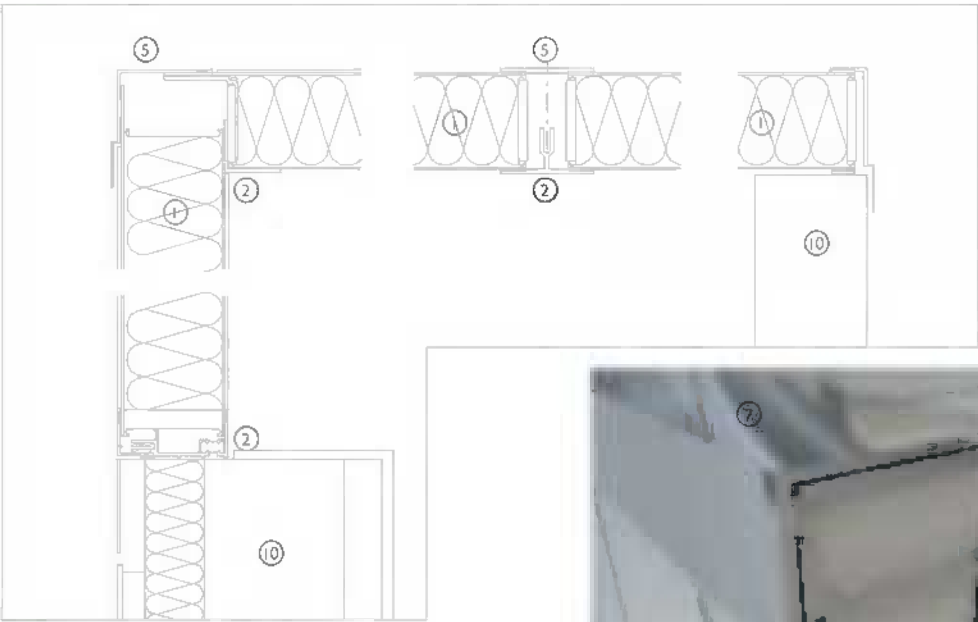
PLASTIC ROOFS



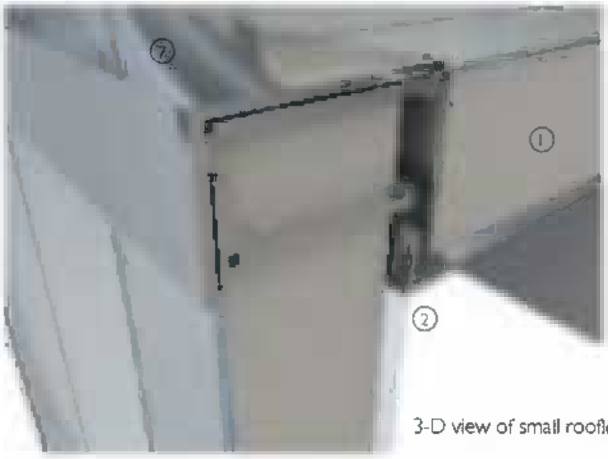
Vertical section 1:5. Large rooflight upstand at base



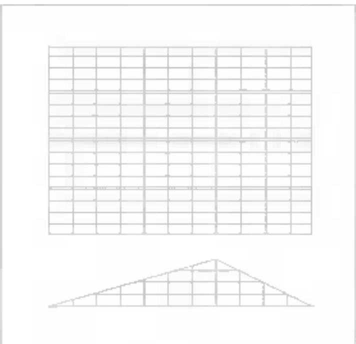
3-D view of small rooflight



Vertical section 1:5 Small rooflight verge



3-D view of small rooflight verge



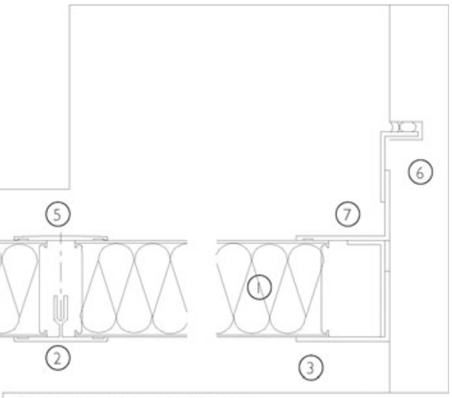
Key plan and elevation
Typical small rooflight layout

Details

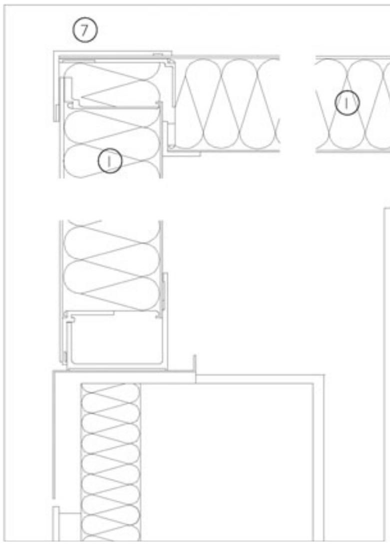
1. Translucent and insulated GRP roof panel
2. Thermally broken aluminium framing
3. Inside
4. Outside
5. Pressure plate
6. Adjacent masonry/concrete wall
7. Folded metal cover strip
8. EPDM strip
9. Supporting structure
10. Concrete upstand

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 damage. 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.

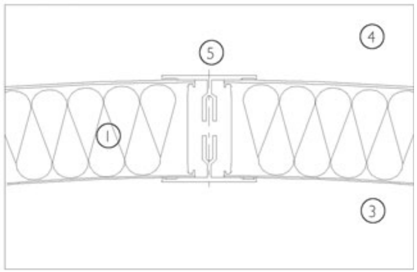
Rooflights are made from GRP sheet which is bonded to an aluminium carrier frame around its edges. Thermal insulation set into the void is usually bonded to the outer GRP facing sheets to provide true composite action between the GRP skin and the insulated core. Like metal composite panels, GRP



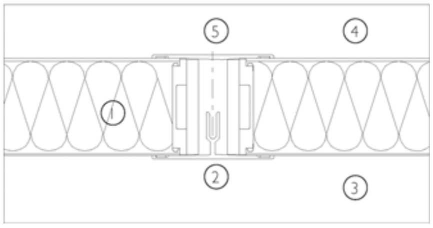
Vertical section 1:5. Abutment

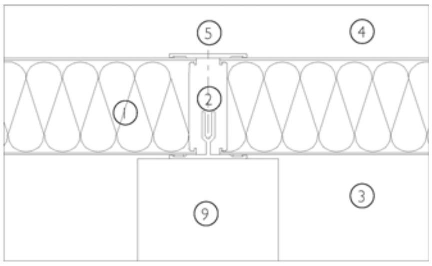


Vertical section 1:5. Verge

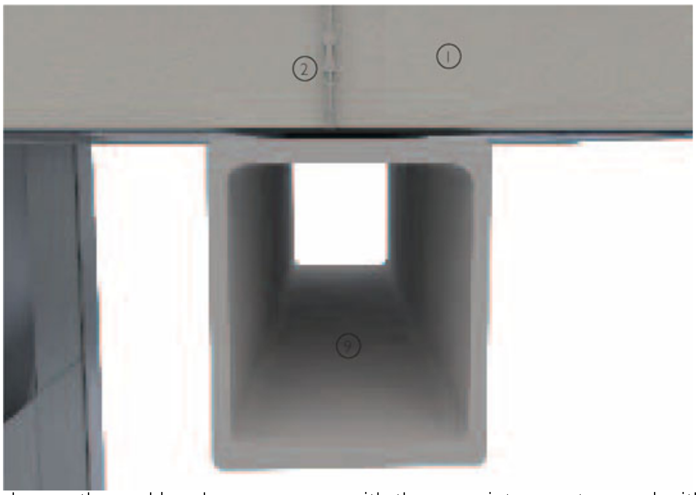


Vertical section 1:5. Small rooflight panel to panel junction

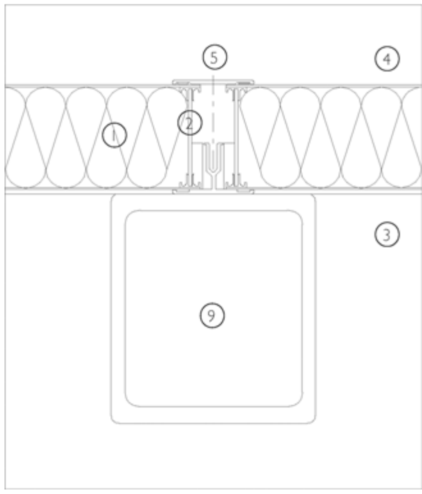




Vertical sections 1:5. Small rooflight panel to panel junction



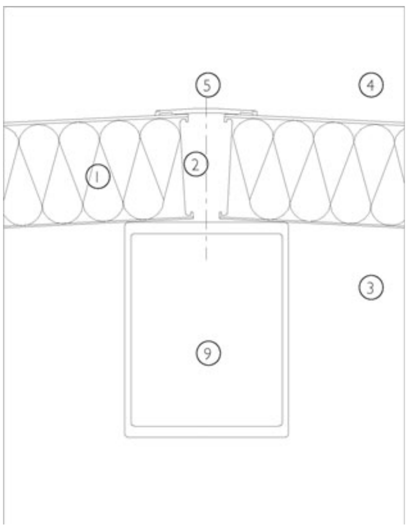
3-D view of small rooflight panel to panel junction



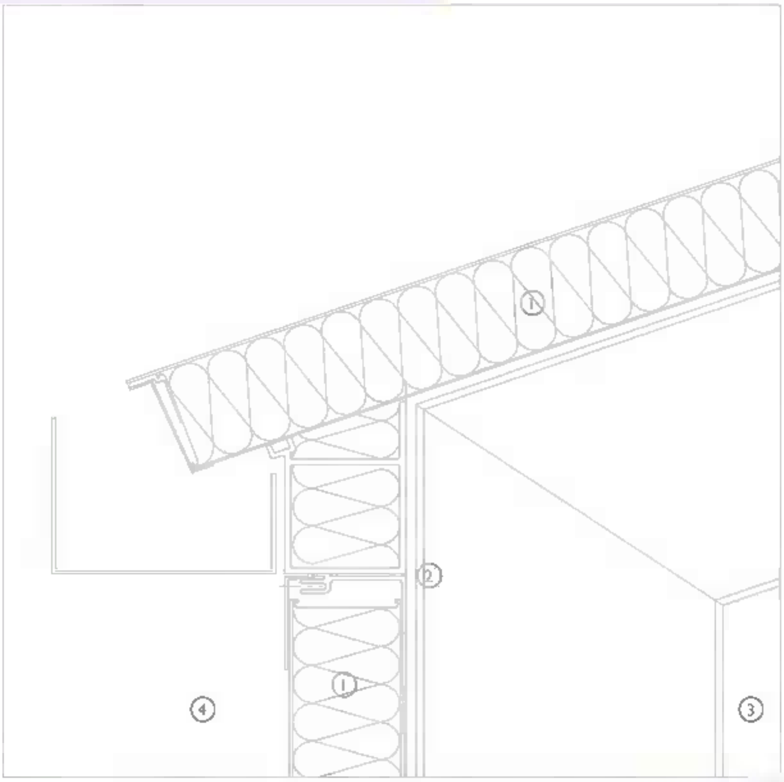
Vertical section 1:5. Large rooflight panel to panel junction

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.

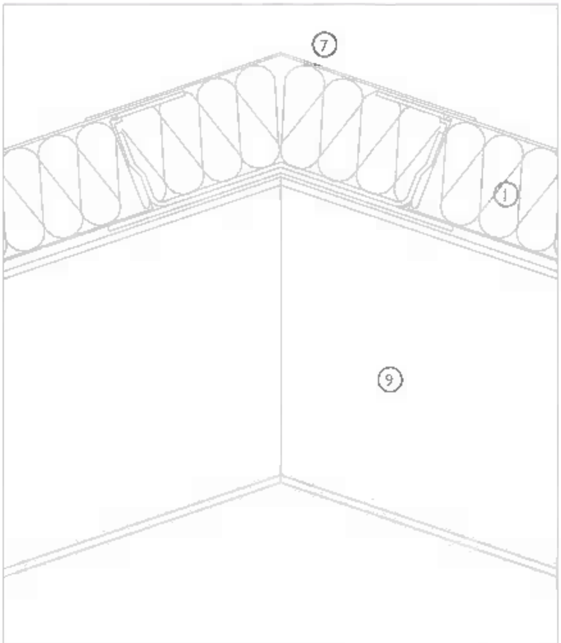
In small rooflights, up to around a 3000mm (10ft) span, GRP composite panels require no additional support, while those of greater span use an additional aluminium or steel frame beneath to support the composite panels over the greater span. Panel sizes vary with the proprietary system and with the individual rooflight design. Typical panel sizes range from around 400mm × 800mm (16in × 32in) to 800mm × 3000mm (32in × 120in). 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



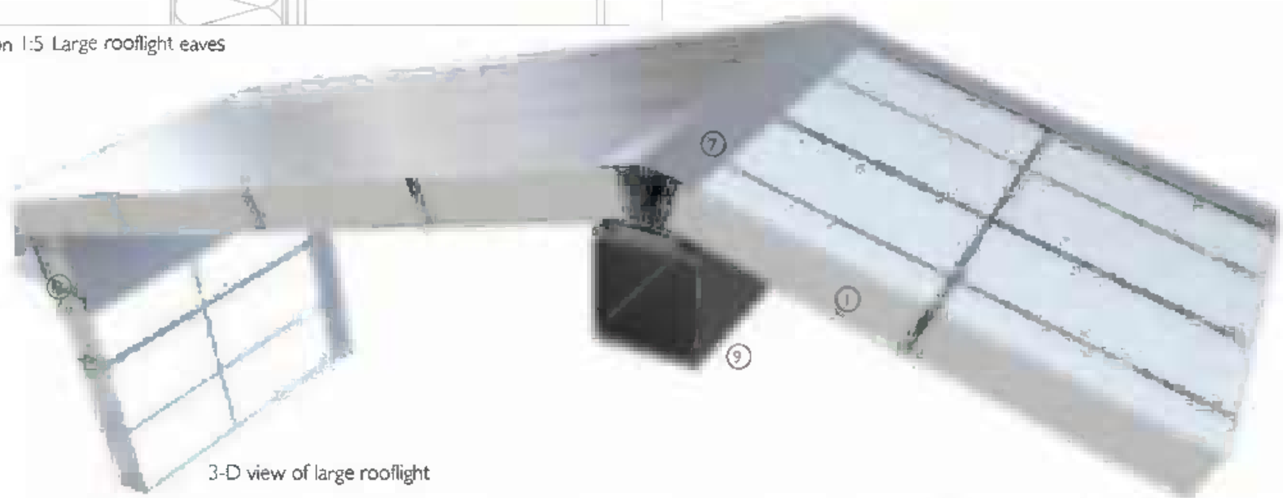
Vertical section 1:5. Large rooflight ridges.



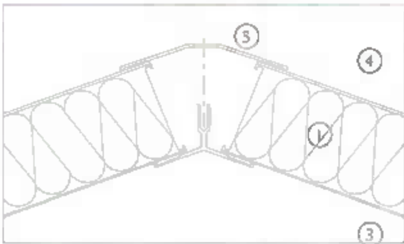
Vertical section 1:5 Large rooflight eaves



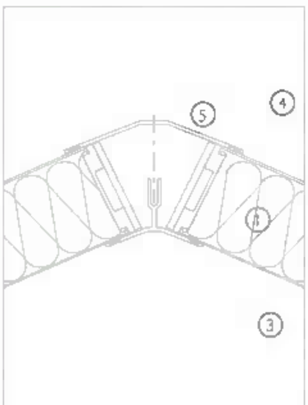
Vertical section 1:5. Large rooflight ridge



3-D view of large rooflight



Vertical section 1:5. Small rooflight ridge and eaves



Vertical section 1:5. Small rooflight ridge

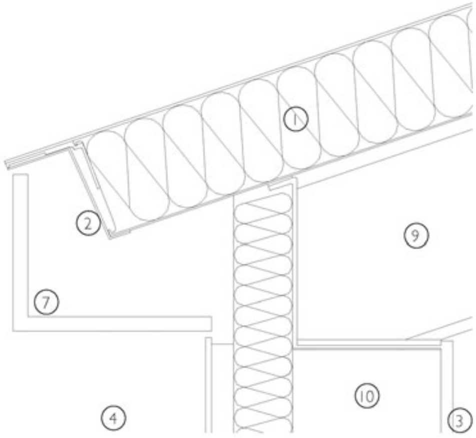
by an extruded EPDM gasket clipped into the aluminium extrusion. Proprietary tapes are also used, but are more dependent upon good workmanship on site than gaskets which are fixed to the pressure plate in factory conditions.

Pressure plates for panel joints running down the slope, 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 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 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.

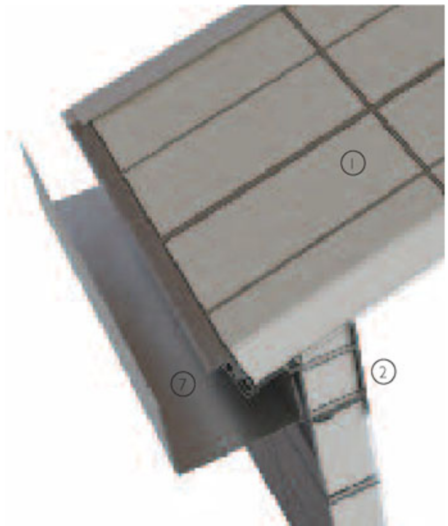
In addition to these standard junctions which form part of proprietary systems, panels are jointed with folded metal sheet, where unusual junctions are to be formed. A folded metal sheet is fixed over the top of the upper panels, to ensure that rainwater runs down the panel, and forms a drip where it 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 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

Details

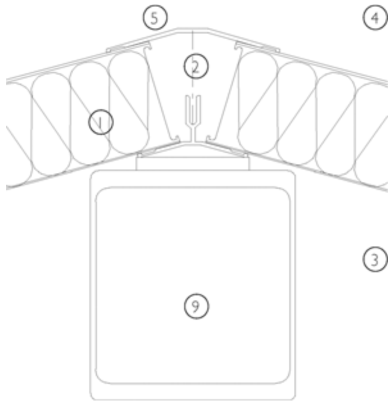
1. Translucent and insulated GRP roof panel
2. Thermally broken aluminium framing
3. Inside
4. Outside
5. Pressure plate
6. Adjacent masonry/ concrete wall
7. Folded metal cover strip
8. EPDM strip
9. Supporting structure
10. Concrete upstand



Vertical section 1:5. Large rooflight eaves



3-D view of large rooflight eaves



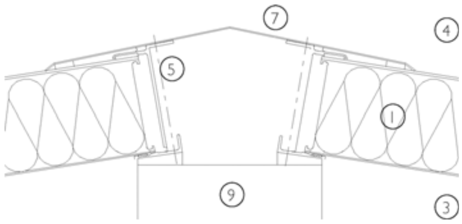
Vertical section 1:5. Large rooflight ridges

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.

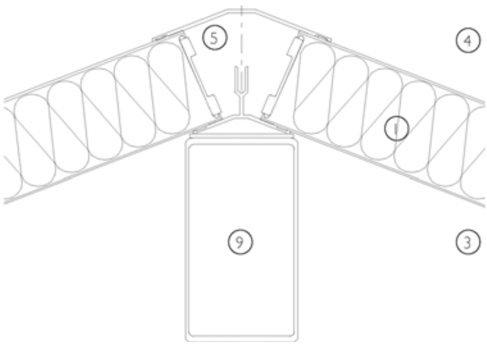
A ridge flashing can be formed in the same way, with a metal sheet fixed to the upper face of the GRP panel frame and a membrane waterproofing layer beneath. Any rainwater that penetrates the outer seal is drained either at the ends of the ridge or down the joint between the panels that run down the slope of the roof.

Eaves and upstands

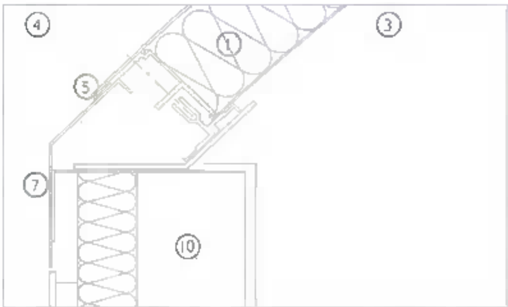
When a rooflight terminates in an eaves, an intermediary aluminium extrusion or folded sheet is used to form the junction. An outer EPDM or extruded silicone seal is used as an outer line of defence against rainwater penetration at the junction with the GRP roof panel. Drainage slots formed in the bottom 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



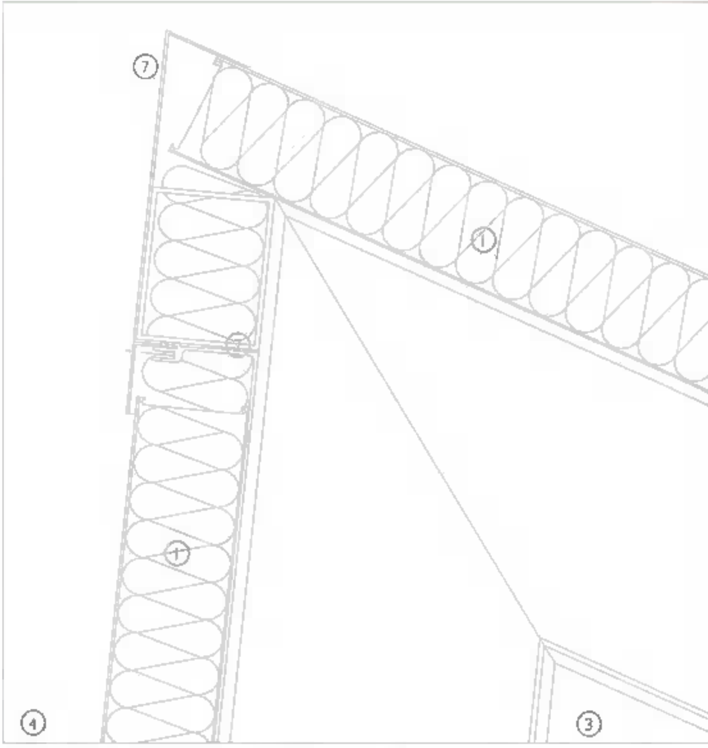
Vertical section 1:5. Small rooflight ridge and eaves



Vertical section 1:5. Small rooflight ridge

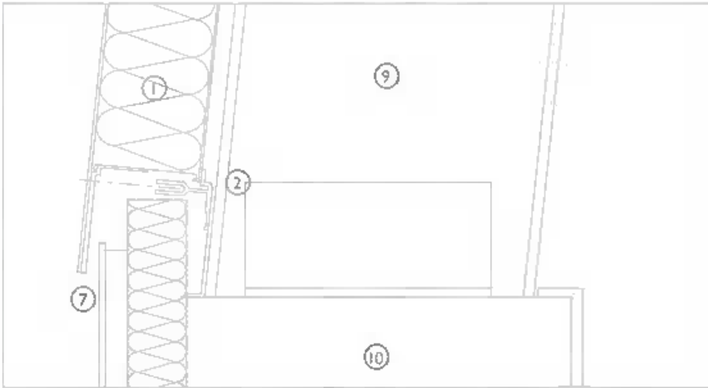


Vertical section 1:5. Small rooflight upstand at base



Vertical section 1:5. Large rooflight monopitch ridge

3-D view of large rooflight monopitch ridge

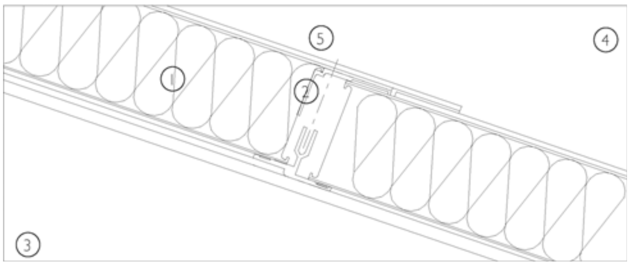


Vertical section 1:5. Large rooflight base

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

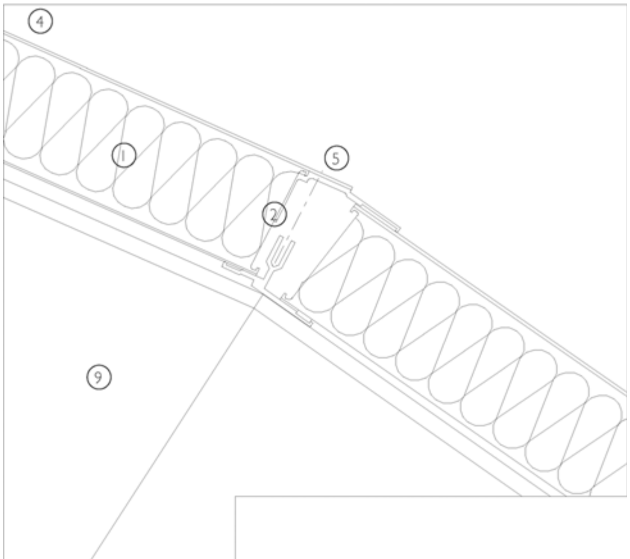
setting the panel behind a vertical aluminium strip that forms a lapped joint over the top of the panel avoiding the possibility of rainwater passing through the joint. The gap between the aluminium closer and the GRP panel is sealed with either an EPDM gasket, a proprietary tape, or a silicone sealant. 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. The gap between the bottom of a GRP 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 pen-

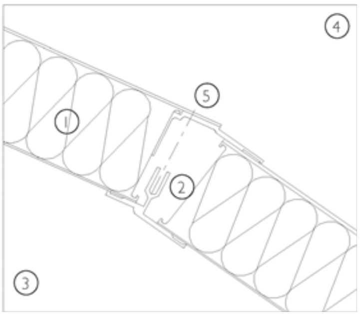


Vertical section 1:5. Large rooflight internal fold

3-D view of large rooflight monopitch ridge



Vertical section 1:5. Large rooflight external fold



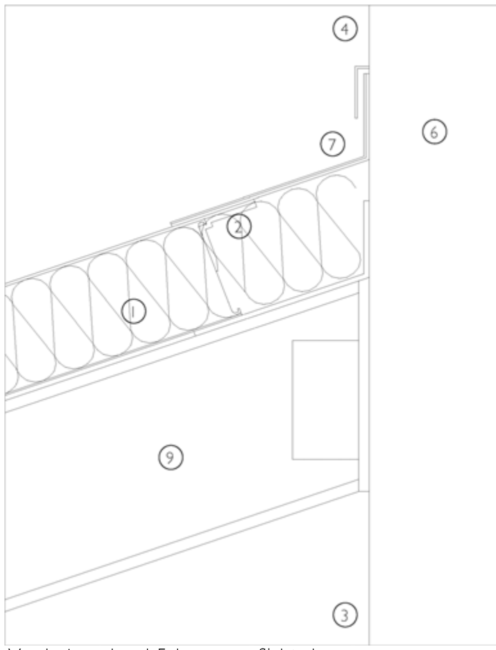
Vertical section 1:5. Large rooflight external fold

3-D view of large rooflight monopitch ridge

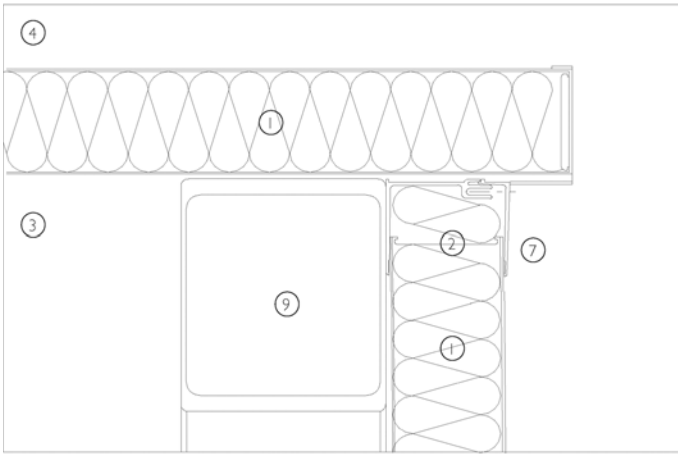
etration. A waterproof membrane, typically EPDM, is bonded to the bottom edge of the metal frame surrounding the GRP panel and is sealed against the waterproofing layer of the upstand, providing a continuous seal from the surrounding area of flat roof up to the rooflight. A thermal break in the framing of the GRP composite panel ensures a continuity in the thermal insulation from upstand to GRP rooflight.

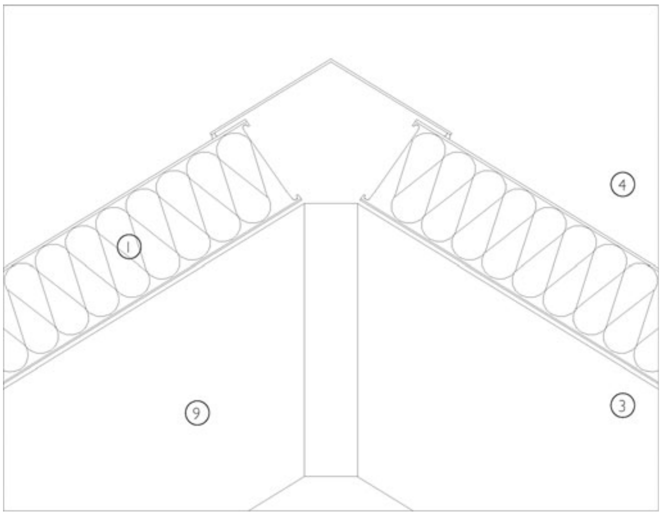
Verges

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. The sloping panel can extend slightly forward of the vertical panels to give a thin edge to the roof. Alternatively the roof can terminate 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.

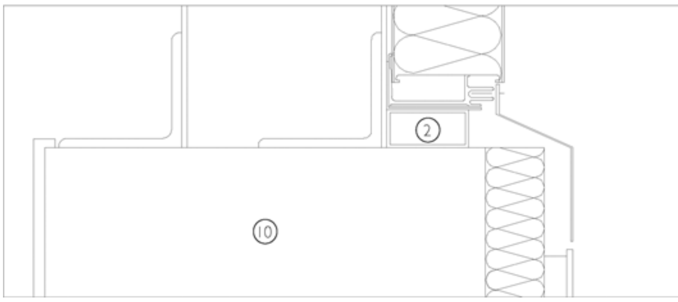


Vertical section 1:5. Large rooflight abutment

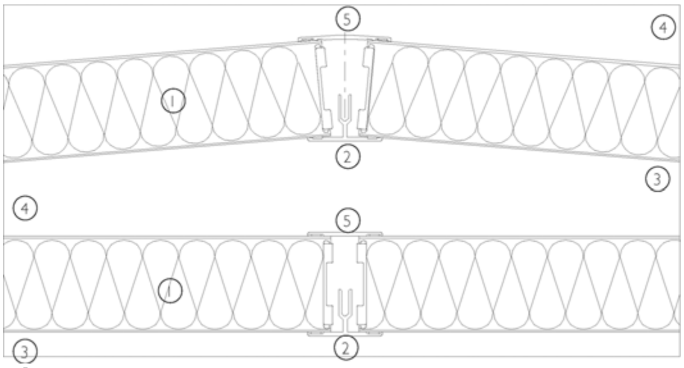




Vertical section 1:5. Ridge



Vertical section 1:5. Verge



Vertical sections 1:5. Small rooflight panel to panel junction

Abutments

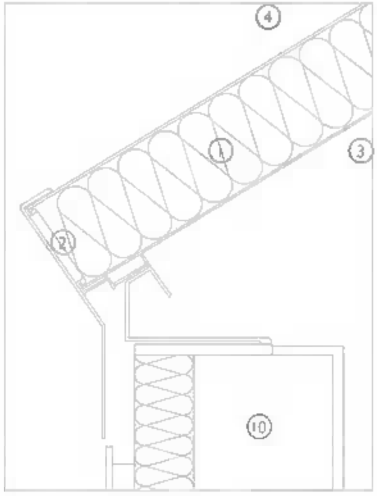
Where a GRP rooflight is set against a vertical wall in another material, such as reinforced concrete or concrete block, a metal flashing is used. Beneath the metal flashing, a waterproof membrane is bonded to the edge of the GRP panel and is folded up the abutting wall to which it is bonded. Where wall and rooflight are not connected structurally, 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, 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.

Sliding roof panels

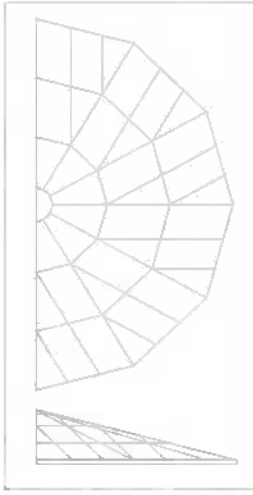
The lightweight nature of GRP rooflight panels is being used increasingly in sliding panels that allow a rooflight to be opened at different times of the year. Typically up to around 40% of panels in a rooflight are opened by sliding them over adjacent fixed panels, in relatively modest electrically operated systems. Whereas 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 lower 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. For example, one side of the horizontally sliding panel would have an upstand, while the other three sides would be 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 ten 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.

3-D view of eaves detail



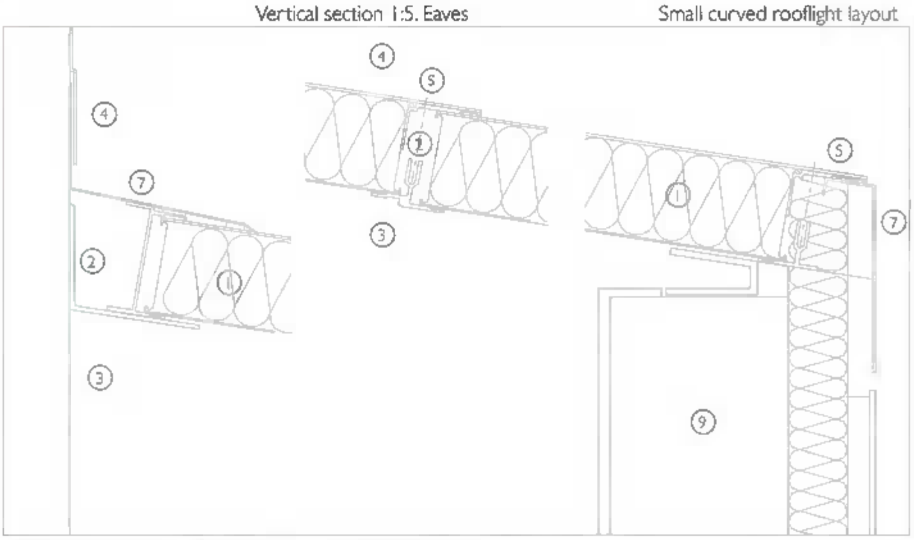
Vertical section 1:5. Eaves



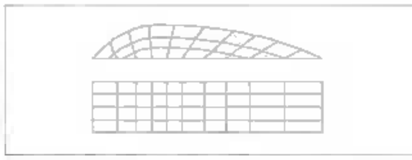
Small curved rooflight layout

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



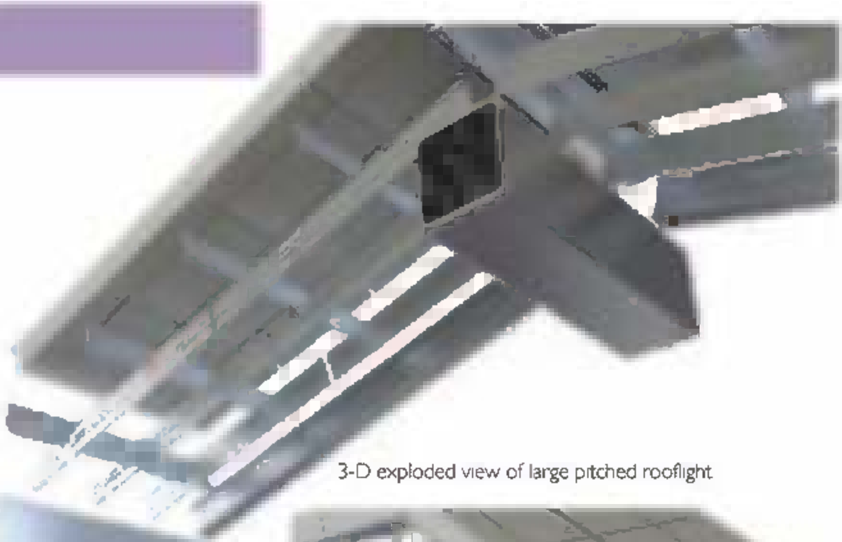
Vertical sections 1:5 Small rooflight panel to panel junction



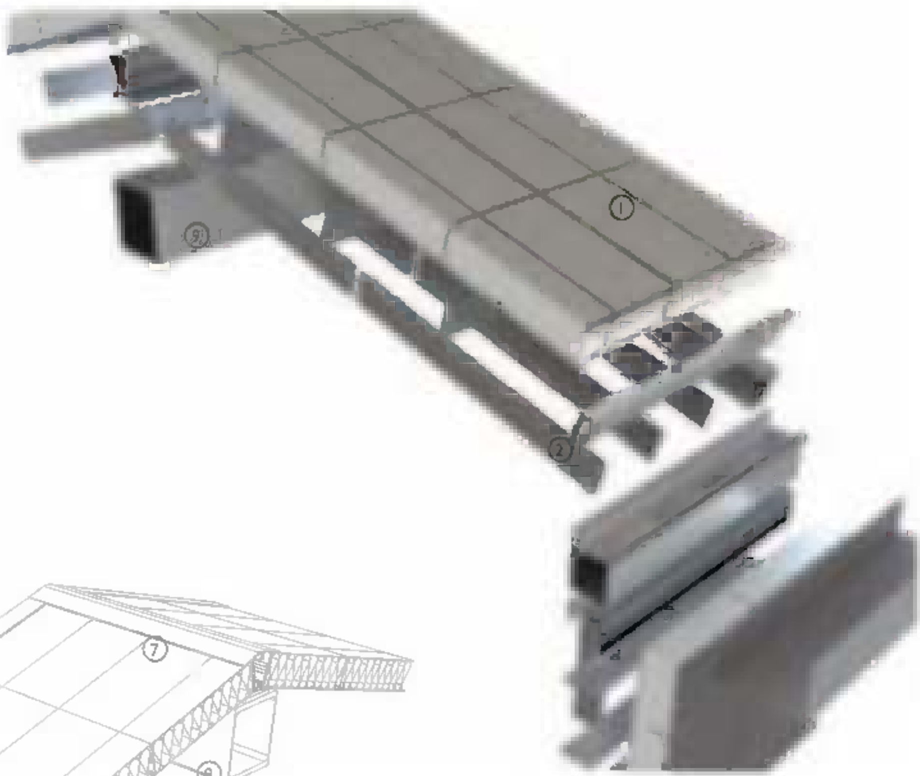
Key plan Small curved roof layout

3-D view of small curved rooflight

3-D view of ridge detail



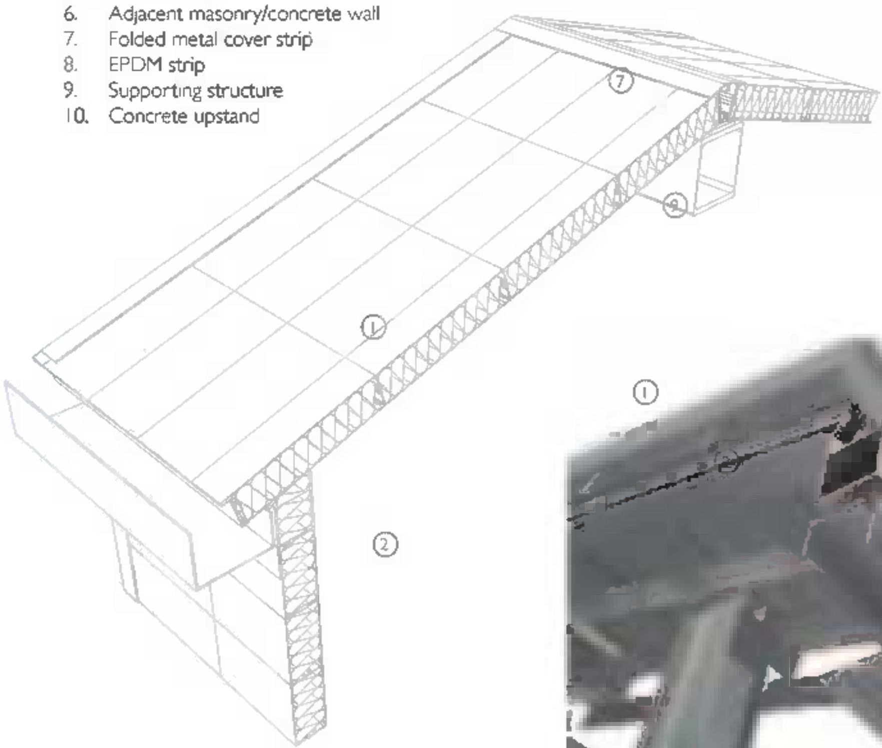
3-D exploded view of large pitched rooflight



3-D exploded view of large pitched rooflight

Details

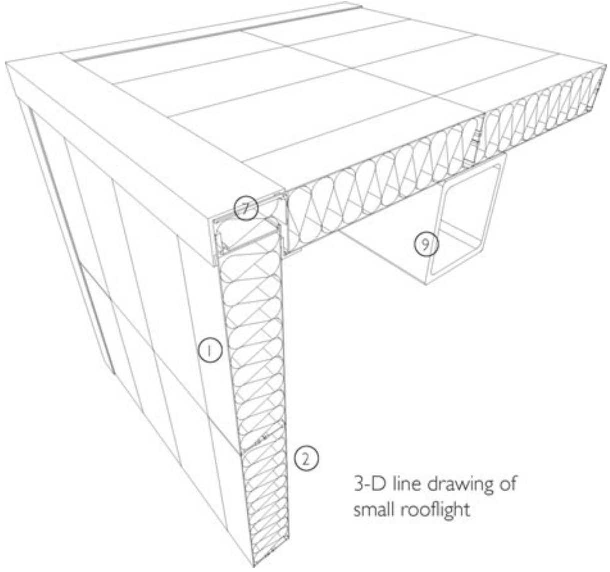
1. Translucent and insulated GRP roof panel
2. Thermally broken aluminium framing
3. Inside
4. Outside
5. Pressure plate
6. Adjacent masonry/concrete wall
7. Folded metal cover strip
8. EPDM strip
9. Supporting structure
10. Concrete upstand



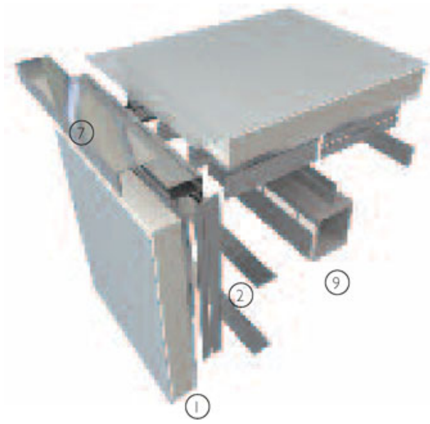
3-D line drawing of large pitched rooflight

3-D exploded view of parapet junction of GRP pitched rooflight

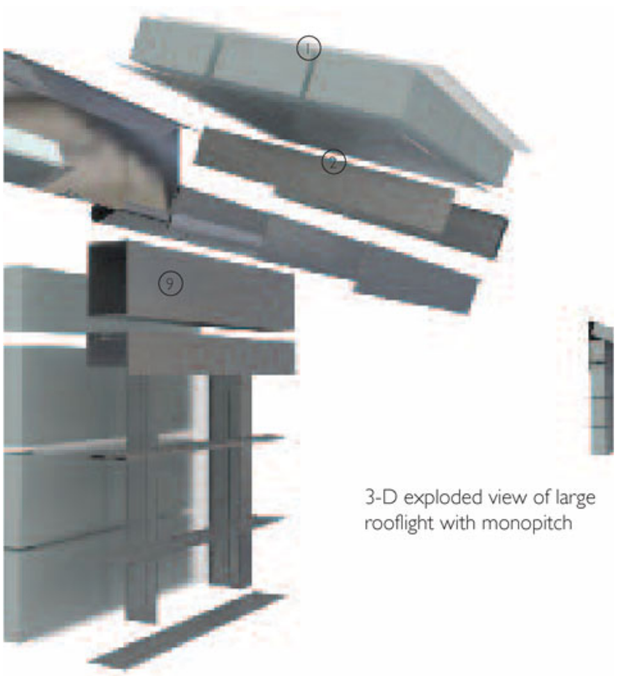
3-D exploded view of small rooflight



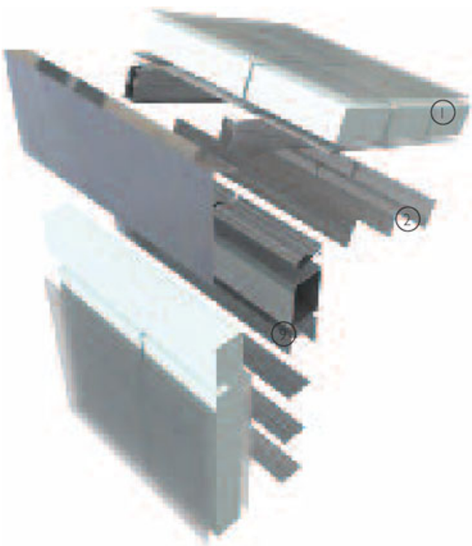
3-D line drawing of small rooflight



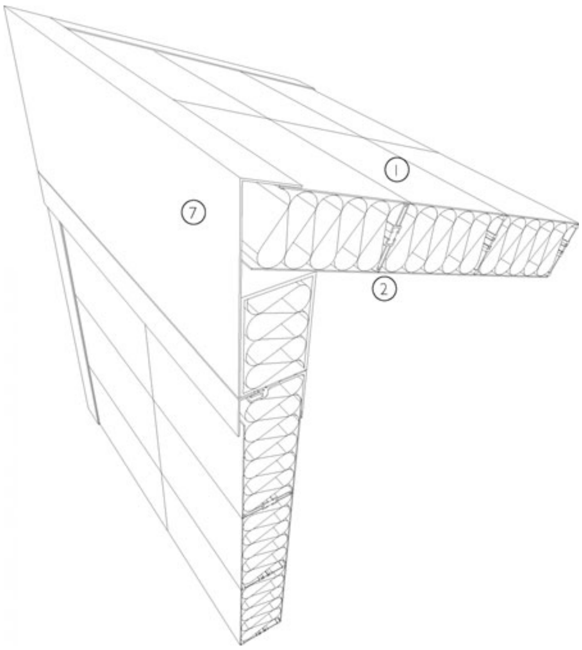
3-D exploded view of small rooflight



3-D exploded view of large rooflight with monopitch

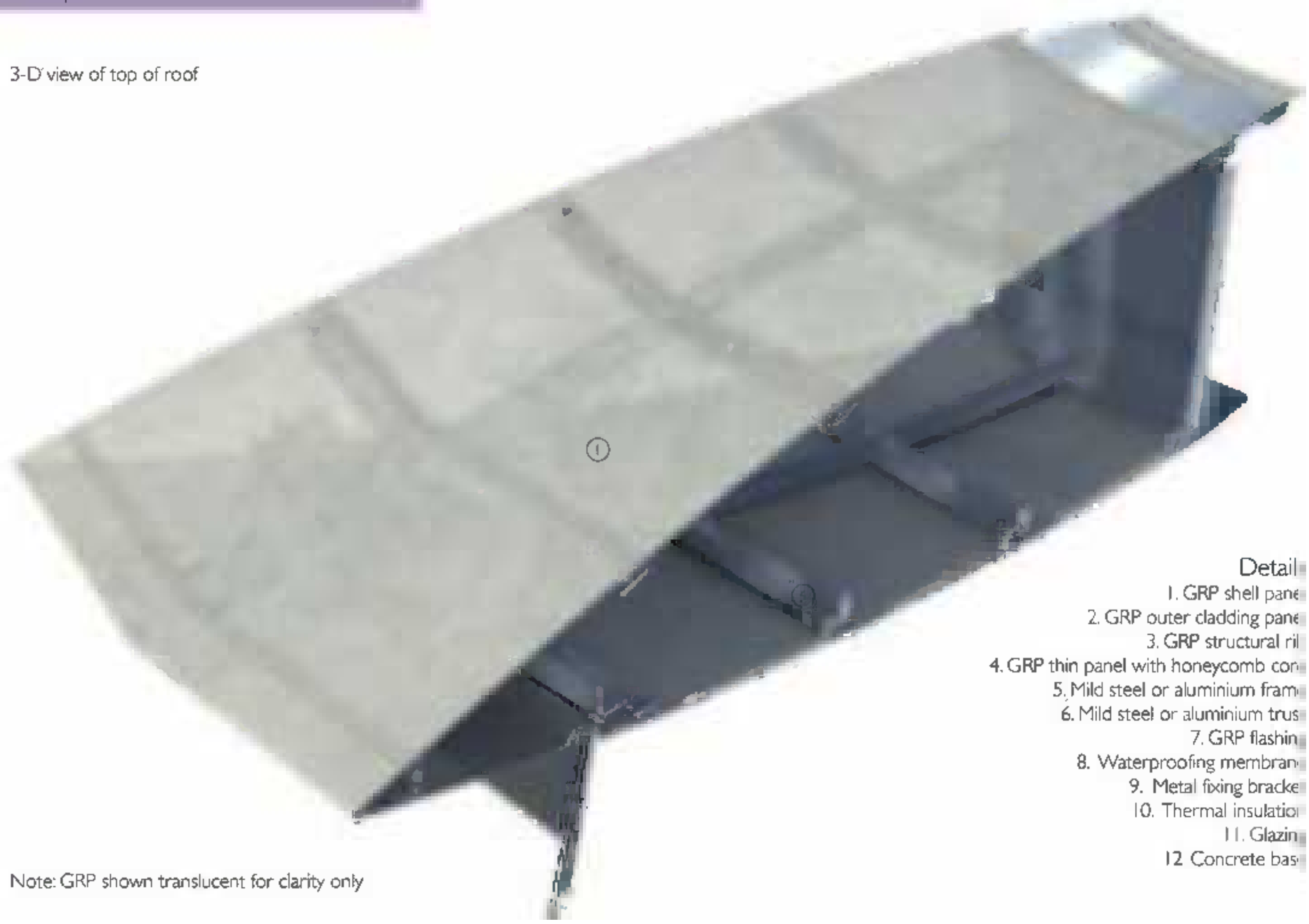


3-D exploded view of large rooflight with monopitch



3-D line drawing of large rooflight with monopitch

3-D view of top of roof



Note: GRP shown translucent for clarity only

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.

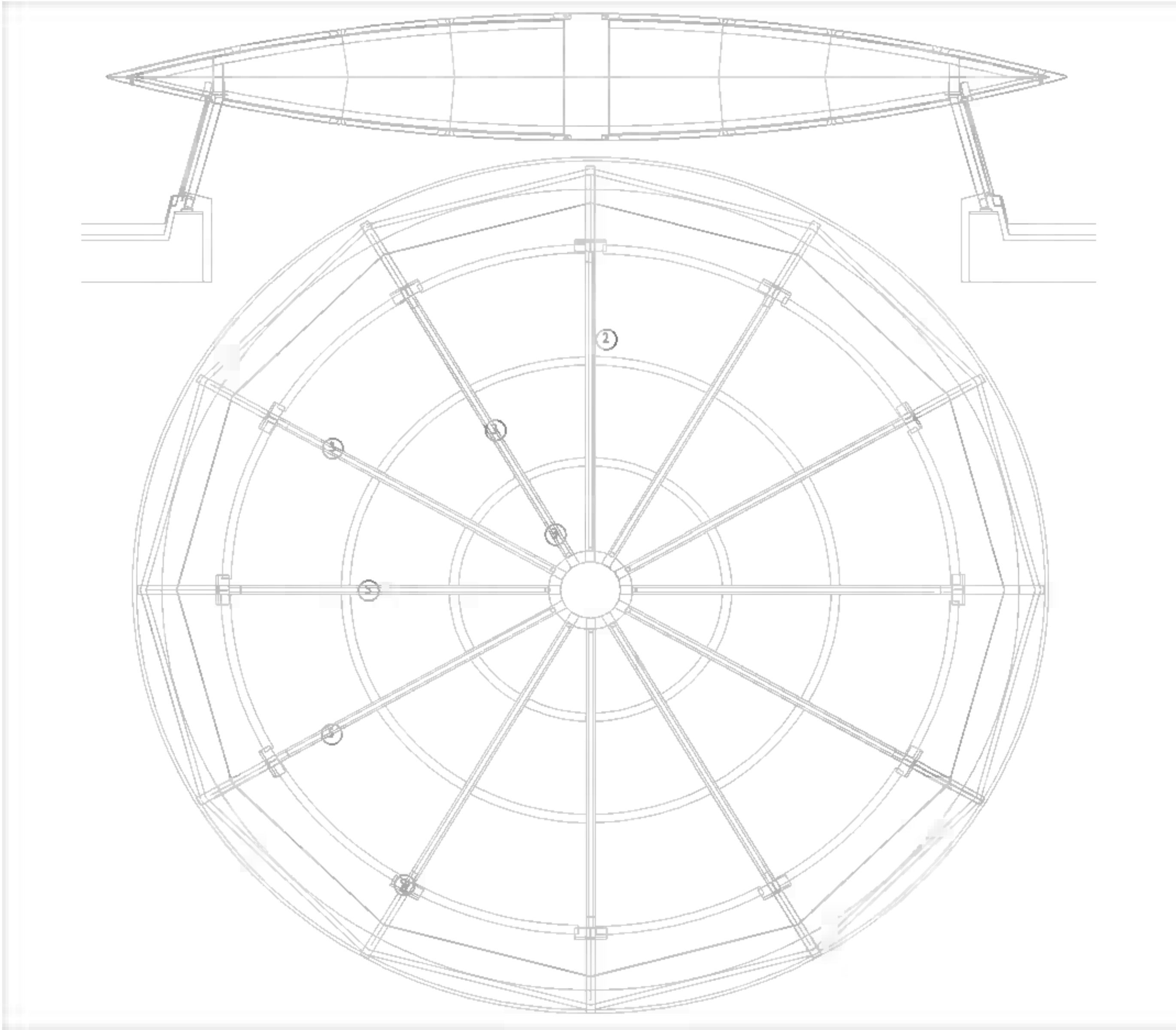
Smaller panels and shells

Smaller shells consist of a set of segmented panels which are bolted together to form a roof shell of approximately 7.0 metres diameter. Some variations are supported by an additional frame, while others are self-supporting GRP shells.

GRP panels can be 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.

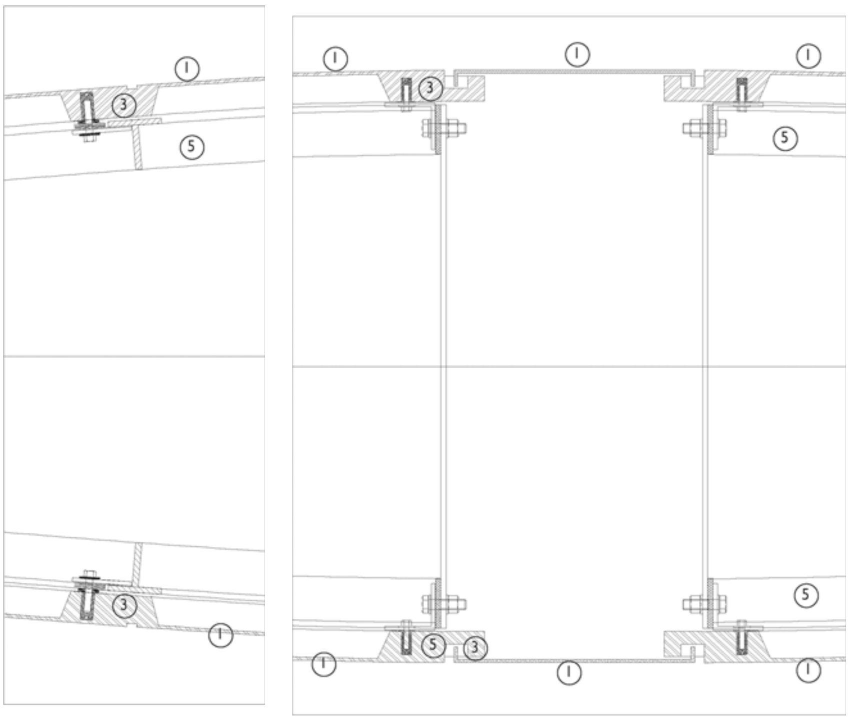
The metal frame is clad in prefabricated GRP panels which are bolted to the support frame on their internal face in order to avoid visible fixings. Panels are made with an outer skin of GRP around 5mm thick, with an overall panel depth of around 45mm for the panels sizes shown of 3500mm long and 1800mm wide. The GRP panels are stiffened by concentric ribs, around 120mm wide. The long edges of panels do not require thick ribs, and these are around 10mm thick . 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.

Typical examples use glass fibre ribs that form part of the shell to provide integral structural stability to the shell. Panels are generally around 200mm deep, and are bolted together to form a self-supporting GRP shell. Ribs are made in solid GRP in order to allow



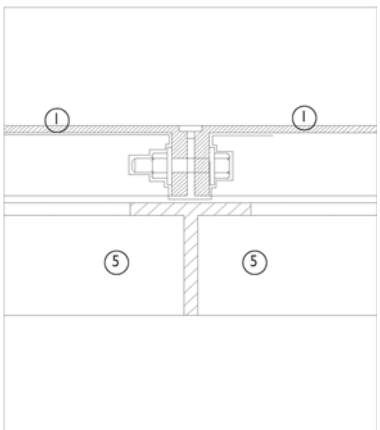
Horizontal and vertical sections 1:50. GRP shell roof

-D section through roof
ssembly

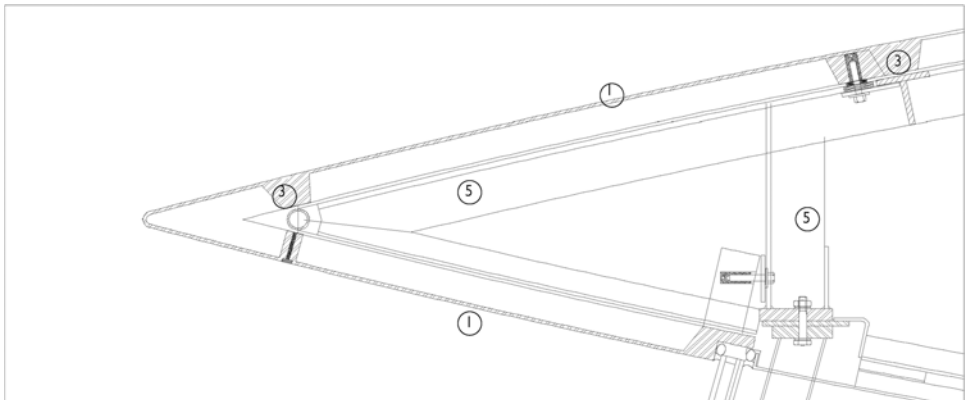


Vertical sections 1:10. Panel to panel junction

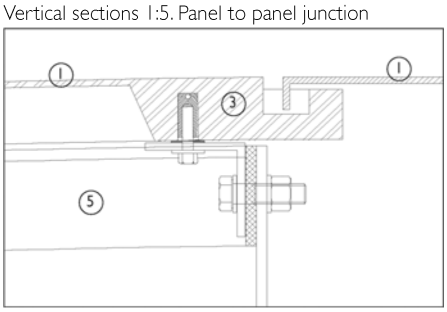
3-D view showing GRP shell roof internal structure



Vertical sections 1:5. Panel to panel junction



Vertical section 1:10. Perimeter

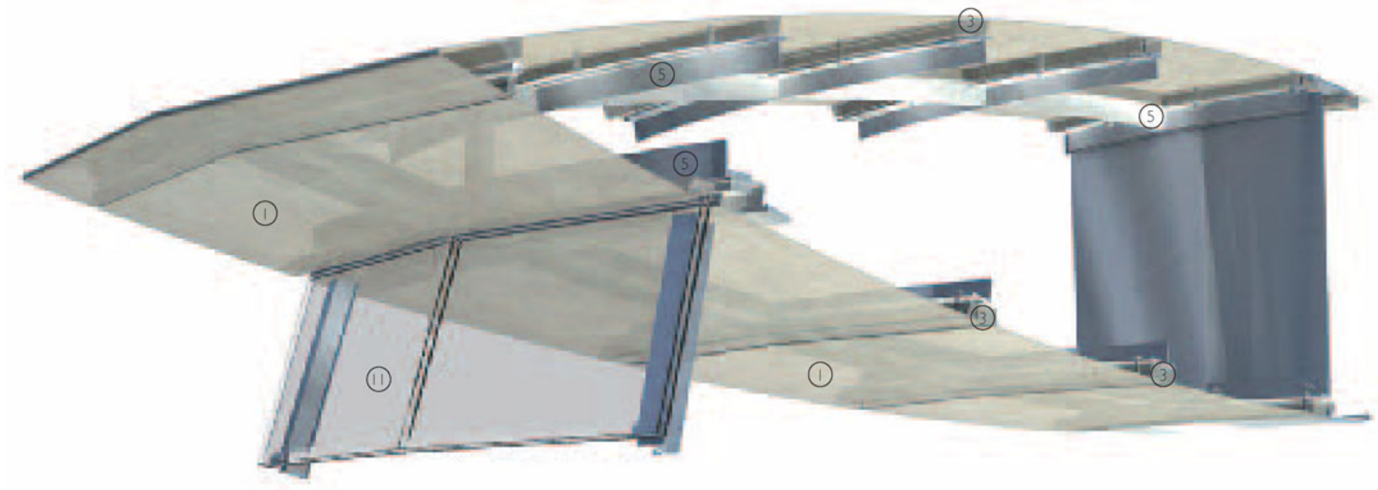


Details
1. GRP shell panel
2. GRP outer cladding panel
3. GRP structural rib
4. GRP thin panel with honeycomb core
5. Mild steel or aluminium frame
6. Mild steel or aluminium truss
7. GRP flashing
8. Waterproofing membrane
9. Metal fixing bracket
10. Thermal insulation
11. Glazing
12. Concrete base

them to be bolted together easily. Panels are joined and sealed on their external face. There are various methods for forming the top of the roof. 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 grinding required on site to ensure a smooth finish.

The underside of the shell is mostly set internally behind curved glazed units installed 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



3-D view of underside of GRP roof assembly fragment and connection to glazed wall

3-D fragment of GRP shell showing internal structure

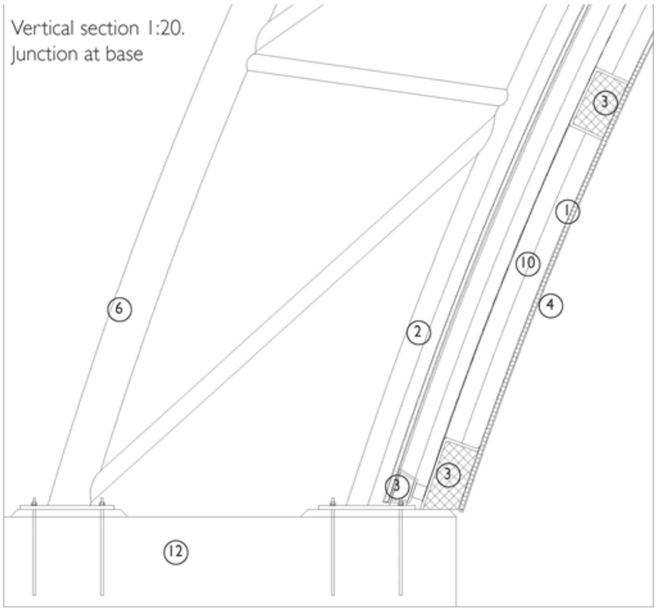
joint. The recess avoids the possibility of a weakness in the seal that could result in using a butt joint between shell and glazing. The edge of the double glazed unit is sealed completely around the junction with the shell, typically with silicone.

Both the cladding panels and the self-supporting shell 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 finished 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 many cases a hemispherical dome of 20 metre diameter is constructed as a self-supporting shell. The GRP shell can either be made from GRP only, or can use additional

3-D fragment showing GRP shell and mild steel structural frame fixing details at top of glazed wall



3-D fragment of base junction on domed GRP roof with external exposed truss structure

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
11. Glazing
12. Concrete base

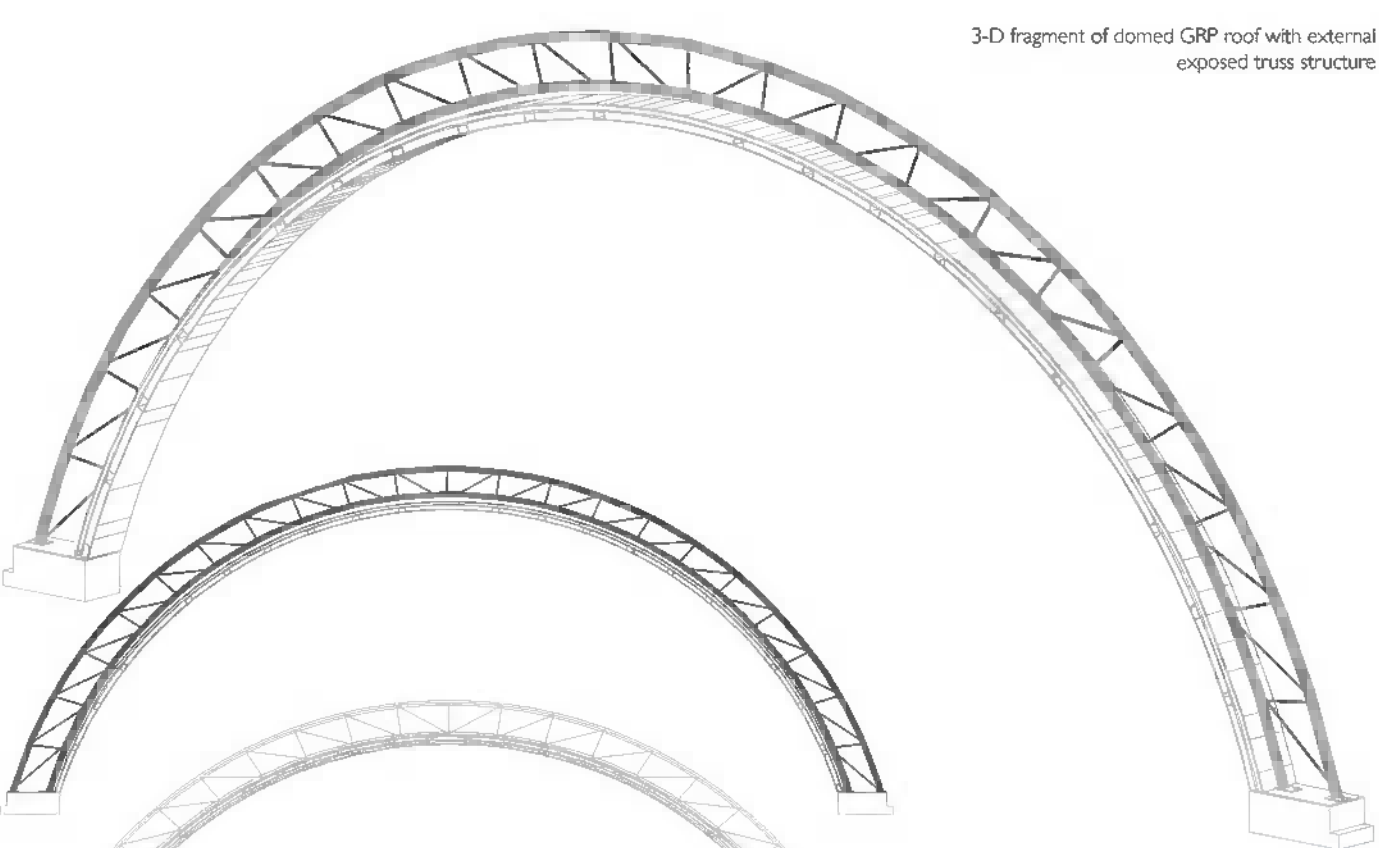
structural stability provided by an external steel or aluminium truss. The truss might be used to support a decorative outer screen or a lighting system to illuminate translucent panels, for example.

In many instances, 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 is the more difficult construction method.

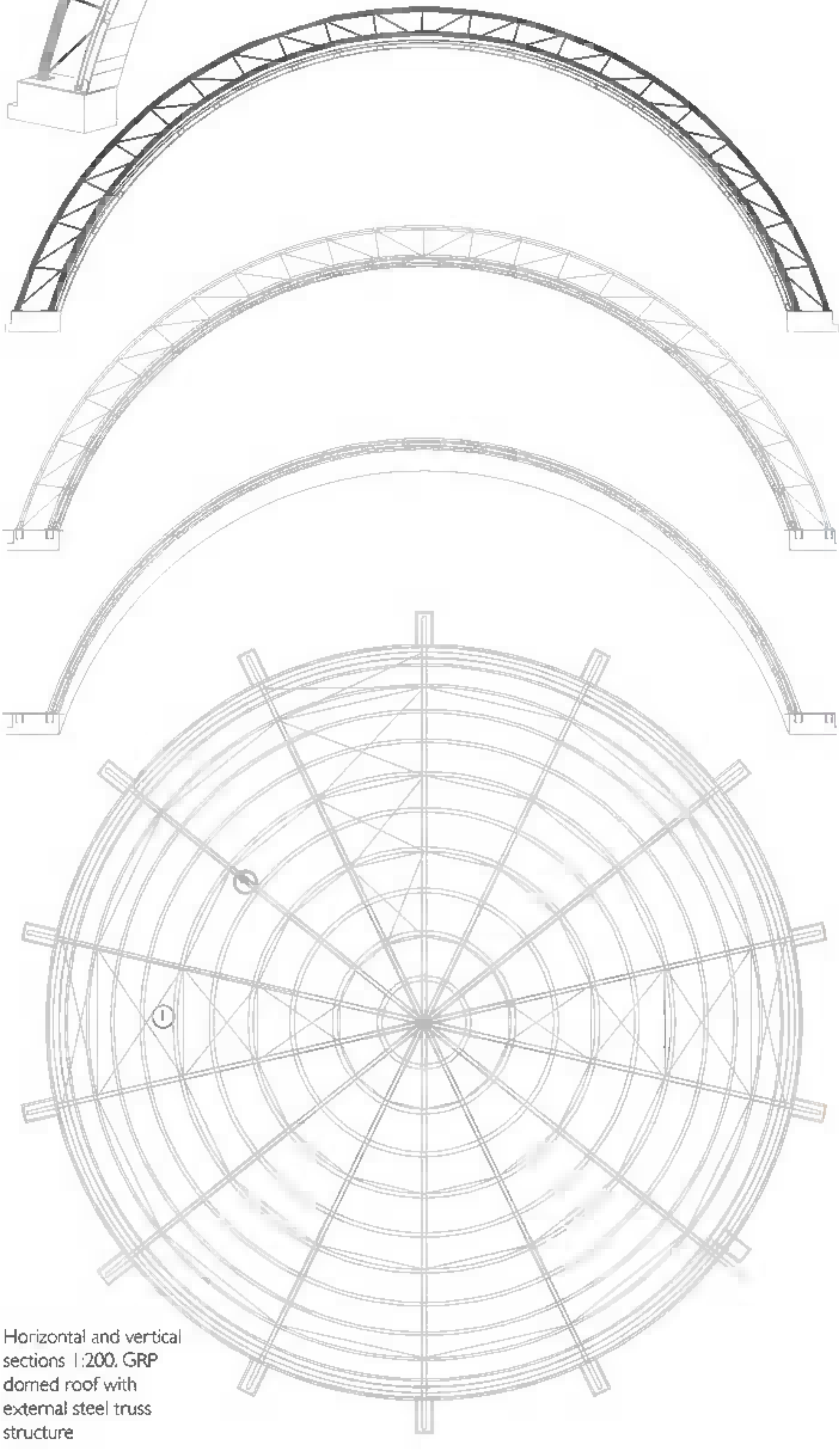
The structural shell is usually assembled by bringing the panel segments to site individually, due to their size. The panels are then bolted together on site, on the ground. The joints are then formed on the finished face, either internal or external. Finally, the shell is lifted by crane into position 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 make the inner face of the shell smooth and continuous, and ready for painting, usually require the in-situ constructed solution to be in an enclosed space to avoid GRP dust particles from spreading around the building.

The inner shell is generally 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. The horizontally-set ribs span a maximum of around 450mm at the base of the shell, deceasing in size until they reach the top of the shell. 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.

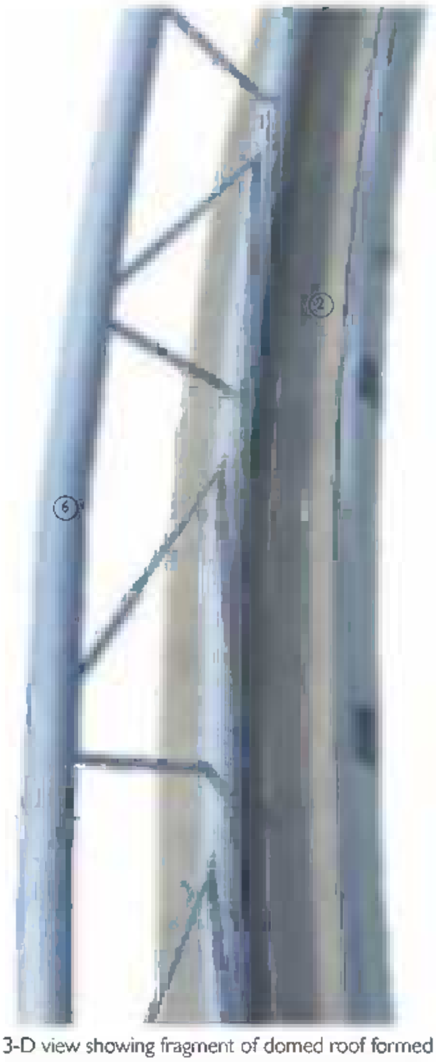
The shell is thermally insulated with mineral fibre or foam-based insulation set in the voids between the ribs. The outer face of the shell is covered with a GRP skin that provides an outer seal against rainwater penetration. The layer is given a further protection and visual screen provided by outer cladding panels. Like the inner shell, the outer cladding is



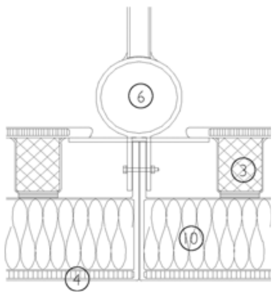
3-D fragment of domed GRP roof with external exposed truss structure



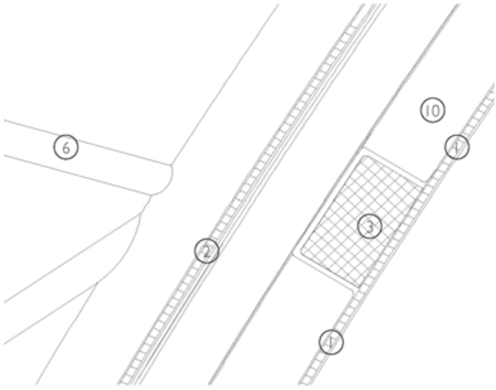
Horizontal and vertical sections 1:200. GRP domed roof with external steel truss structure



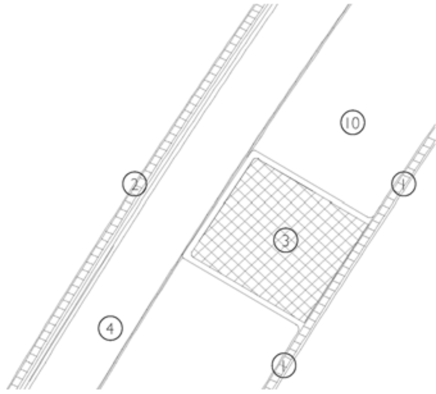
3-D view showing fragment of domed roof formed using GRP shell panels and external exposed truss structure



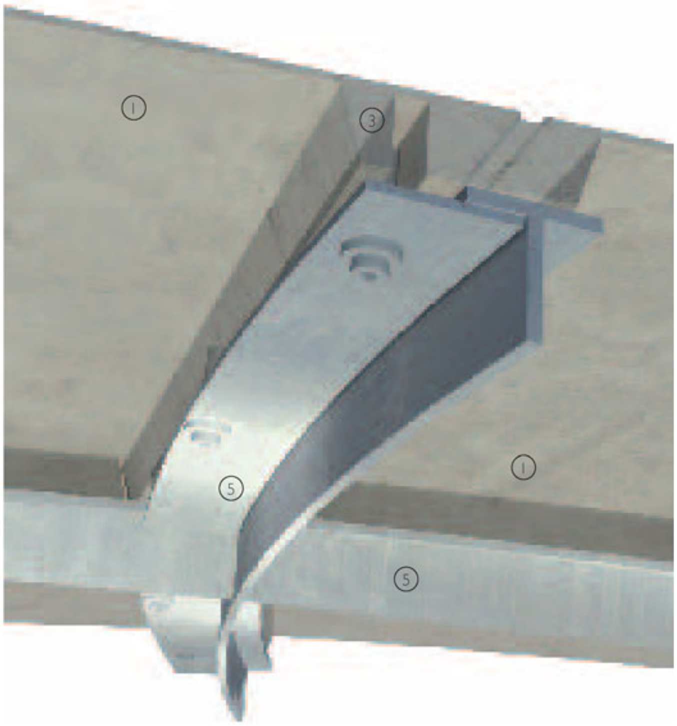
Horizontal section 1:10. Panel to panel junction



Vertical section 1:10. Junction between shell panels and external supporting truss



Vertical section 1:10. Junction between shell panels and external supporting truss

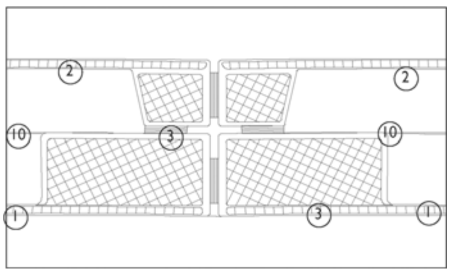


3-D view showing fixing method for GRP roof panel formed with steel structure

3-D view showing fixing method for GRP roof panel formed with steel structure

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
11. Glazing
12. Concrete base

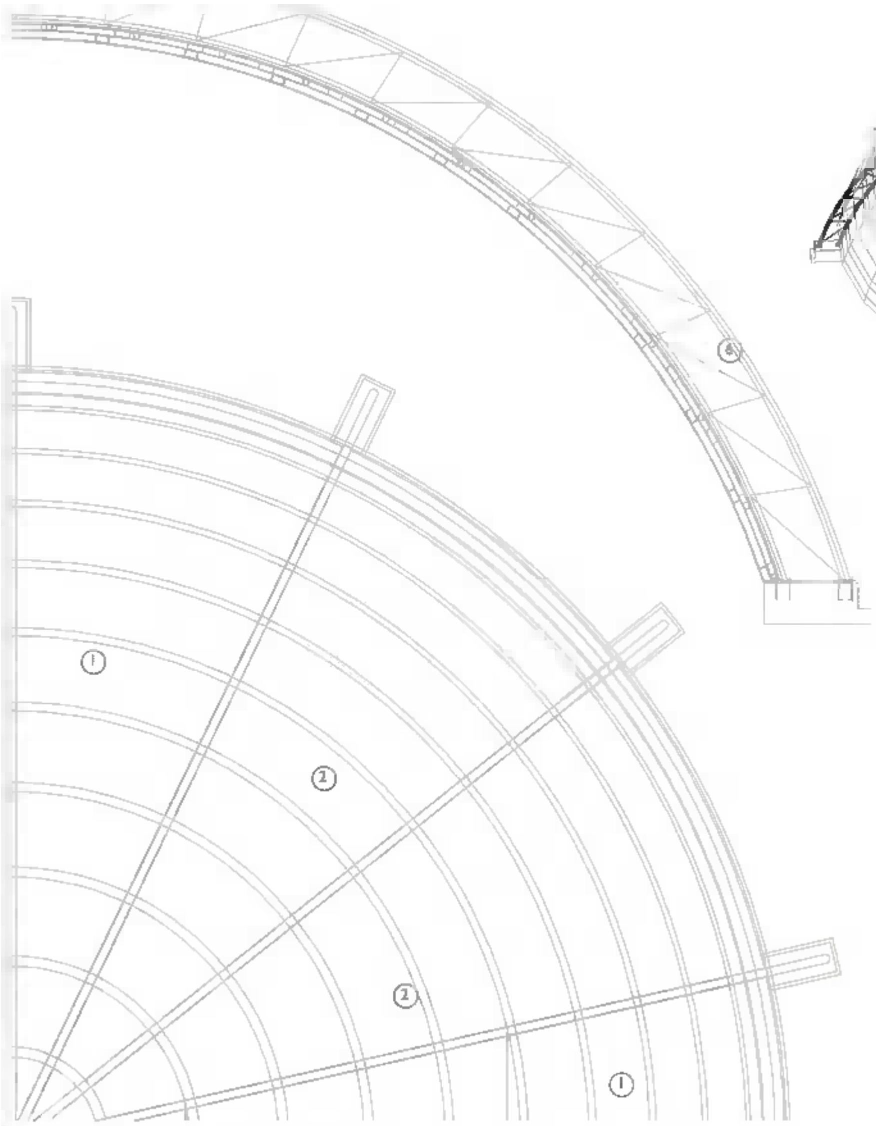


Horizontal section1:10. Panel to panel junction

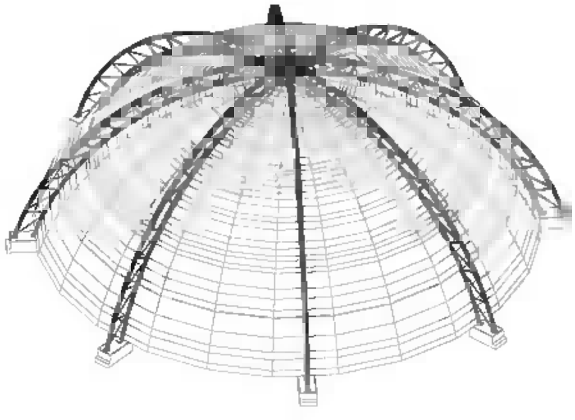
made from 15mm thick composite panels, stiffened by GRP ribs around 100mm deep x 200mm wide. These outer segmented panels are bonded to the inner shell with resins or with silicone, and sealed with silicone at their joints to form a continuous outer skin. Small amounts of rainwater that might penetrate 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 on larger shells. For this reason, visible joints are usually preferred in larger-scale GRP shells.

In generic examples, 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. A metal plate is set between the adjacent panels, with the joint being sealed with silicone. An outer skin of GRP cladding panels can provide an outer line of defence against rainwater 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.

In many cases the junction at the base of the shell is treated as an upstand. This allows the shell to be set a minimum of 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. The base plate is set on levelling shims to take up the construction tolerances



Horizontal and vertical sections 1:100

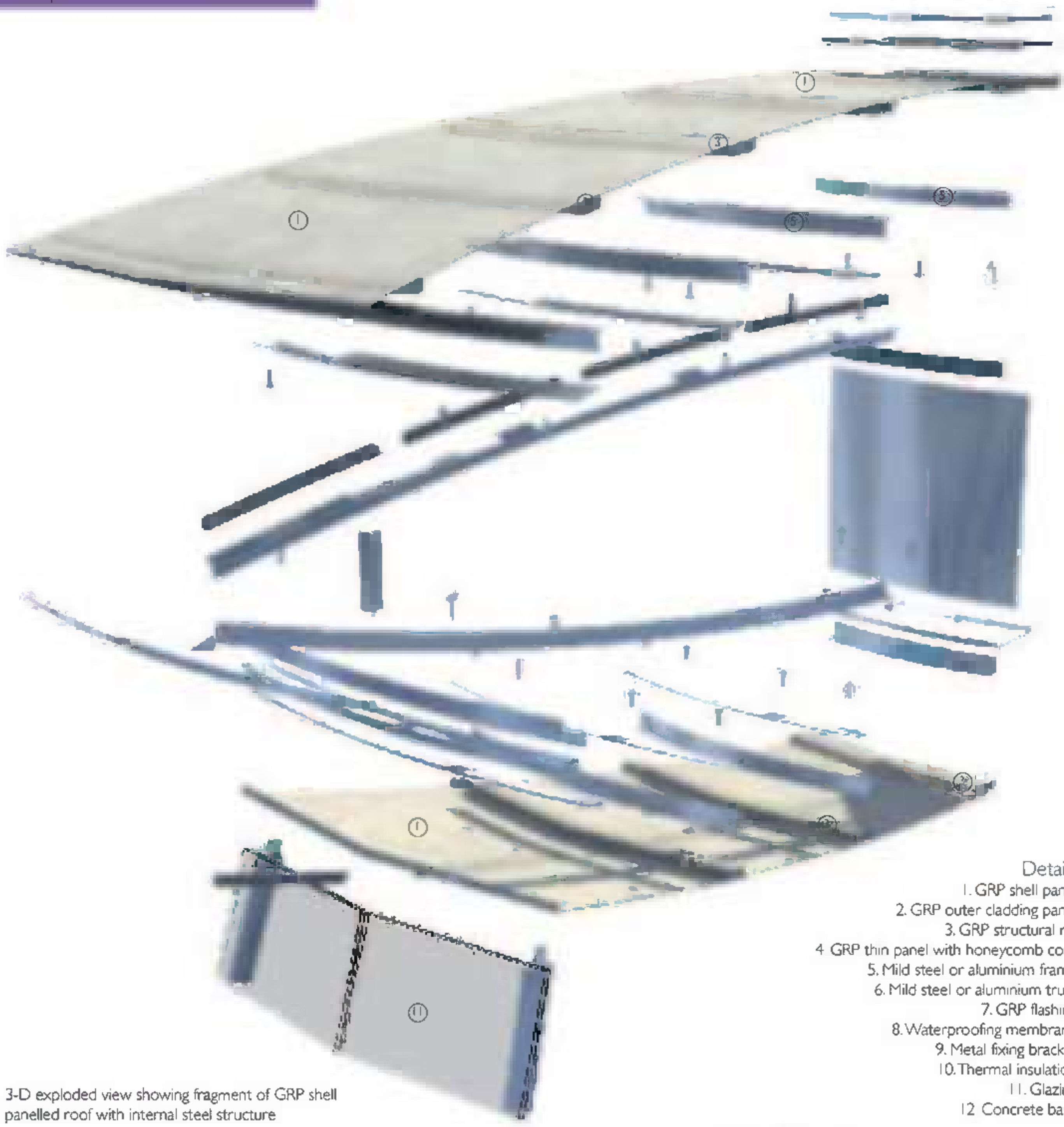


3-D view showing stripped-back GRP panel-clad dome

3-D view showing base junction of dome formed with GRP shell panels and external steel truss

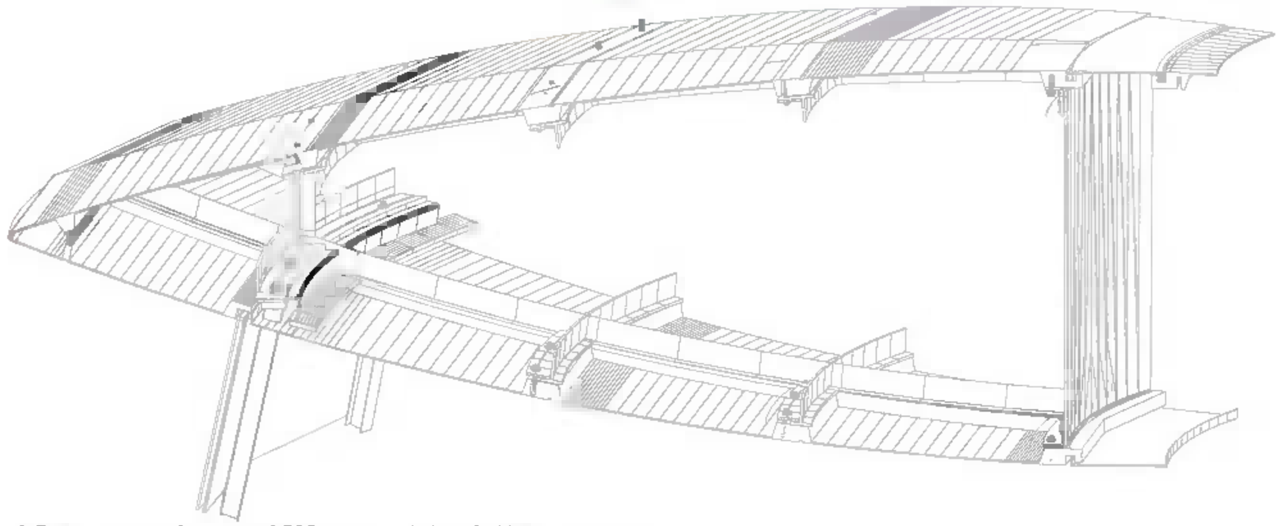
in the height of the concrete upstand. The waterproofing membrane of the adjacent roof is taken up to the top of the upstand and is lapped under the GRP flashing. An additional waterproofing membrane may extend to the inside of the inner shell and up the internal face of the shell where it is protected by another GRP cover strip, concealed from view by internal finishes.

3-D view showing hemispherical dome formed with GRP shell panels and external steel structural truss



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
11. Glazing
12. Concrete base

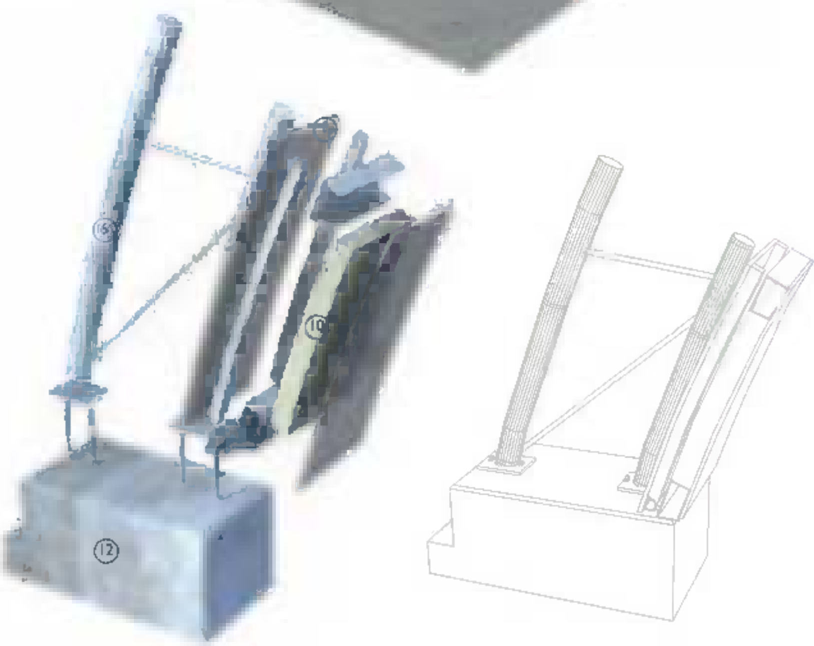
3-D exploded view showing fragment of GRP shell panelled roof with internal steel structure



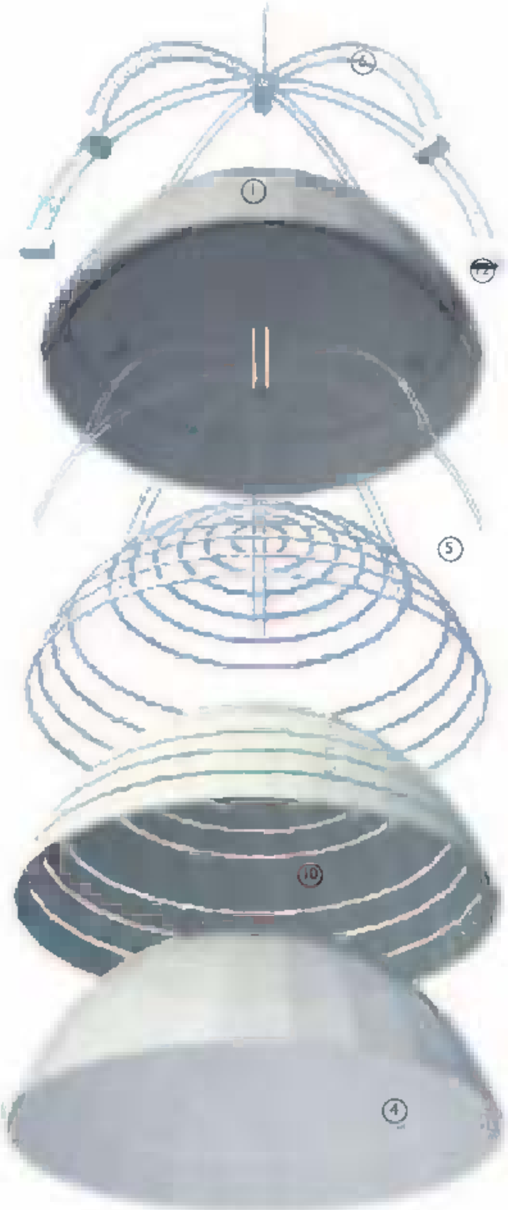
3-D view showing fragment of GRP shell panelled roof with internal steel structure

3-D exploded view showing outer edge of fragment of GRP shell panelled roof with internal steel structure

3-D exploded view showing fixing method for GRP panel roof assembly



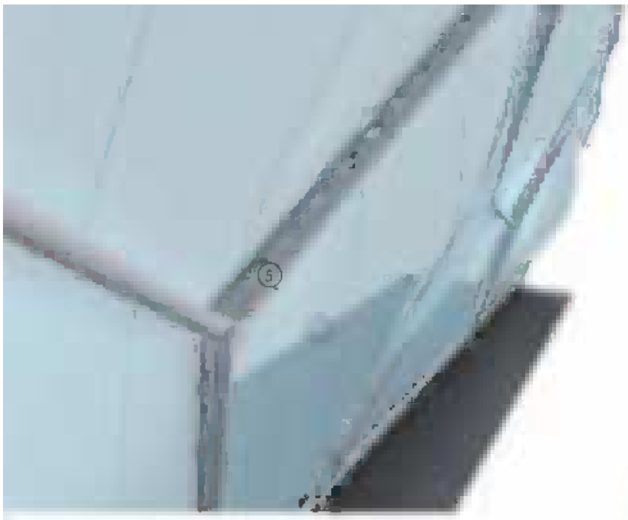
3-D exploded view showing base condition of domed roof formed using GRP shell panels and steel truss



3-D exploded view showing assembly of hemispherical dome formed with GRP shell panels and external steel structural truss

12

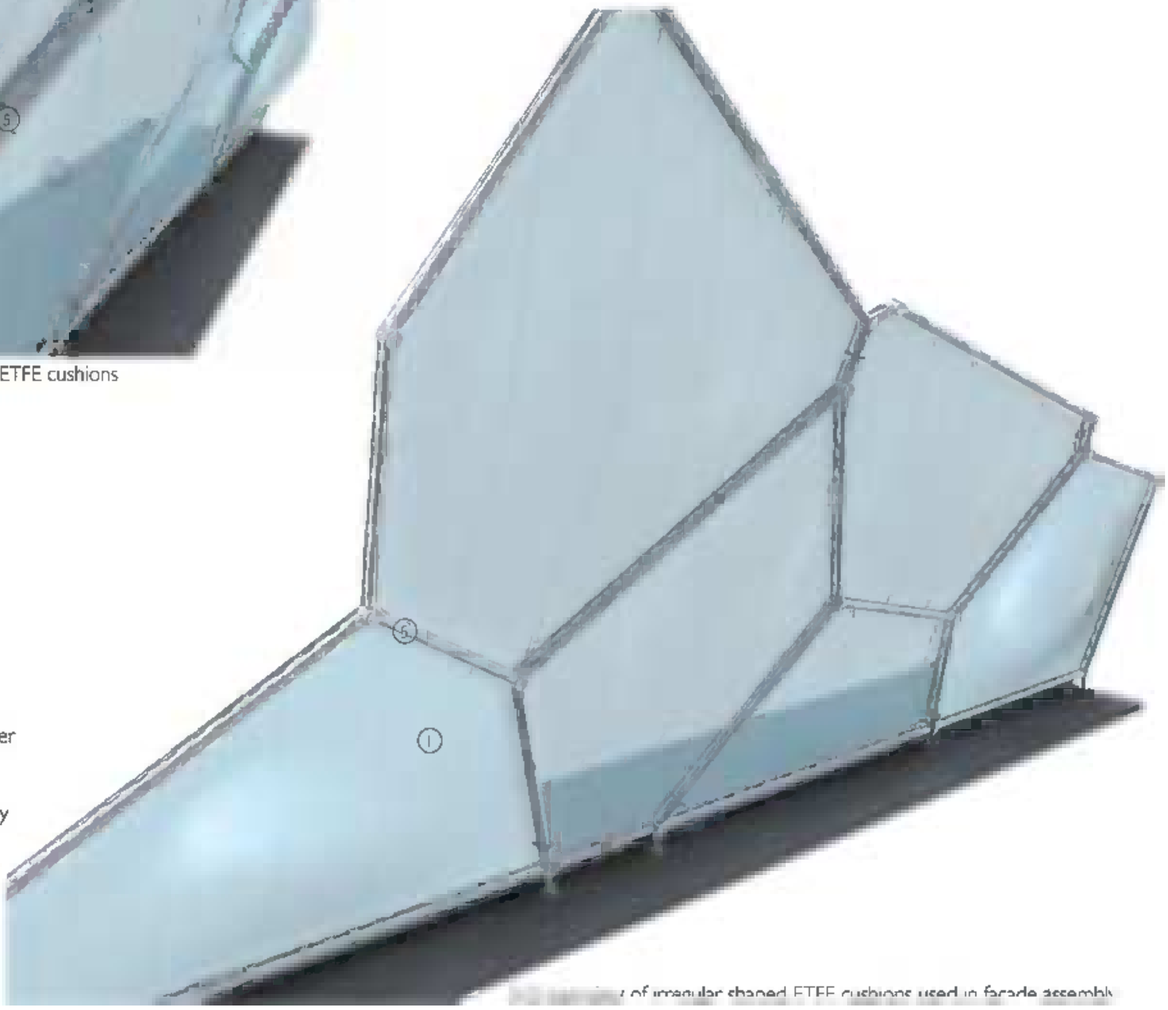
FABRIC ROOFS



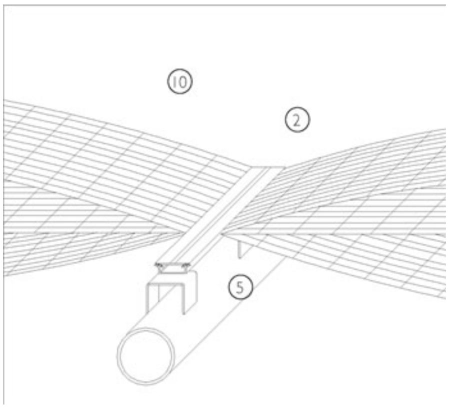
-D view of junction between ETFE cushions

Details

- ETFE cushion
- Extruded aluminium clamping plate
- Extruded aluminium retaining profile
- Plastic edge bead to fabric membrane
- Supporting structure
- Plastic air supply tube
- Main air supply tube
- Insulated metal lined gutter
- Metal flashing
- 0. ETFE cushion with contours shown for clarity



of irregular shaped ETFE cushions used in facade assembly



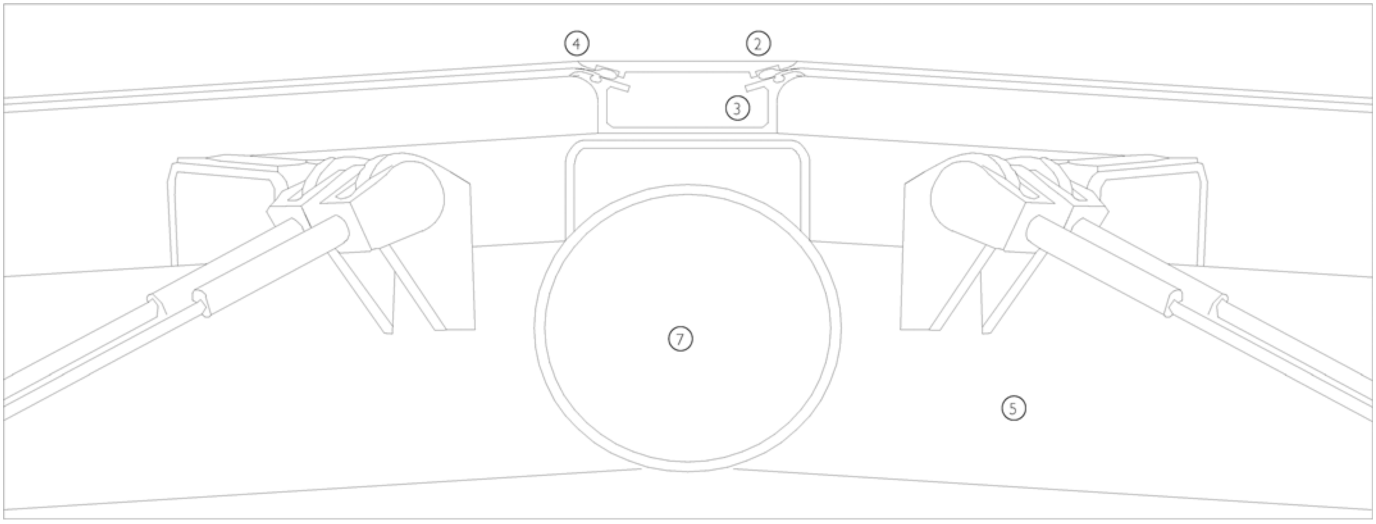
Isometric view of junction of clamping plates

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 application of inflatable fabric roofs.

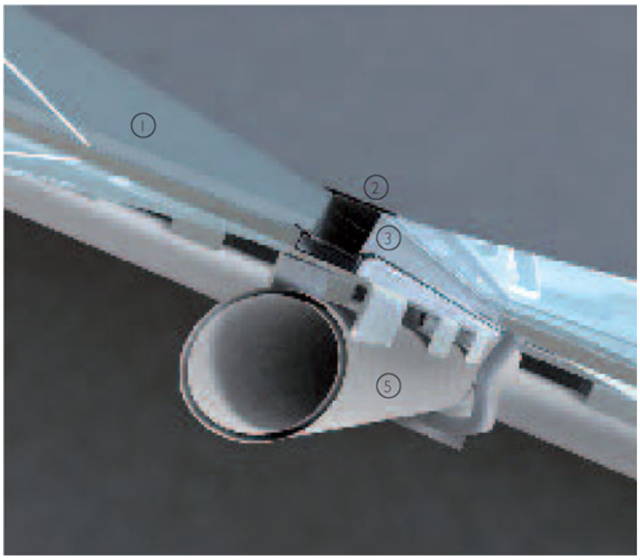
Although large scale self-supporting inflatable roof structures are in use, particularly for covering sports stadiums, they remain structurally stable only while air is being supplied to the structure. If the air supply is interrupted, the complete roof structure deflates. In smaller scale applications, 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

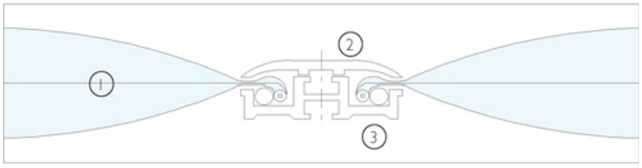
ETFE cushions usually consist of a minimum of two layers of ETFE sheet which are set



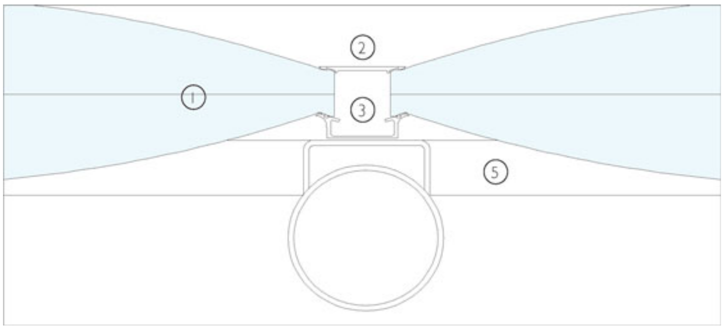
Vertical section 1:5. Junction of clamping plates



3-D view of junction of clamping plates



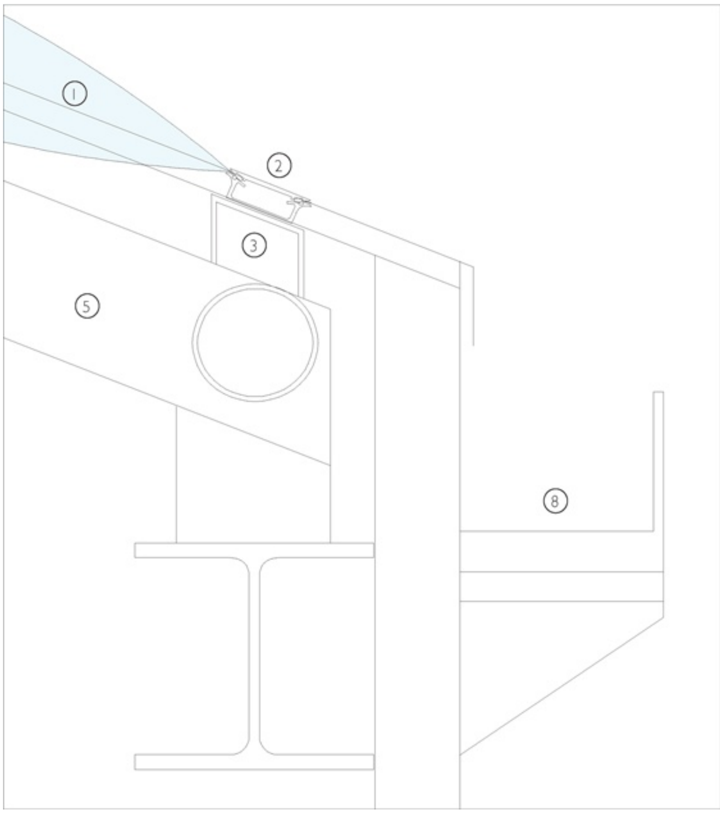
Vertical section 1:5. Clamping plate assembly



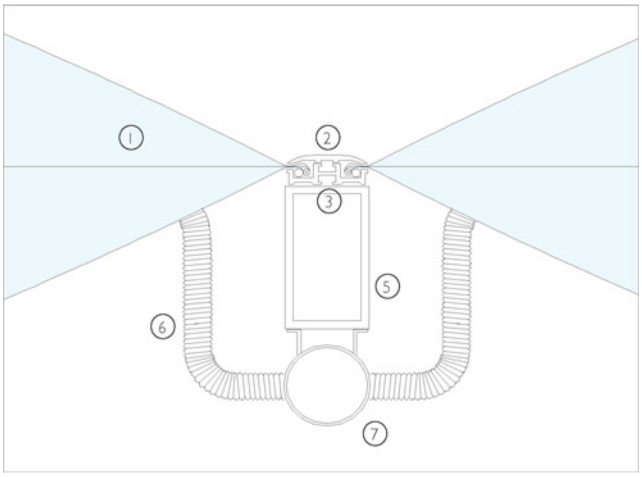
Vertical section 1:10. Junction of clamping plates

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 structure formed typically as box sections or tubes. Cushions typically have three layers that form two chambers. 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 W/m2K, 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, to provide a consistently wide air space within the cushion. Thermal insulation performance can also be improved by increasing the number of air

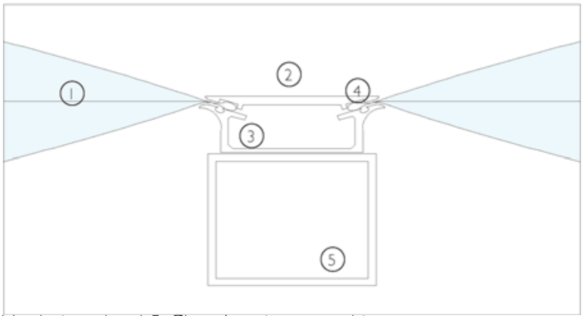
3-D cutaway view of junction between ETFE facade and ground



Vertical section 1:5. Junction with gutter



Horizontal section 1:10. Clamping plate with air supply pipes



Vertical section 1:5. Clamping plate assembly

3-D detail of cushion to cushion air supply

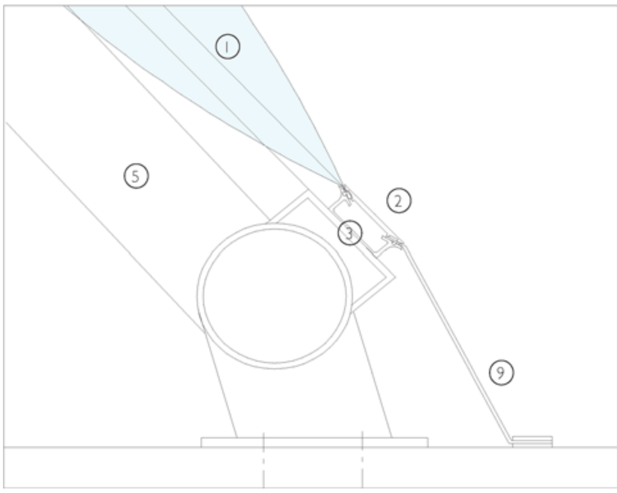
3-D detail of junction between ETFE cushions

chambers within the cushion by adding further layers of ETFE membrane.

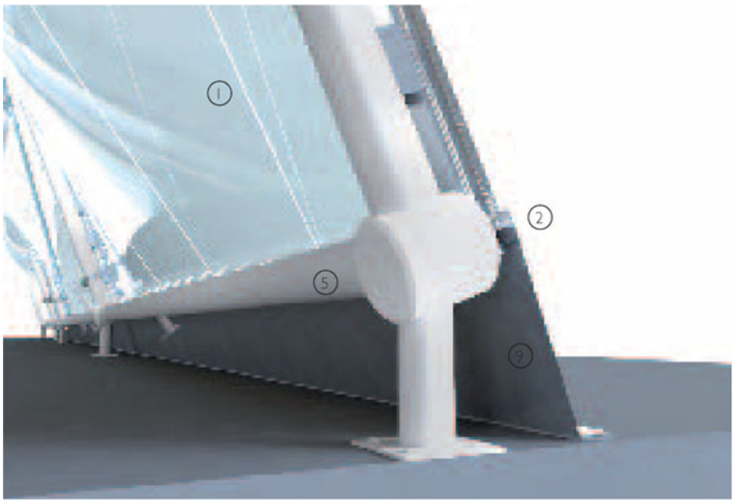
Air supply

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. 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 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

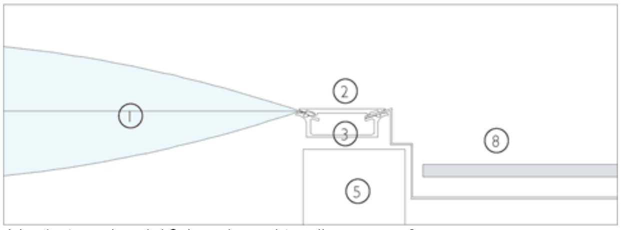


Vertical section 1:10. Junction at base

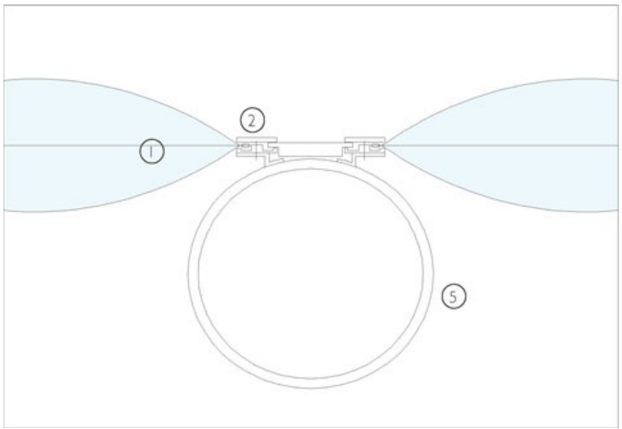


3-D detail of junction between ETFE facade and ground

3-D detail of junction with adjacent roof



Vertical section 1:10. Junction with adjacent roof



Vertical section 1:10. Junction of clamping plates

valves to prevent loss of air pressure from the cushions back to the supply pipes.

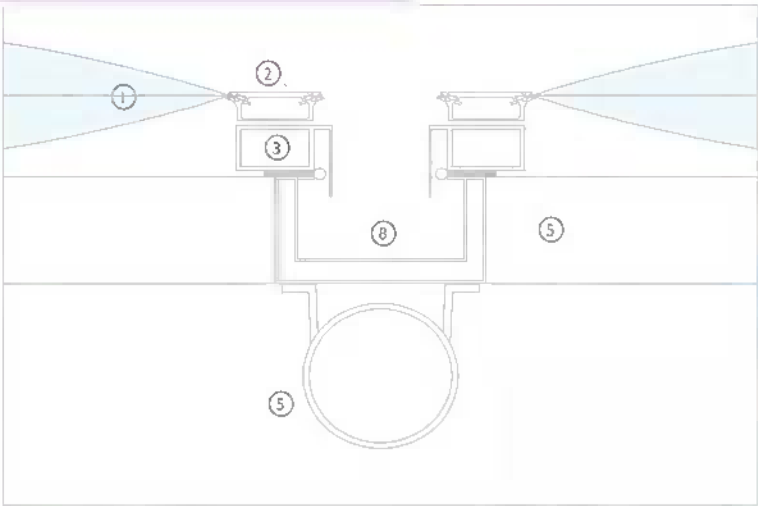
Condensation on the underside, or internal face, of ETFE cushions is avoided by ensuring that ventilation levels within the building are sufficiently high to avoid this occurring, and that levels of relative humidity are suitably controlled. Where condensation is still a risk, condensation channels are fixed to the underside of the cushion clamping assembly, 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

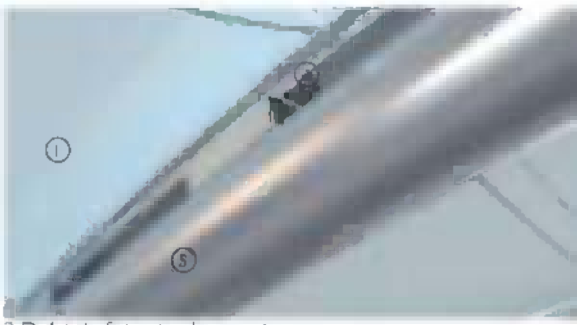
ETFE (ethylene-tetra-flouro-ethylene) is a polymer similar to PTFE (marketed as Teflon) which is made by extrusion as a sheet material. Thicknesses vary but 0.2mm is a common thickness of material for ETFE cushions, allowing them to be very light in weight at around 350g/m^2 for this thickness of sheet. Heavier gauge sheet at 0.5mm thickness weighs around 1000g/m^2. 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

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



Vertical section 1:10. Opening smoke vents with insulated gutter



3-D detail of structural supports

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

3-D overview of ETFE roof system

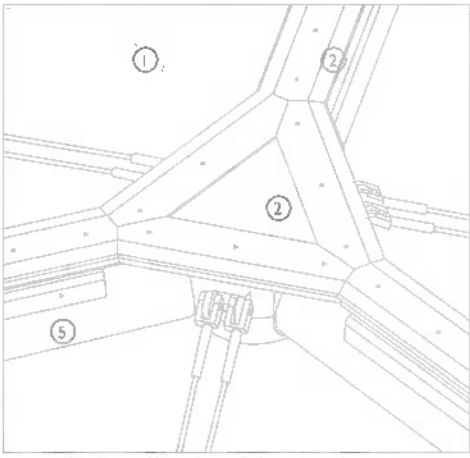
white coloured translucent sheet is manufactured which provides around 40% light transmission. ETFE does not provide a barrier to the passage of UV light, making it ideal for use in buildings where extensive planting is displayed, though the translucent white sheet has greatly reduced UV light transmission. 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.

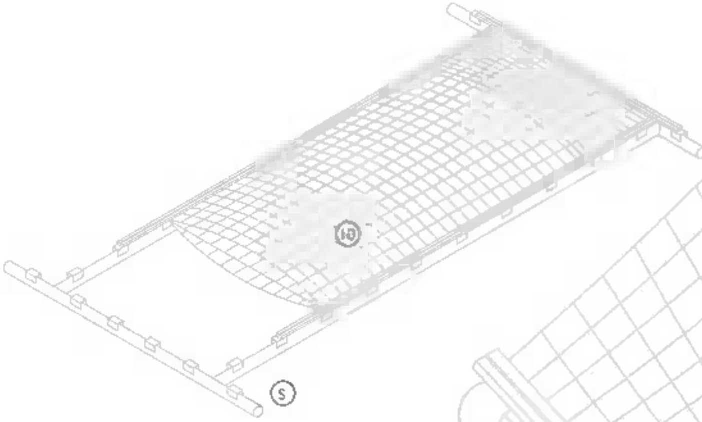
Fabrication

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 form created from a standard width of ETFE sheet. Cushions up to around 7.0 × 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.

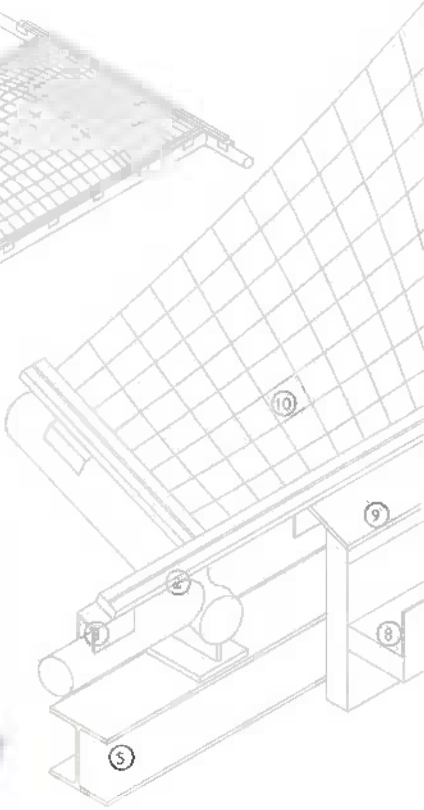
The cushions have an edge bead, typically in plastic, which is used to retain the panel in its supporting frame. The cushion is set into a clamping frame, usually made from extruded aluminium, that holds the panel in place by clipping it into an aluminium profile, then holding it in place with an aluminium 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



Isometric view of junction of clamping plates

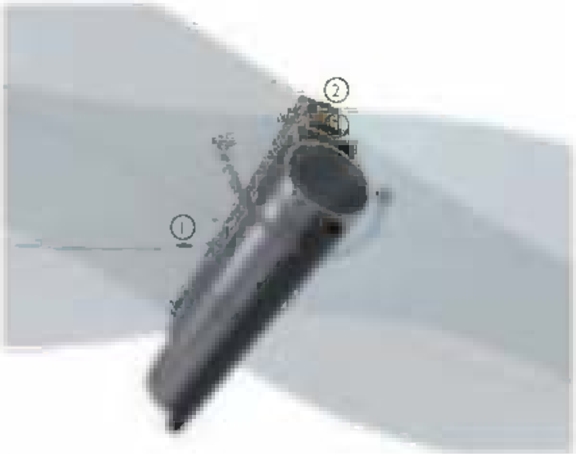


Isometric view of junction of ETFE cushion assembly

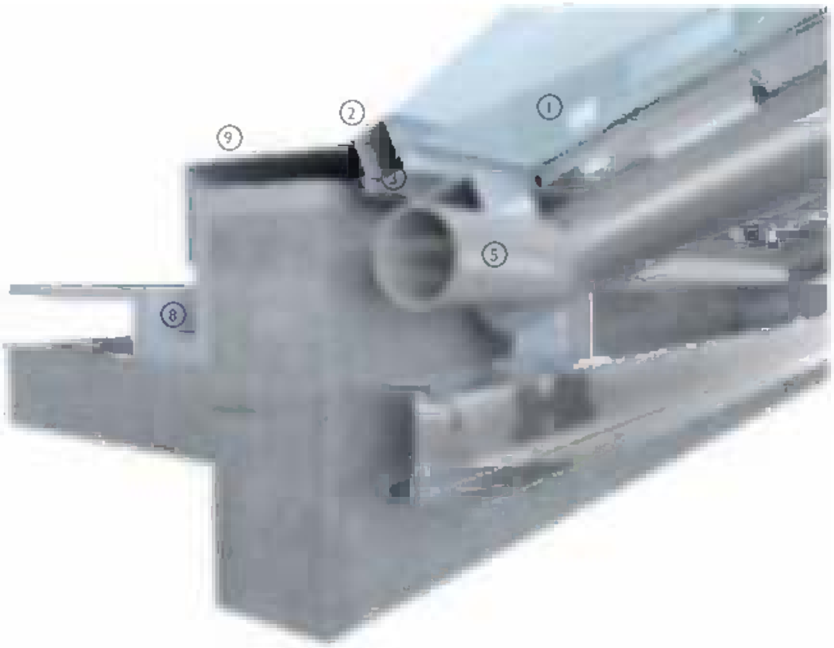


Isometric view of junction with gutter

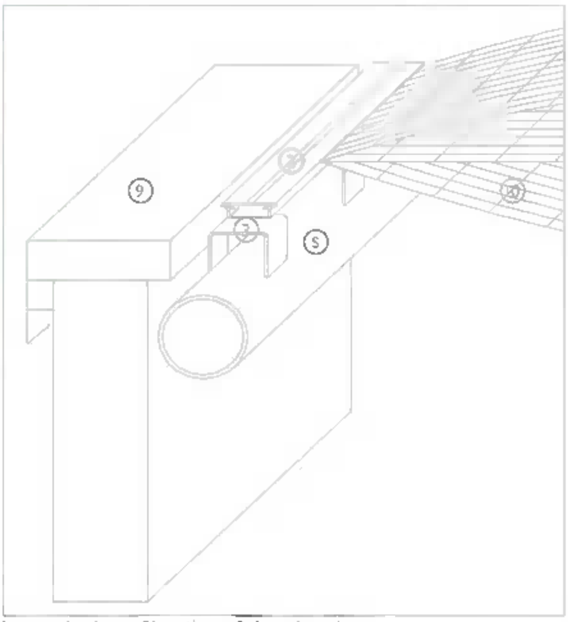
3-D overview of ETFE roof system



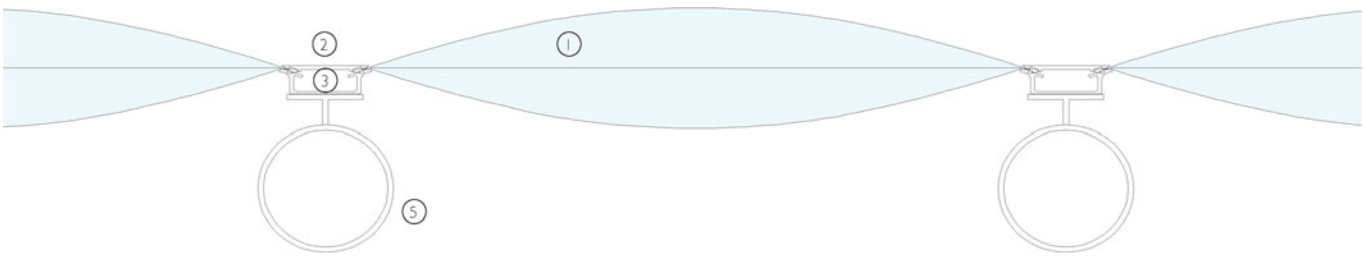
3-D view of joint between ETFE cushions showing air supply pipes



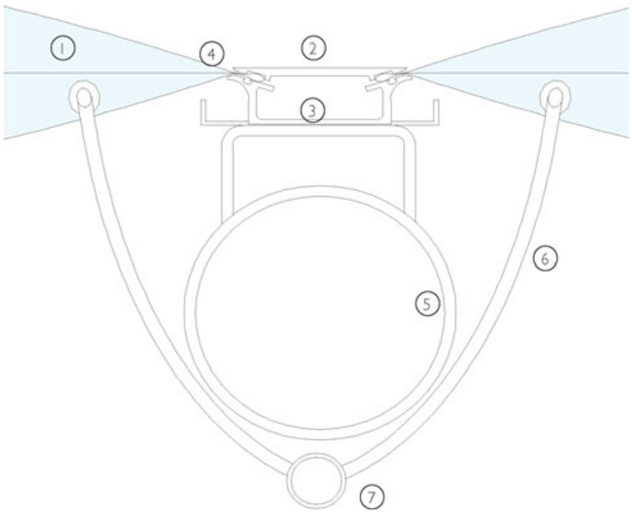
3-D view of junction with adjacent roof



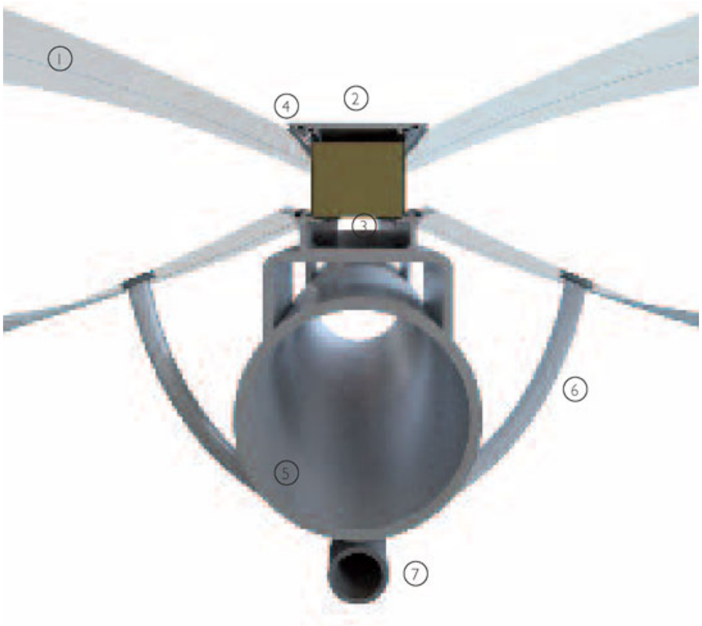
Isometric view of junction of clamping plates



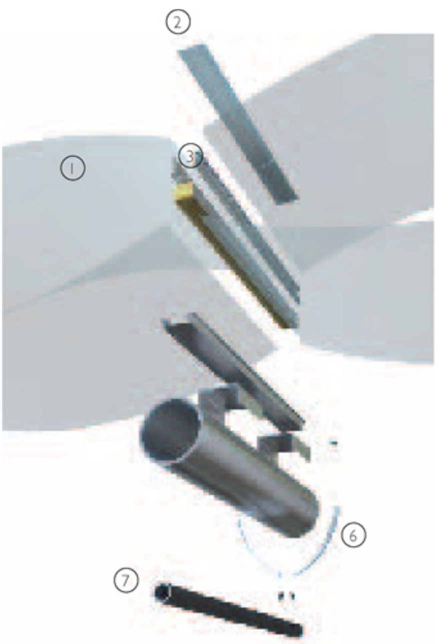
Vertical section 1:10. Junction of clamping plates



Vertical section 1:5. Junction of clamping plates



3-D view of joint between ETFE cushions showing air supply pipes



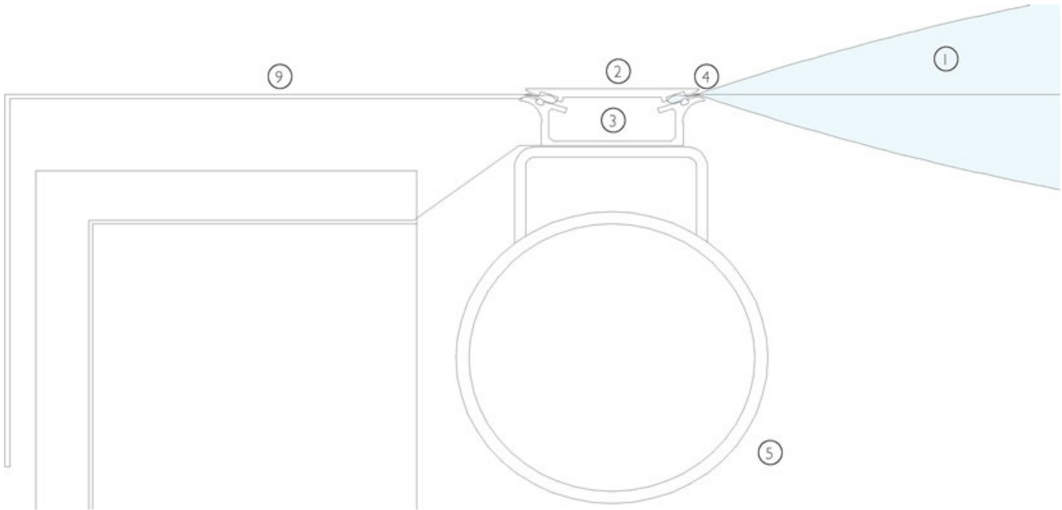
3-D exploded view of joint between ETFE cushions showing air supply pipes

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 commonly used on glazed roofs .

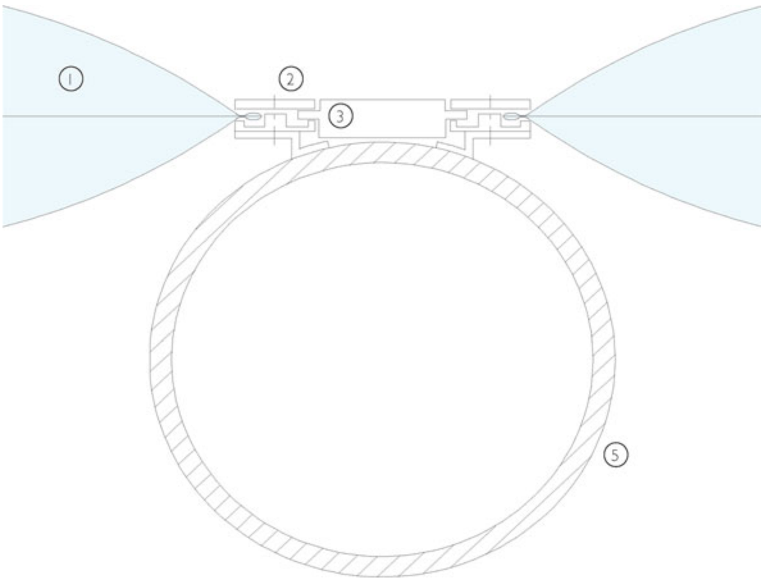
The complete ETFE cushion assembly is supported by a structural frame beneath, with mild steel, aluminium and laminated timber all being used to suit the design. The clamped framing assembly is fixed to mild steel tubes by fixing the framing onto T-sections which are welded in short lengths to the mild 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

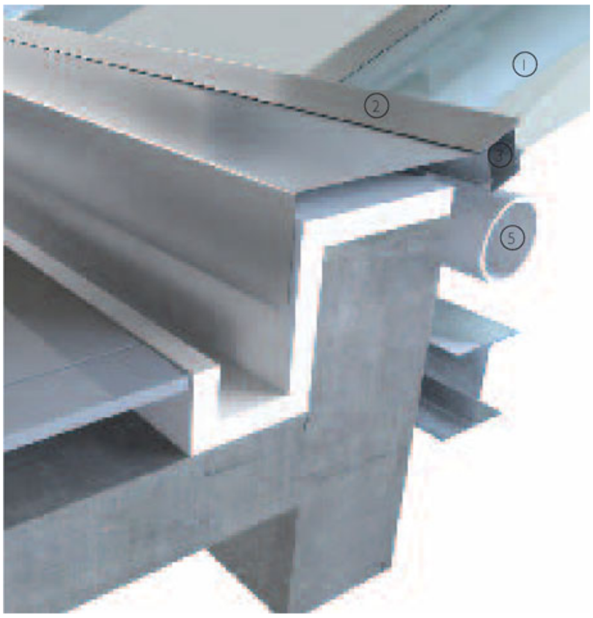
The toughness of ETFE sheet is combined with a high resistance to tear. Damage by sharp objects puncturing an outer membrane does not spread easily into a larger tear. Birds can puncture the outer membrane, but they have great difficulty in coming to rest on the roof itself, except on the clamping plates, 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



Vertical section 1:5. Junction with adjacent roof



Vertical section 1:5. Junction of clamping plates



3-D view of junction with adjacent roof

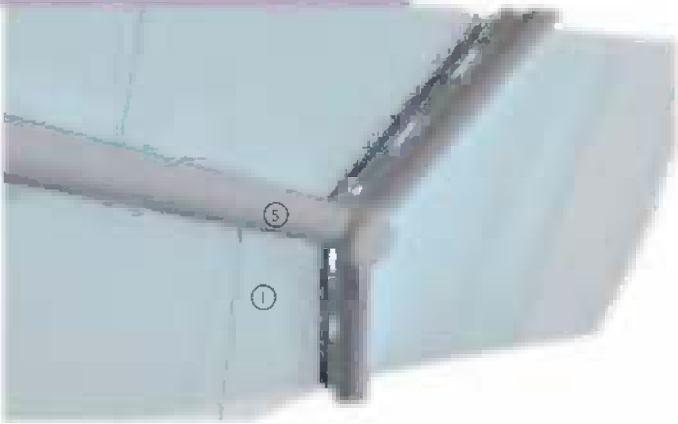
of rain in temperate climates, though access for maintenance is required, usually provided by walking along the external clamping plates with cable assistance or from external structure. Roofs are designed so as to ensure that rainwater drains easily from the roof. Gutters are introduced on long span roofs between sets of clamping plates. 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.

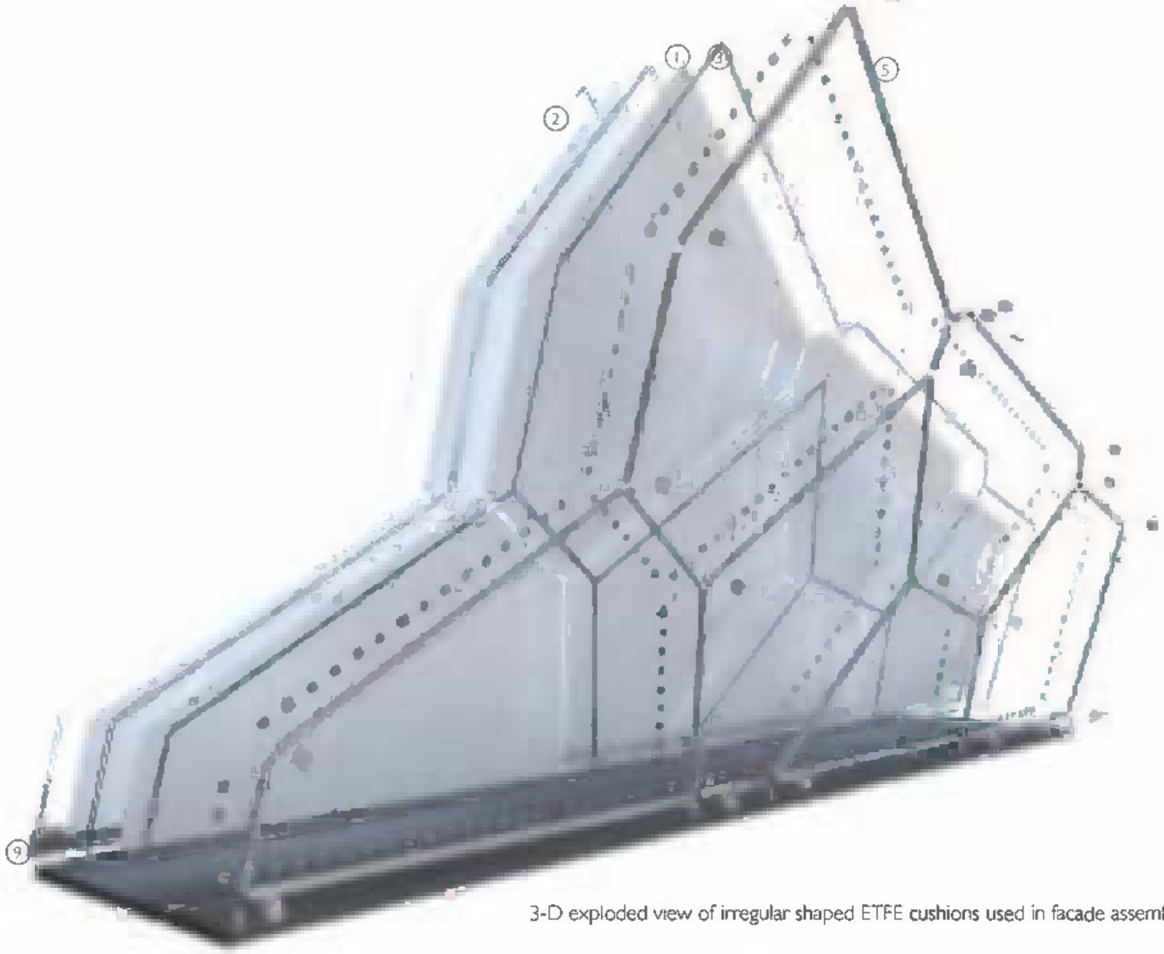
Details

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



3-D detail of junction between ETFE cushions

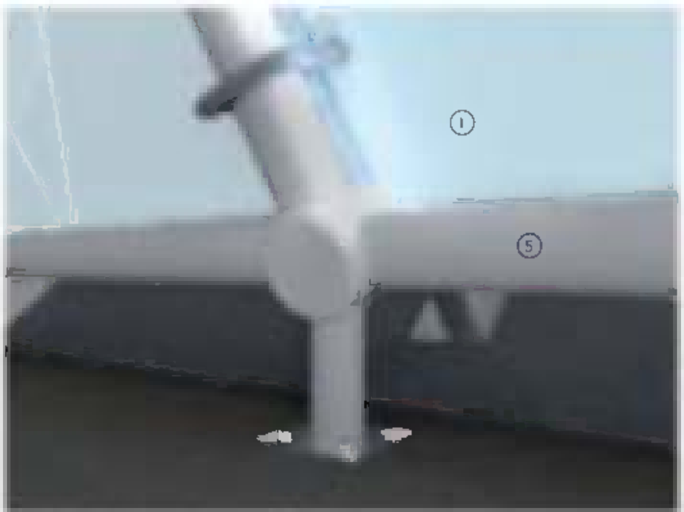
3-D exploded view of junction between ETFE cushions



Details

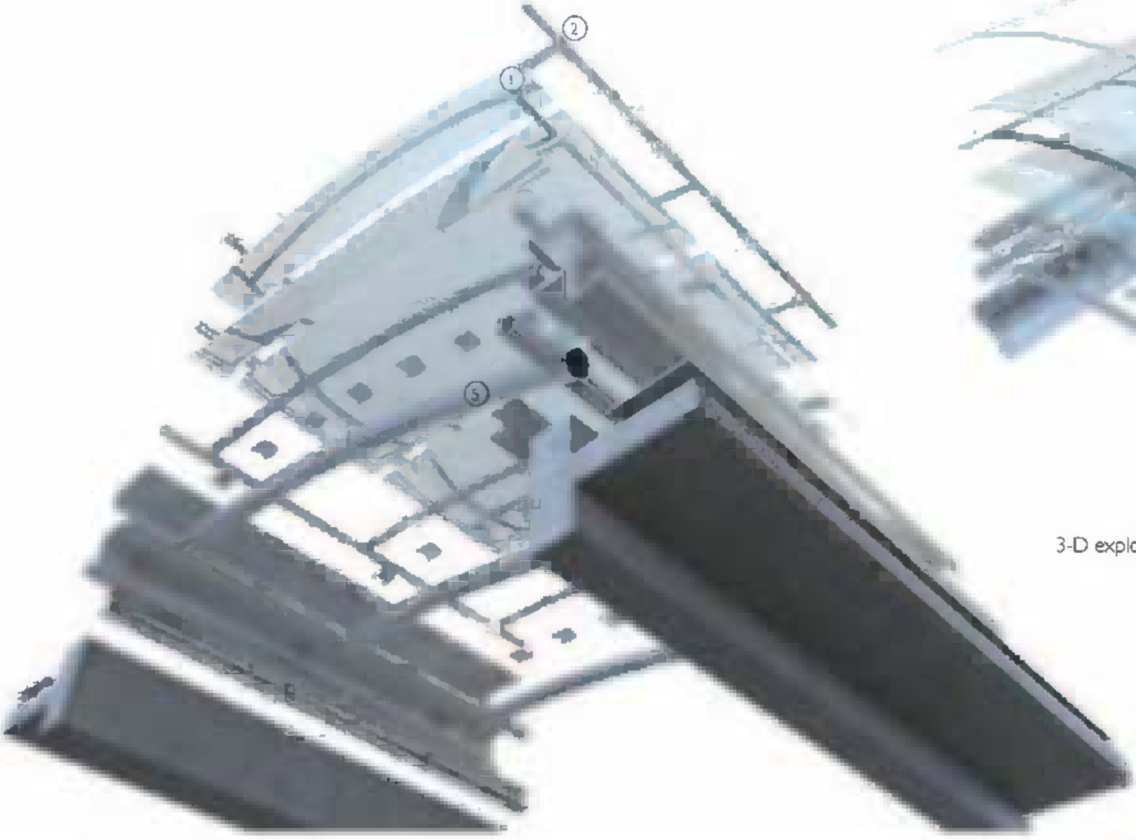
1. ETFE cushion
2. Extruded aluminium clamping plate
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Supporting structure
6. Plastic air supply tube
7. Main air supply tube
8. Insulated metal lined gutter
9. Metal flashing
10. ETFE cushion with contours shown for clarity

3-D exploded view of irregular shaped ETFE cushions used in facade assembly

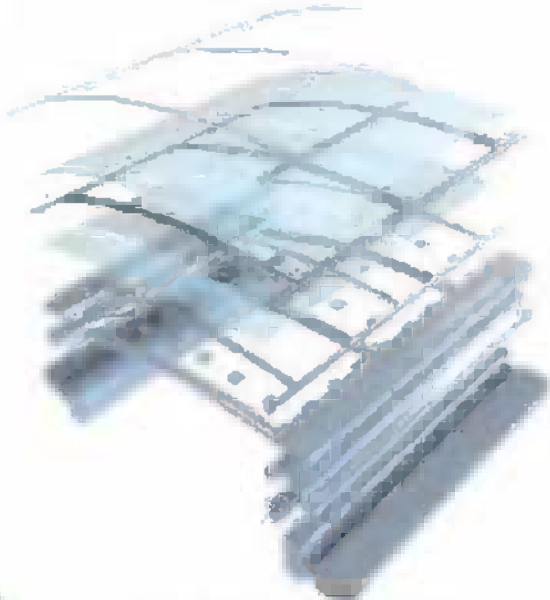


3-D detail of junction between ETFE cushions and ground

3-D exploded view of junction between ETFE cushions and ground

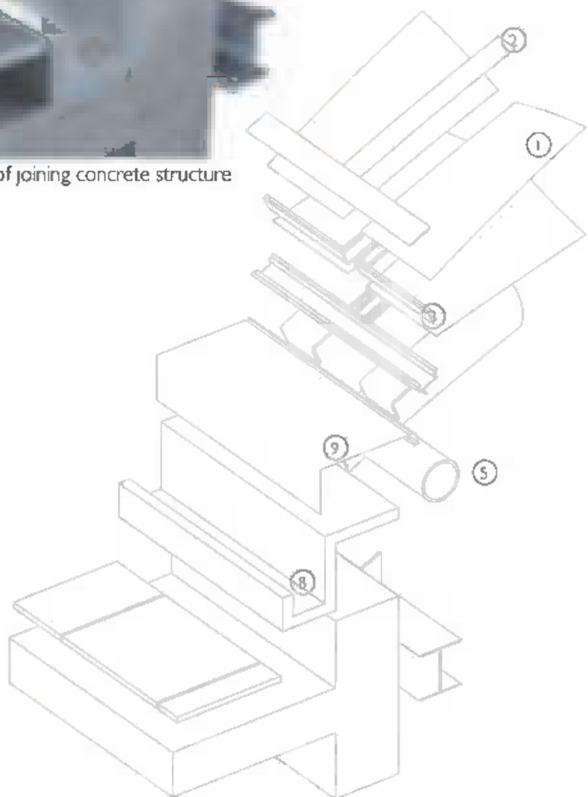


3-D exploded view of ETFE roof system


3-D exploded view of ETFE roof system

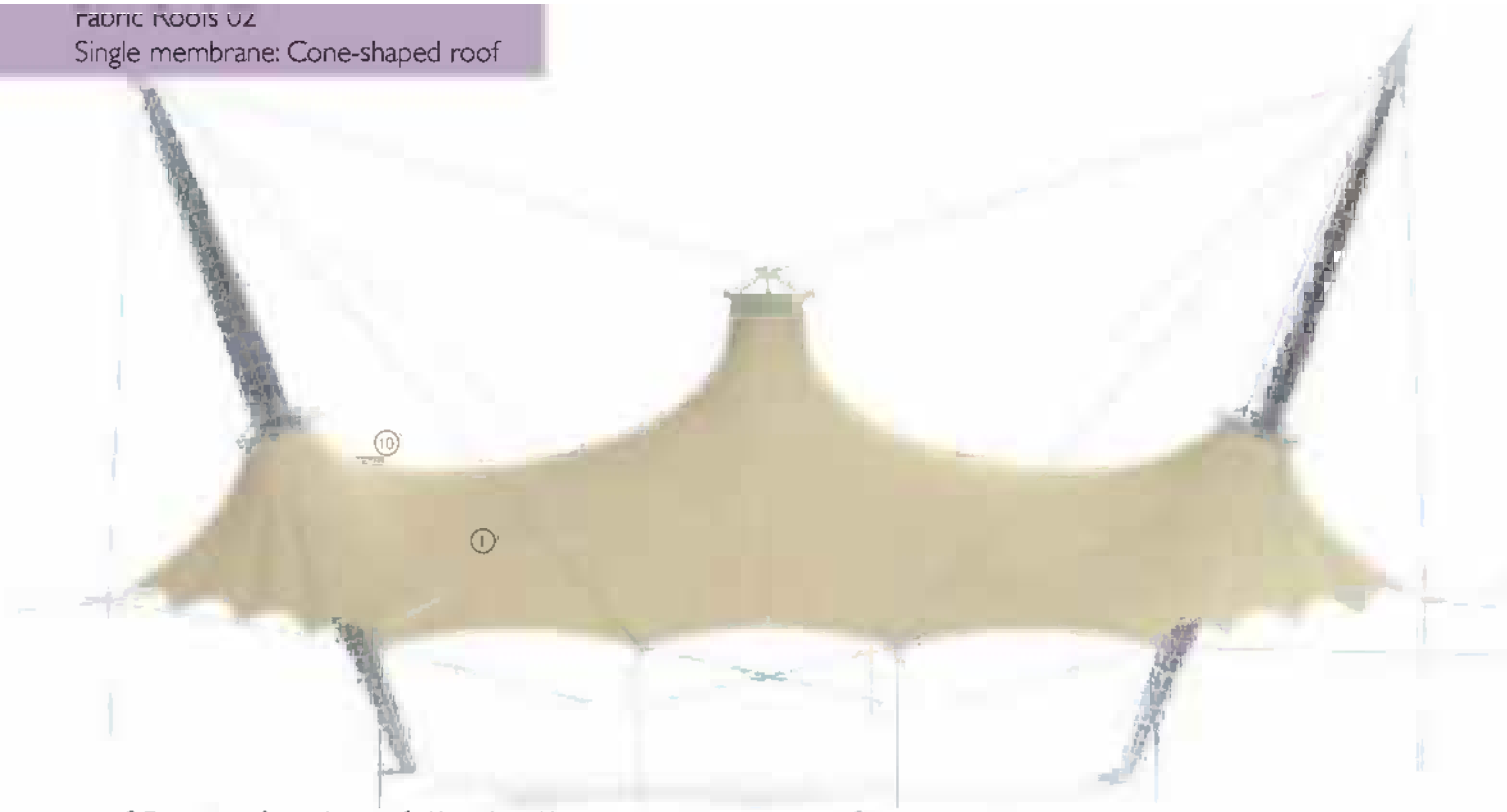

3-D view of ETFE roof joining concrete structure

3-D view of ETFE roof joining concrete structure

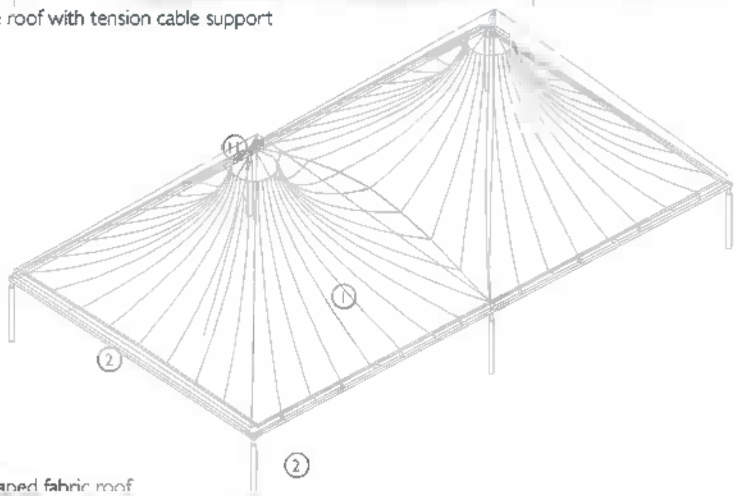


Exploded axonometric view of ETFE roof joining concrete structure

3-D exploded view of ETFE roof joining concrete structure



3-D overview of cone shape roof with tension cable support



Isometric view of cone shaped fabric roof

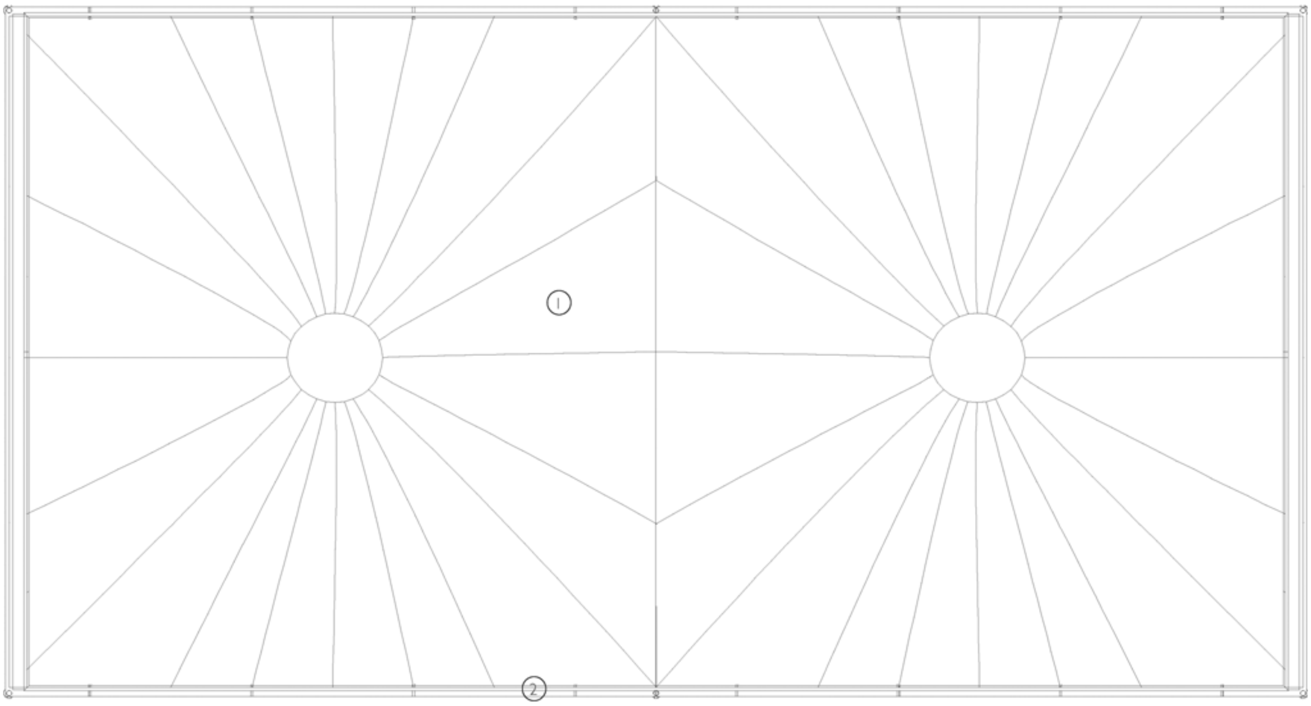
Details
1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. Stainless steel connector
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Mild steel ring support
11. Fabric cover to close ring

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.

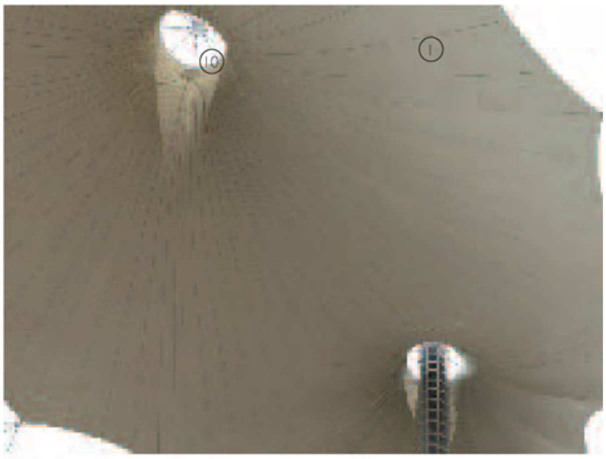
The advantages of single membrane fabric roofs are their smooth curves, typically with different and thin, sharp edges, in opposite directions, that provide translucent roofs that allow diffused daylight to pass through them. They use their curvature as a method of tensioning the membrane against a supporting 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



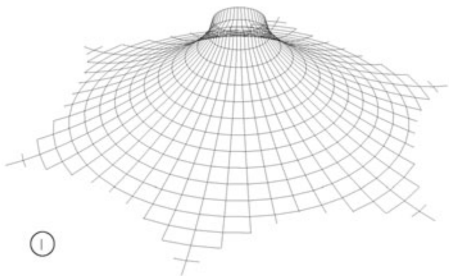
Horizontal section 1:400. Cone-shaped fabric roof

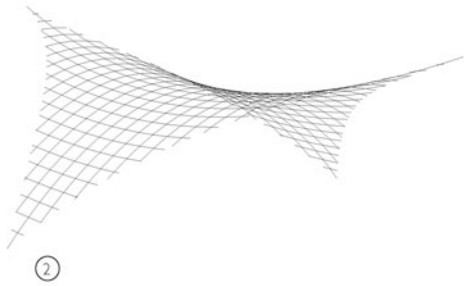


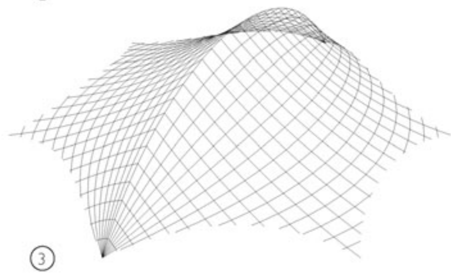
3-D view of underside of cone shape roof

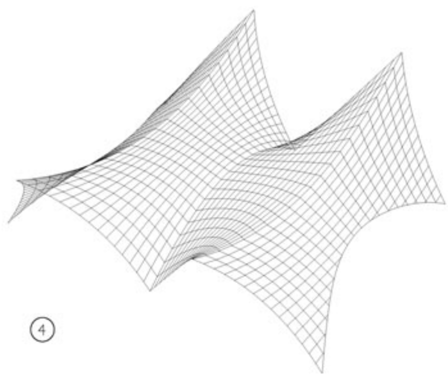
Tensile roof shape types:

1. Cone
2. Saddle
3. Arch
4. Wave



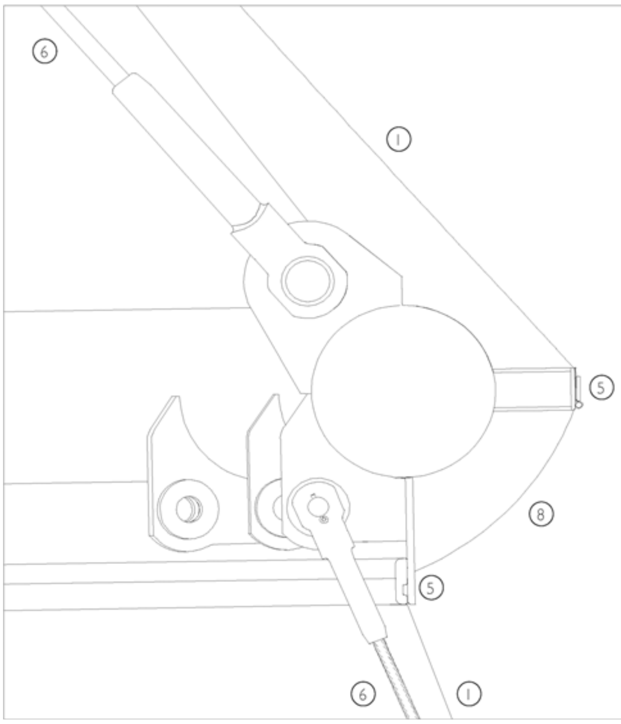




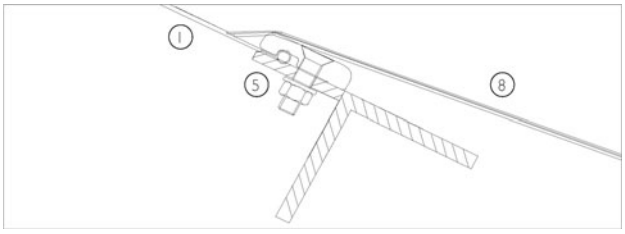


usually developed in the form of a computer model, either by specialist structural consultants or by manufacturers as part of the design development process. The minimal surface form must also be suitable for draining away rainwater, which forms another aspect of design development, together with the treatment of interfaces with adjacent areas of 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 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



Vertical section 1:5. Base of roof with membrane skirt



Vertical section 1:10. Clamping ring

3-D detail of fabric membrane clamped to edge ring

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.

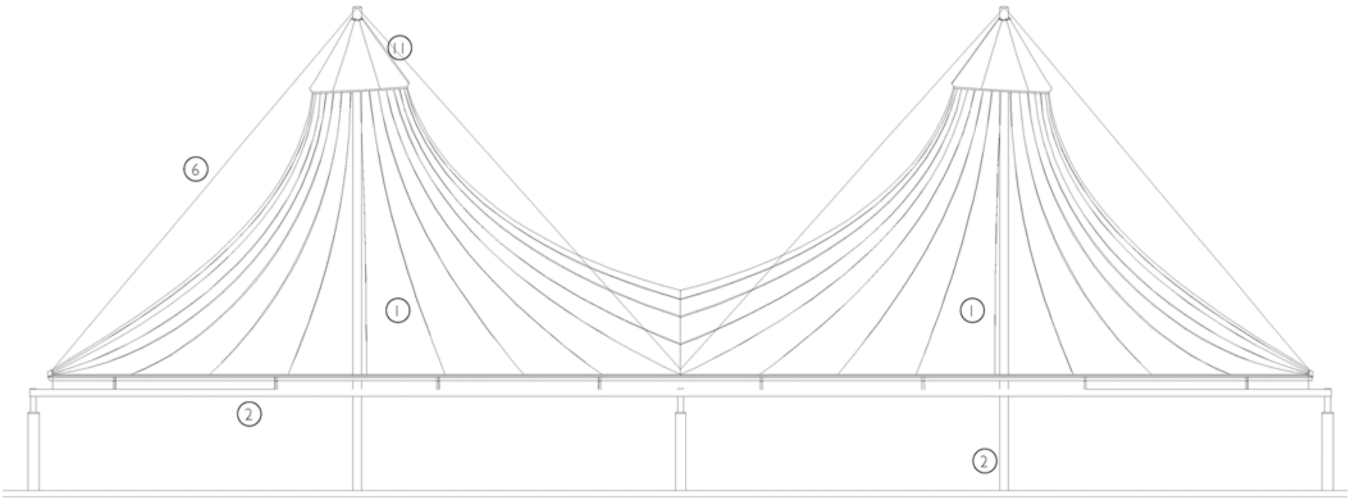
Fabric types

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 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.

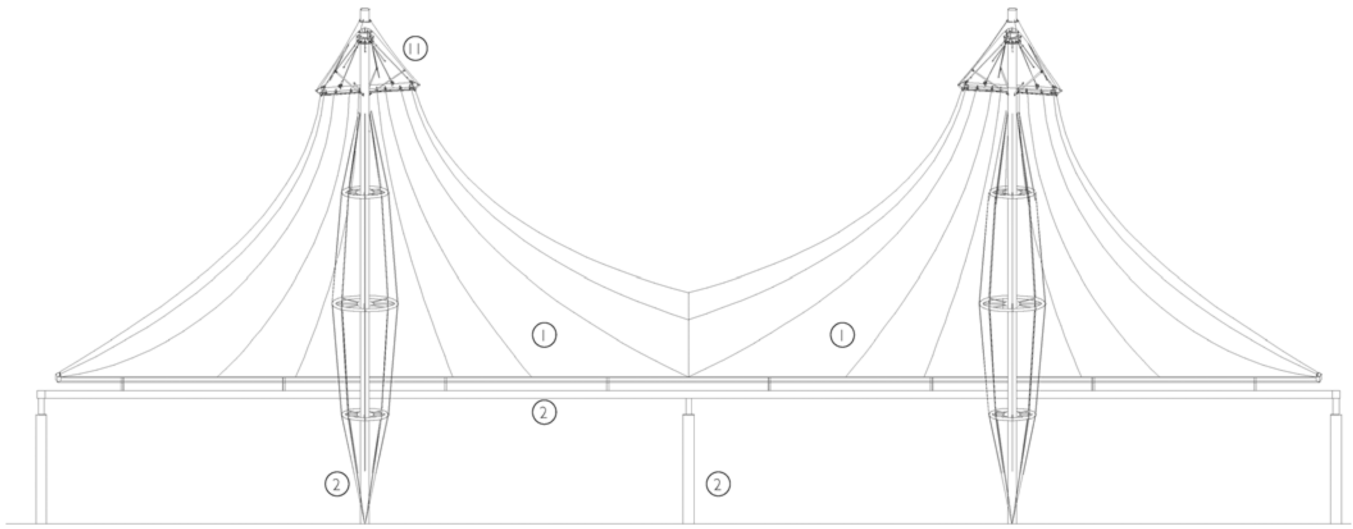
Most fabric roof materials imitate the appearance of natural canvas, but this material is used only where its appearance and individual texture is considered to be the most important consideration. Natural canvas is less stable than synthetic fabrics when used in tension structures, and is difficult 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/m^2. A PVC/polyester membrane roof will last around 15-25 years.

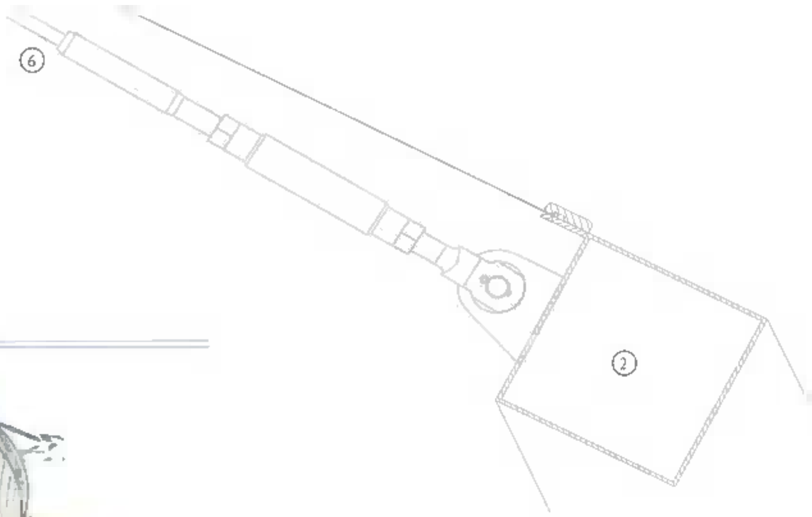
PTFE/glass fibre membranes are made from a glass fibre mat which is coated with a PTFE layer such as Teflon. As with PVC/polyester membranes, the coating protects the fabric from the effects of both the weather and UV light as well as forming a low friction



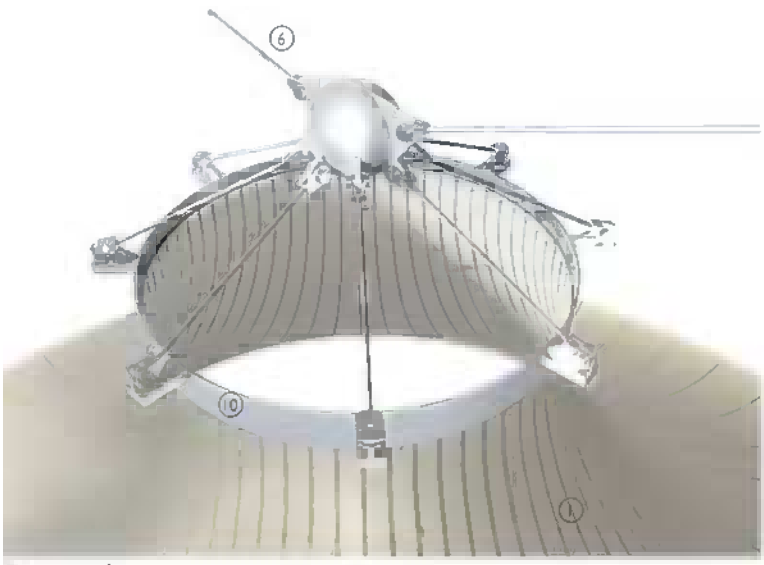
Elevation 1:400.
Cone-shaped fabric roof



Vertical section 1:400. Cone-shaped fabric roof



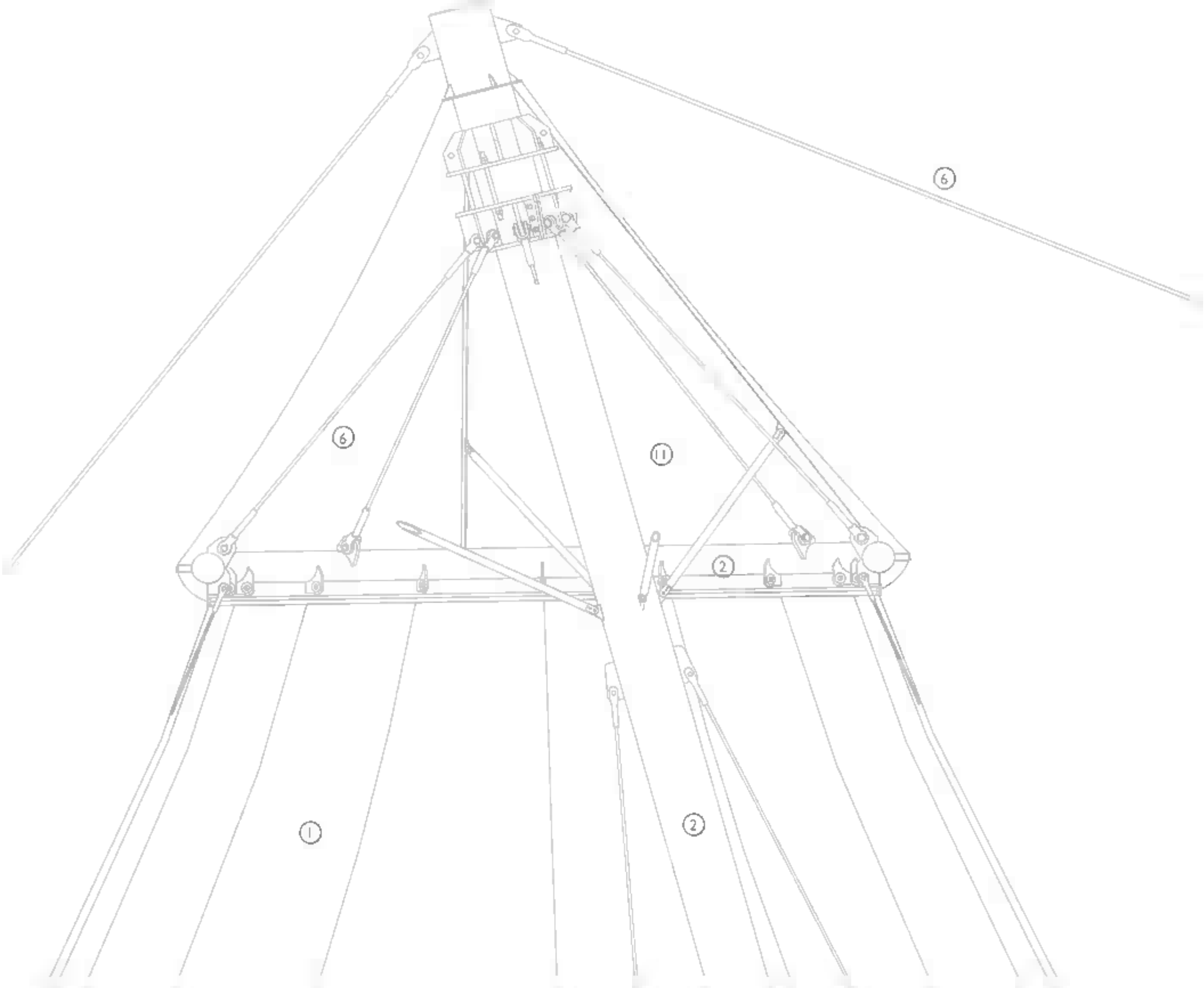
Vertical section 1:10. Base of fabric roof



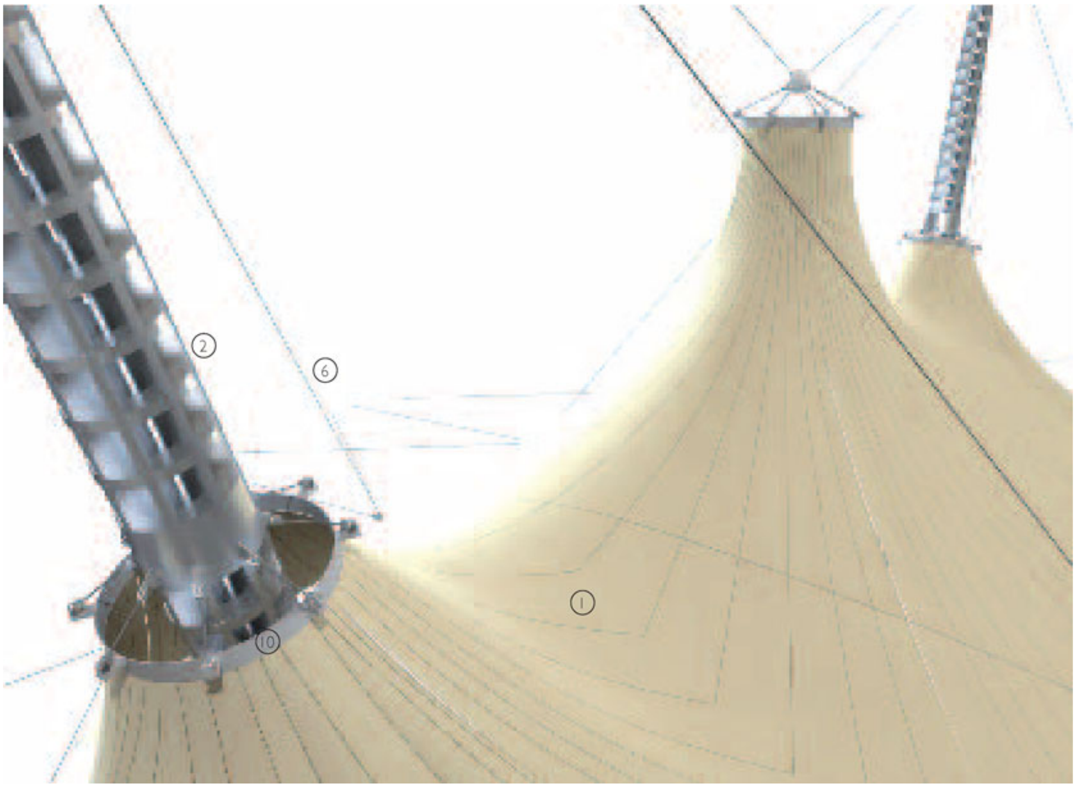
-D detail of edge ring supported by tension cables

Details

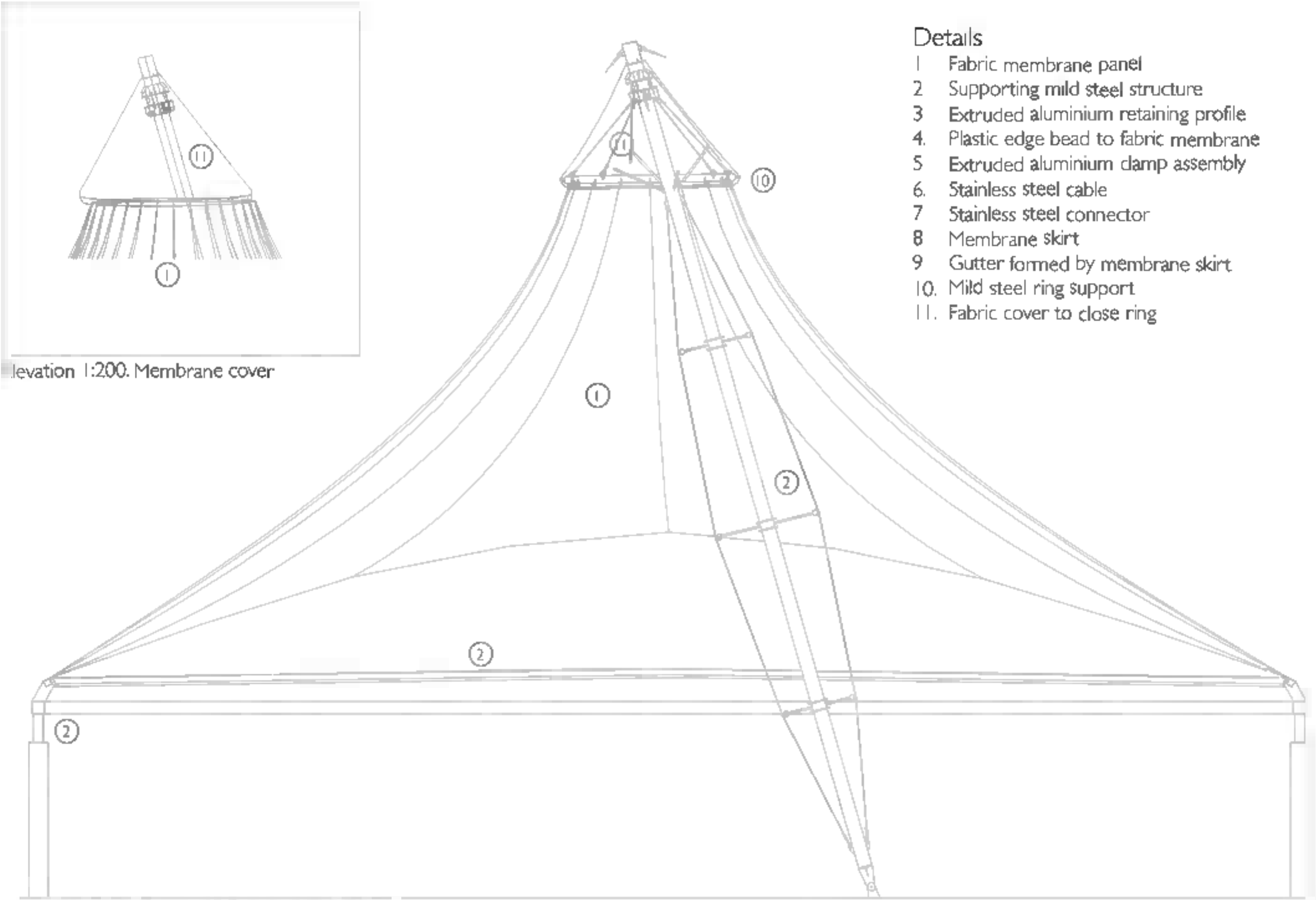
1 Fabric membrane panel
2 Supporting mild steel structure
3. Extruded aluminium retaining profile
4 Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. Stainless steel connector
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Mild steel ring support
11. Fabric cover to close ring



Vertical section 1:50. Clamping ring with fabric cover



3-D detail of cone top with protruding structural support



levation 1:200. Membrane cover

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

ertical section 1:200. Cone shaped fabric roof

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

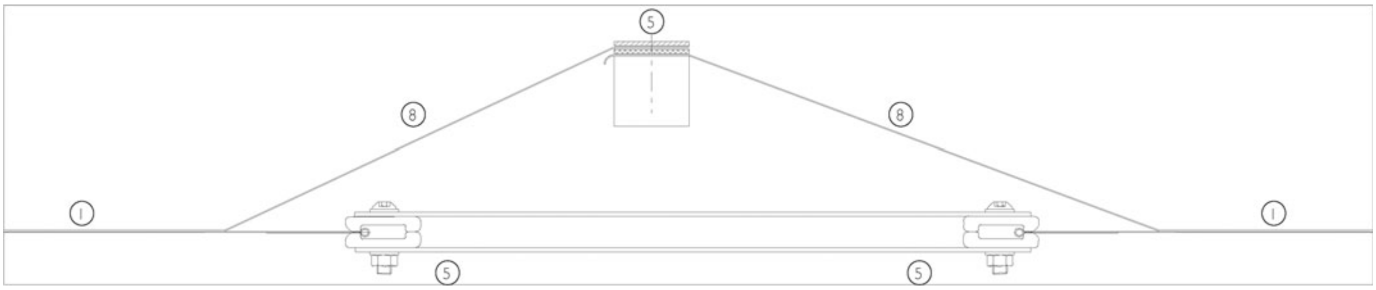
Both PVC/polyester and PTFE/glass fibre have high tensile strength and high flexibility, making them very suitable for curved and double curved roof membranes. They both have a light transmission of 5-20% depending on the thickness of membrane used, reflecting 75-80% of light. Neither will catch fire 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

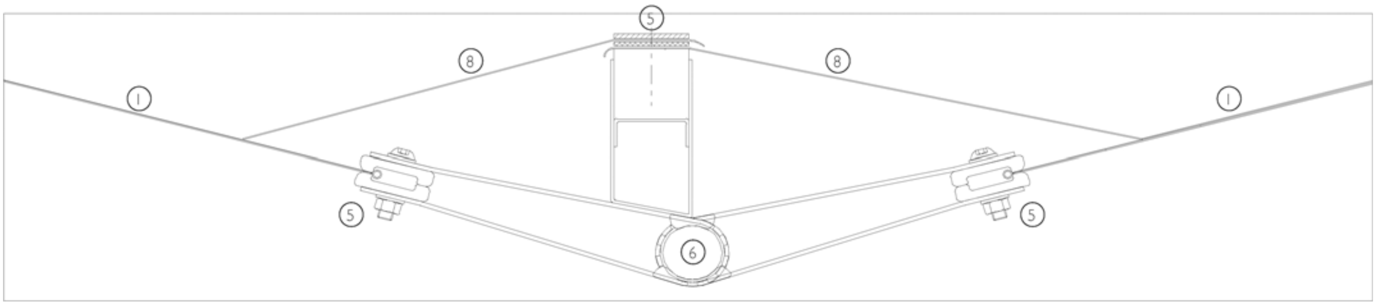
A single layer membrane fabric roof in either PVC/polyester or PTFE/glass fibre typically has a U-value of around 6.0W/m2K. Where two layered membranes are used, with a minimum air gap of 200mm between the membranes, the U-value can be reduced to around 3.0 W/m2K. Double layer membranes are less commonly 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 ten 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.



Vertical section 1:10. Junction of adjacent fabric membranes meeting at same angle



Vertical section 1:10. Junction of adjacent fabric membranes meeting at different angles

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 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 susceptible to mould growth than PTFE/glass fibre fabrics, essentially because the latter has lower surface friction.

Performance in fire

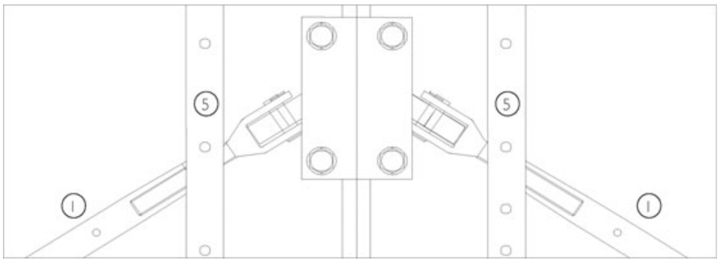
The performance of a membrane during a fire depends on both the fabric used and the stitching at the seams, where this joining method is used. Membranes lose their tension under high temperatures, with PVC/polyester stretching above 70-80°C, and PVC/polyester seams starting to peel at around 100°C. At 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

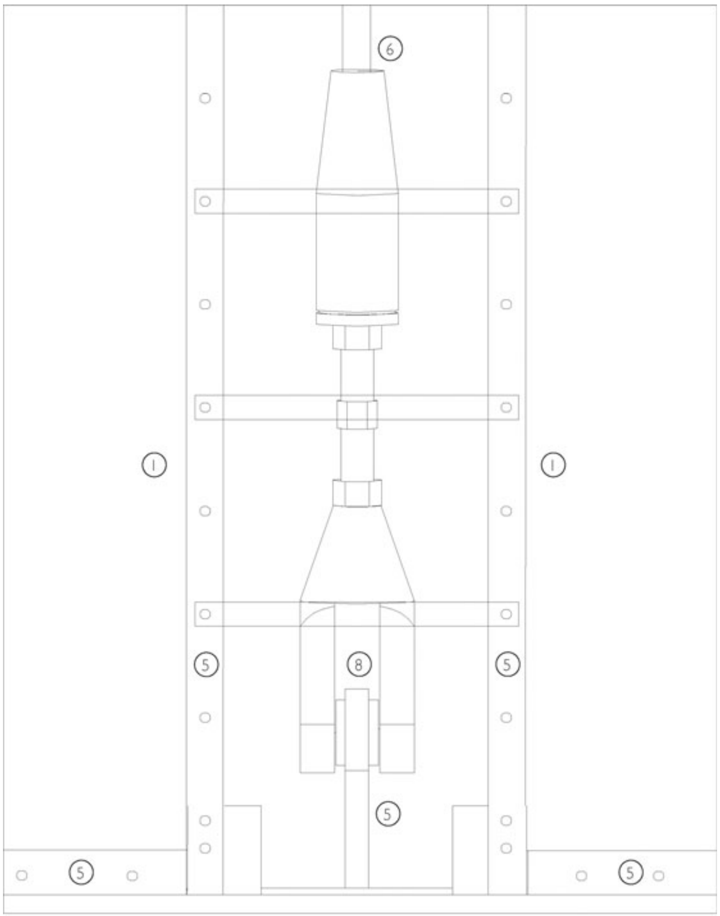
Where condensation is likely to occur on the underside of the membrane in an internal space within the building, either a second membrane is added or, more commonly, increased ventilation is provided within the space below the roof.

Details

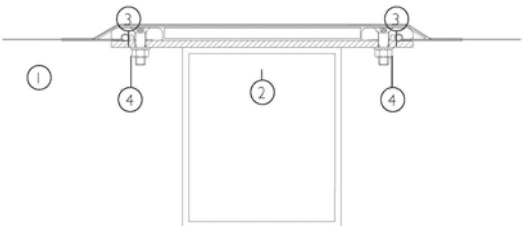
1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. Stainless steel connector
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Mild steel ring support
11. Fabric cover to close ring



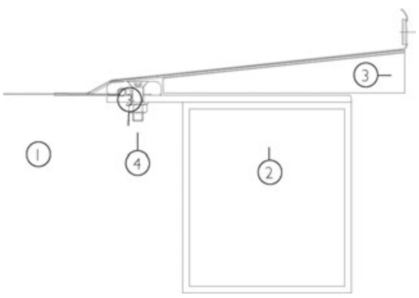
3-D cutaway view of pinnacle condition with membrane hood



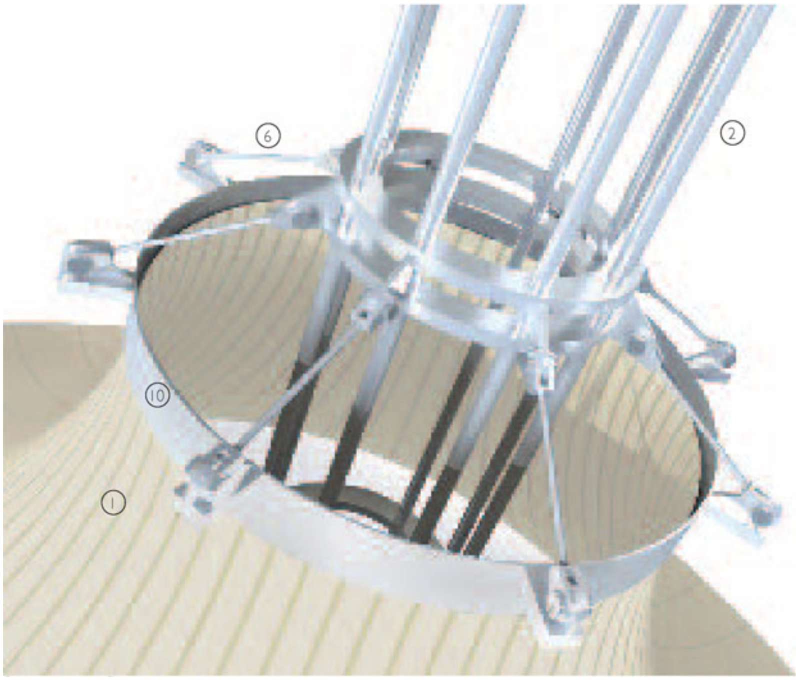
Horizontal section 1:10. Junction of adjacent fabric membranes



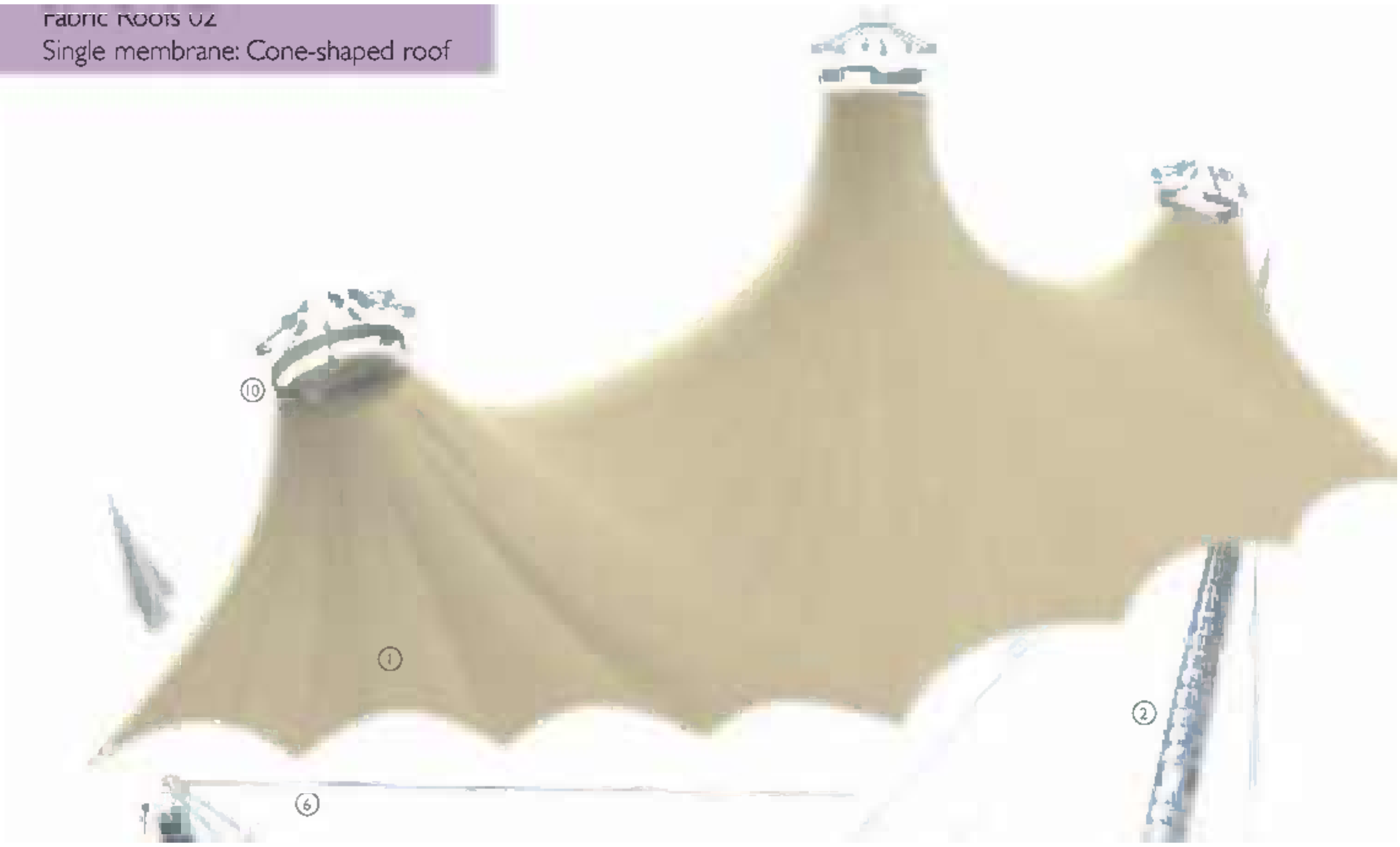
Vertical section 1:10. Junction between panel



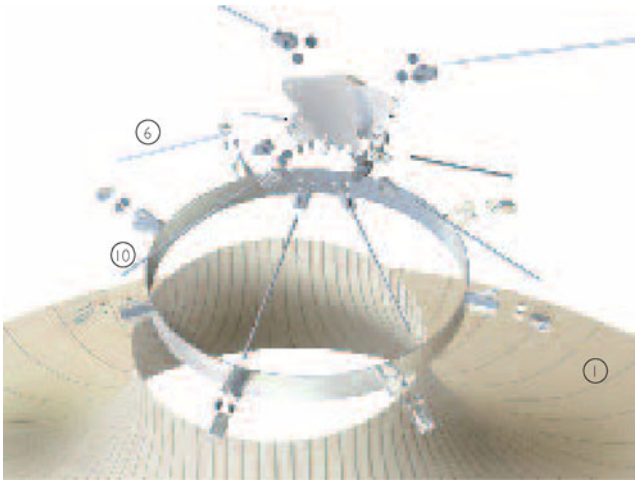
Vertical section 1:10. Edge of roof at abutment



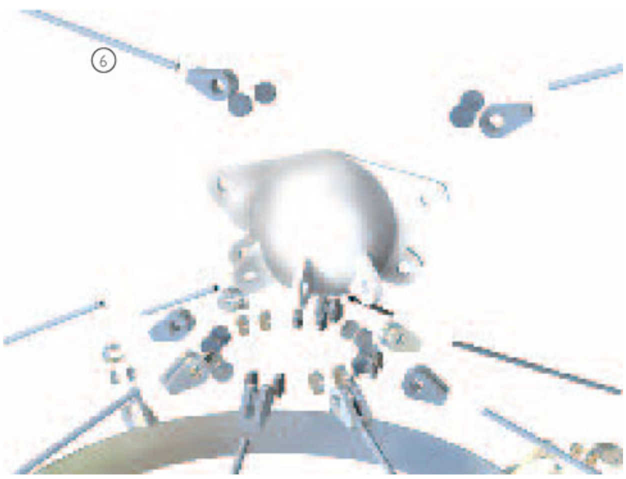
3-D detail of cone top with protruding structural support



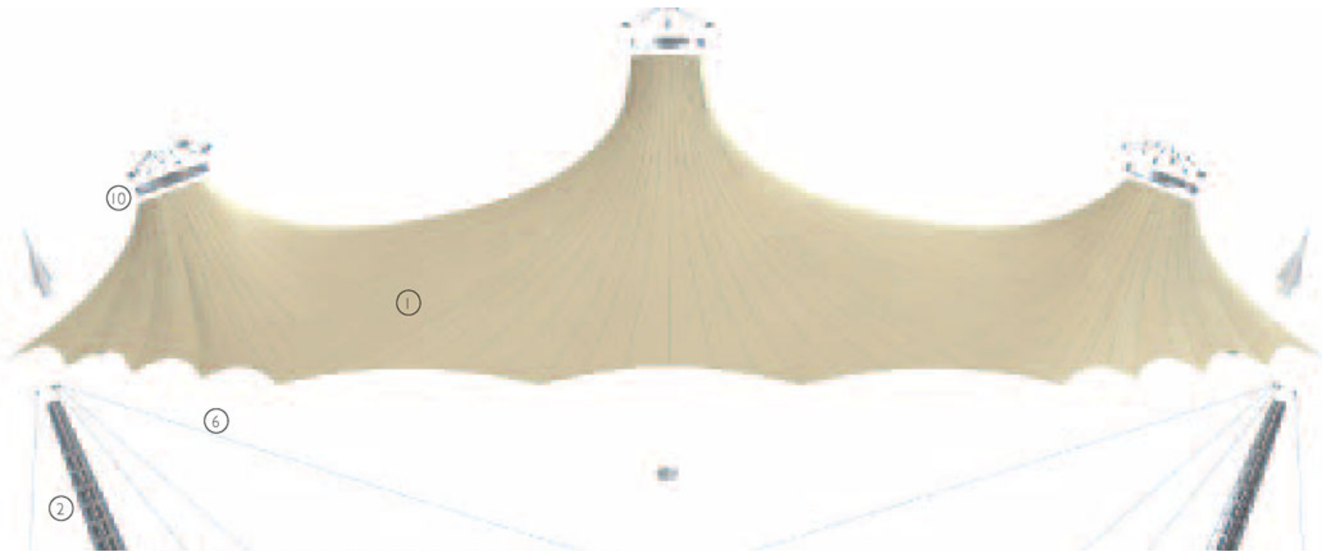
3-D exploded overview of cone shaped roof with tension cable support



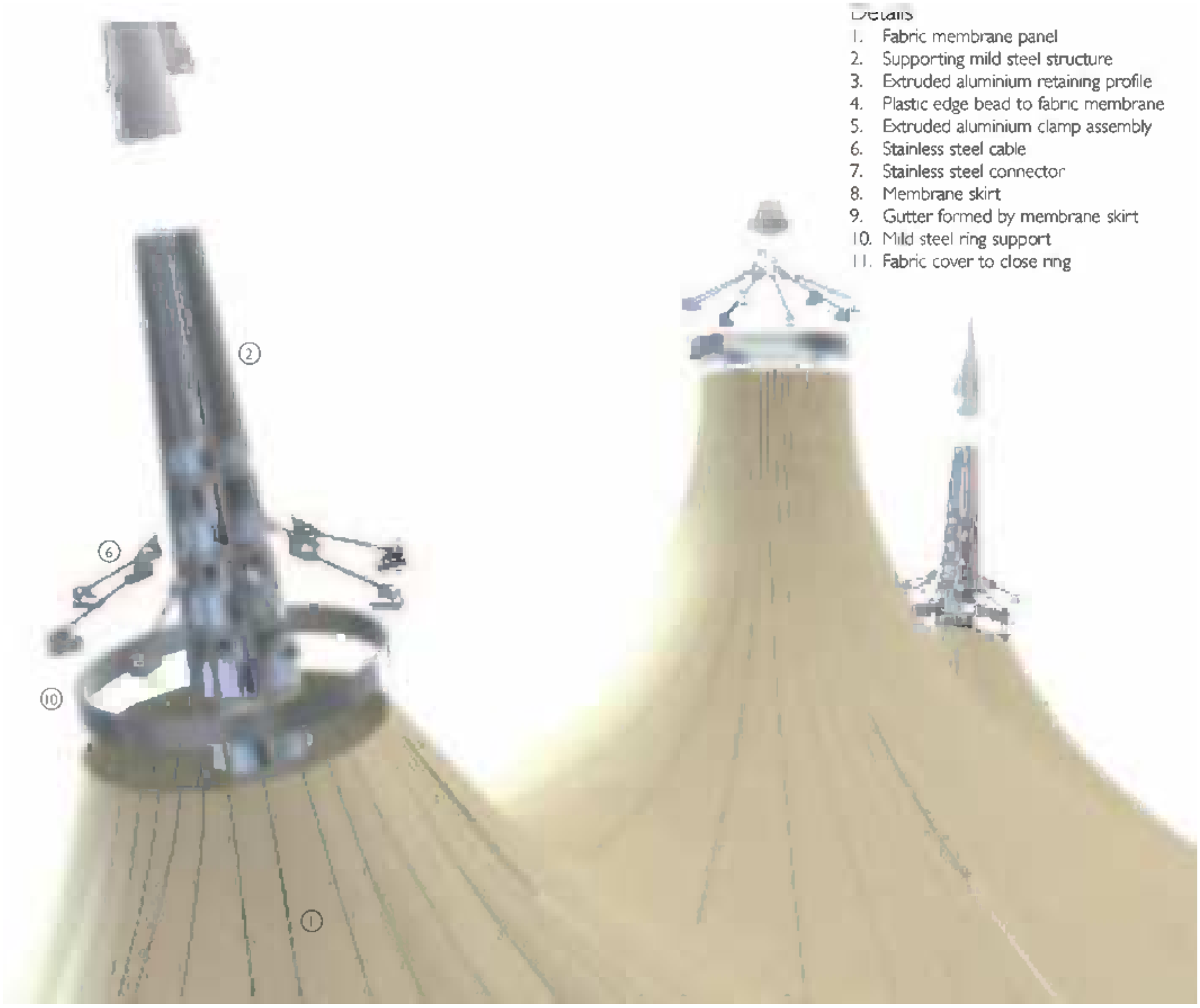
3-D exploded view of edge ring supported by tension cables



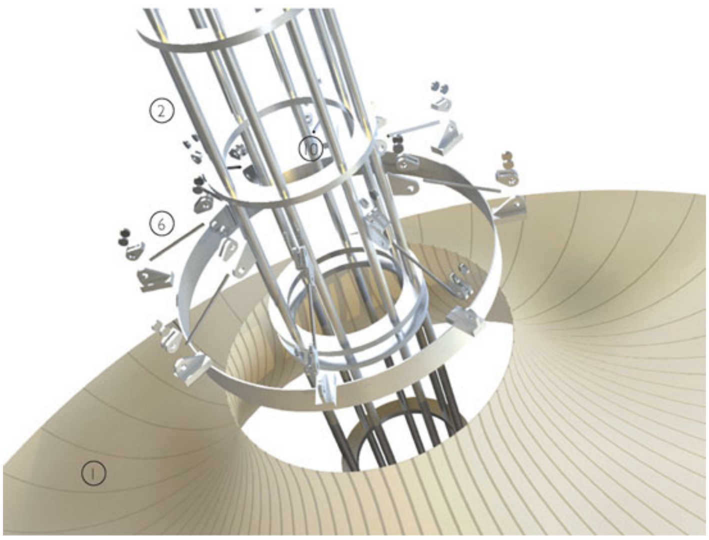
3-D exploded view of edge ring support



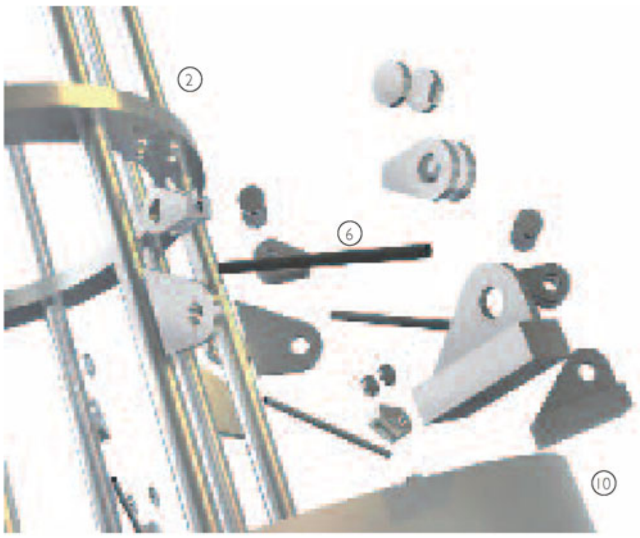
3-D exploded overview of cone shaped roof with tension cable support



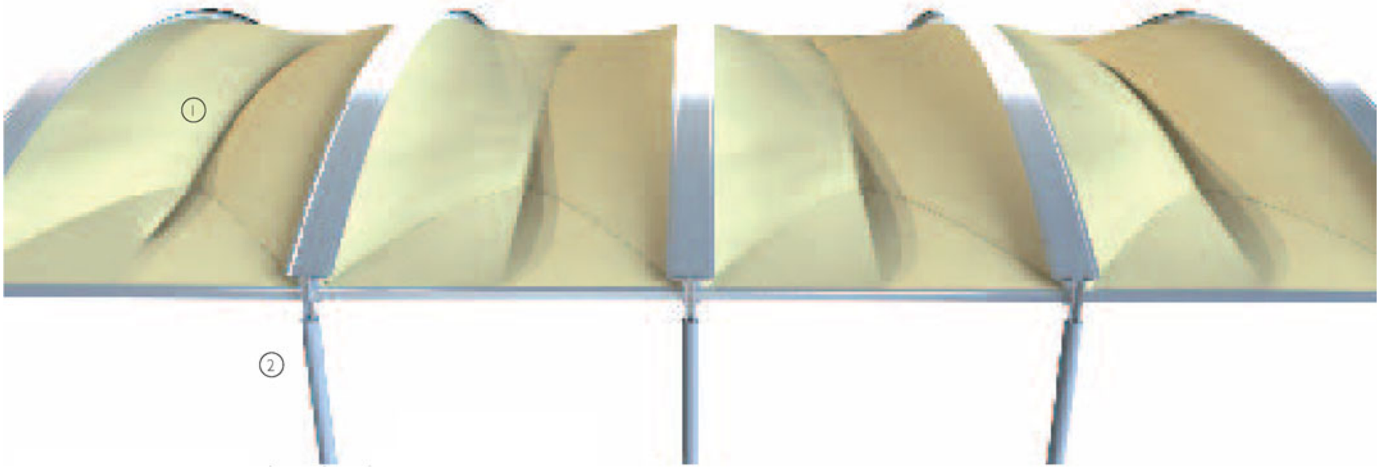
3-D exploded overview of cone shaped roof with tension cable support



3-D exploded view of cone top with protruding structural support

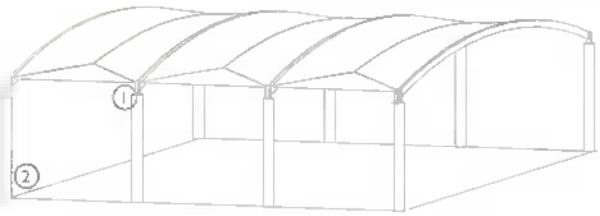


3-D exploded detail view of cable connections with protruding structural support



3-D overview of single membrane barrel-shaped roof

3-D overview of single membrane barrel-shaped roo



Isometric view of roof assembly

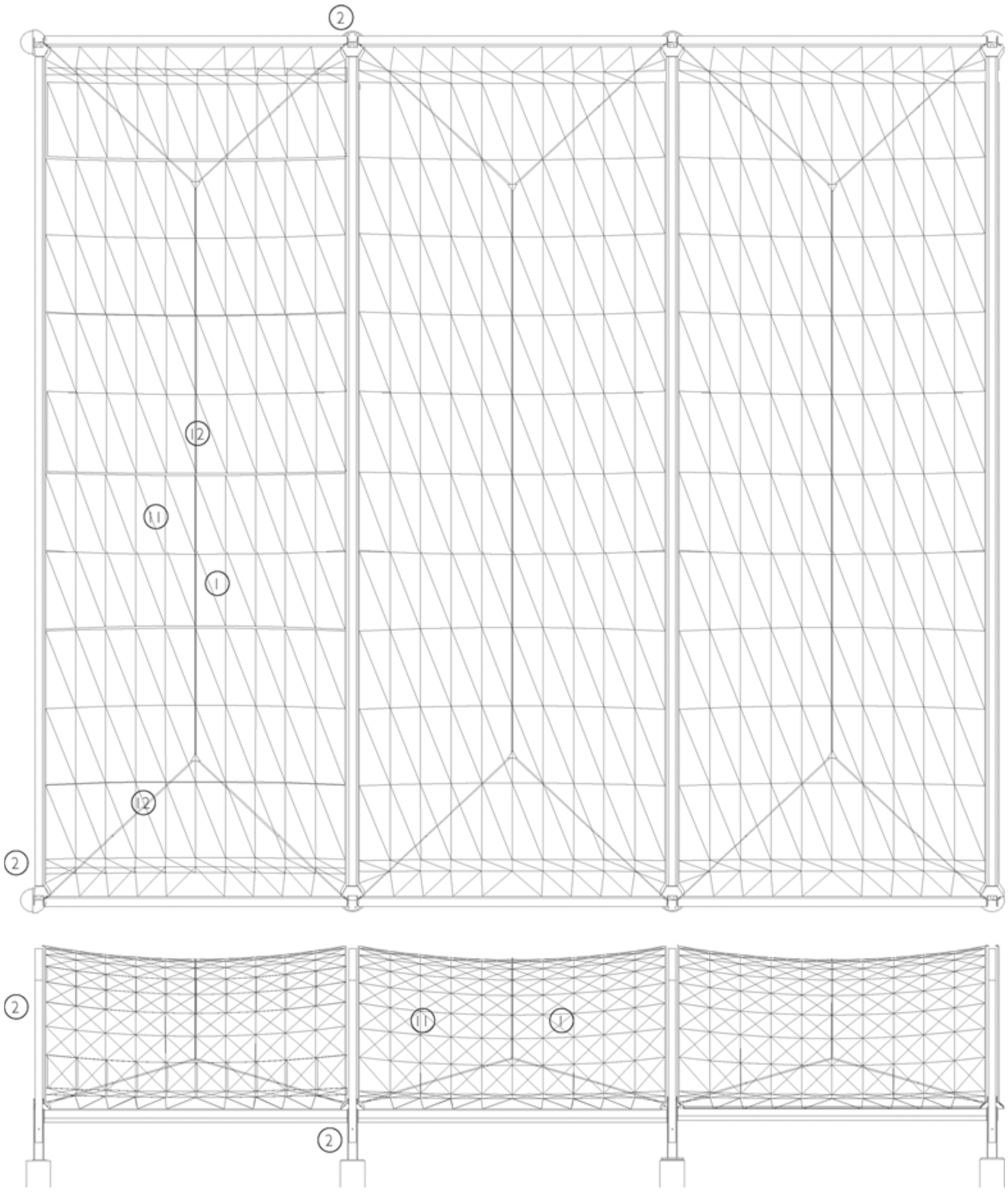
Details
1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. EPDM sealing tape
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Thermal insulation
11. Welding seam
12. Wind up lift cable (above membrane)

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.

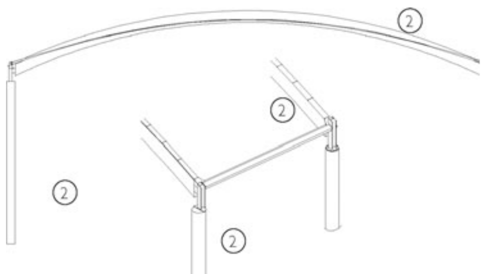
In stitched panel joints, wider seams have more rows of stitching visible, with the material folded over itself to strengthen the joint. Joint widths vary from around 25mm to 100mm depending on the size of the membrane and its associated loads. Addi-



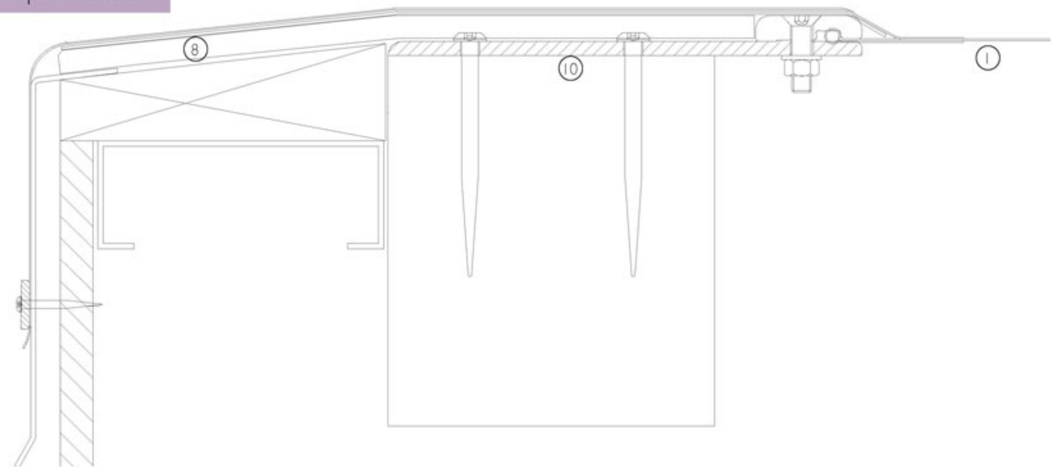
Horizontal section and elevation 1:200. Barrel-shaped fabric roof

tional 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.

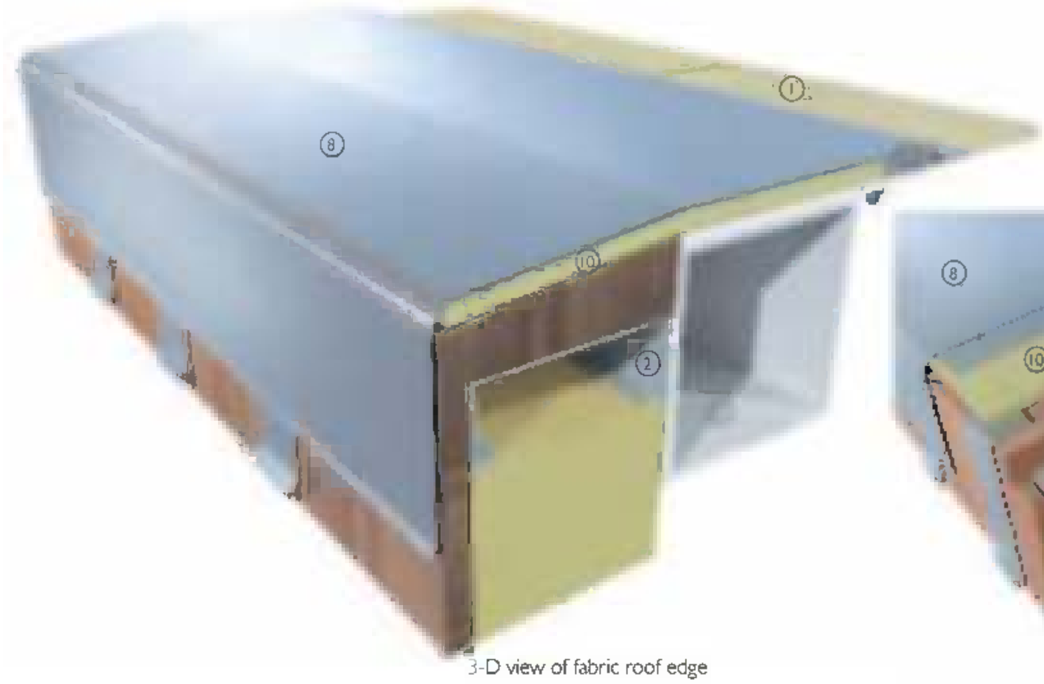
Welded seams are made by forming a lap between panels, then heating the lapped areas and pressing them together. Joint widths are similar to those required for stitched seams. Seams in PTFE/glass fibre panels are formed by hot element welding rather than by stitching or bonding, with an additional fabric 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.



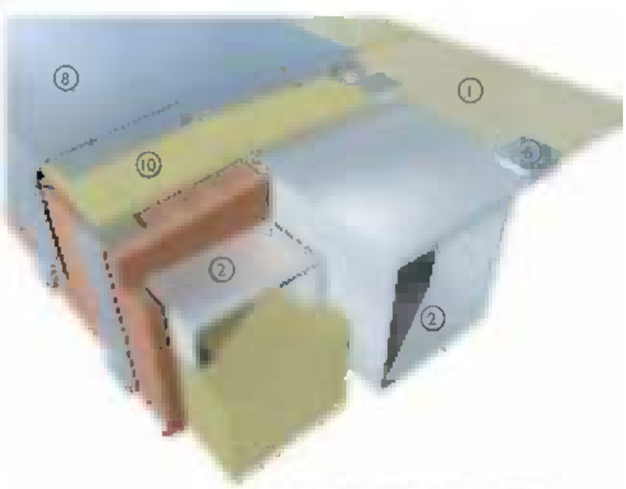
Isometric view of roof assembly



Vertical section 1:10. Edge of roof



3-D view of fabric roof edge



3-D cutaway view of fabric roof edge

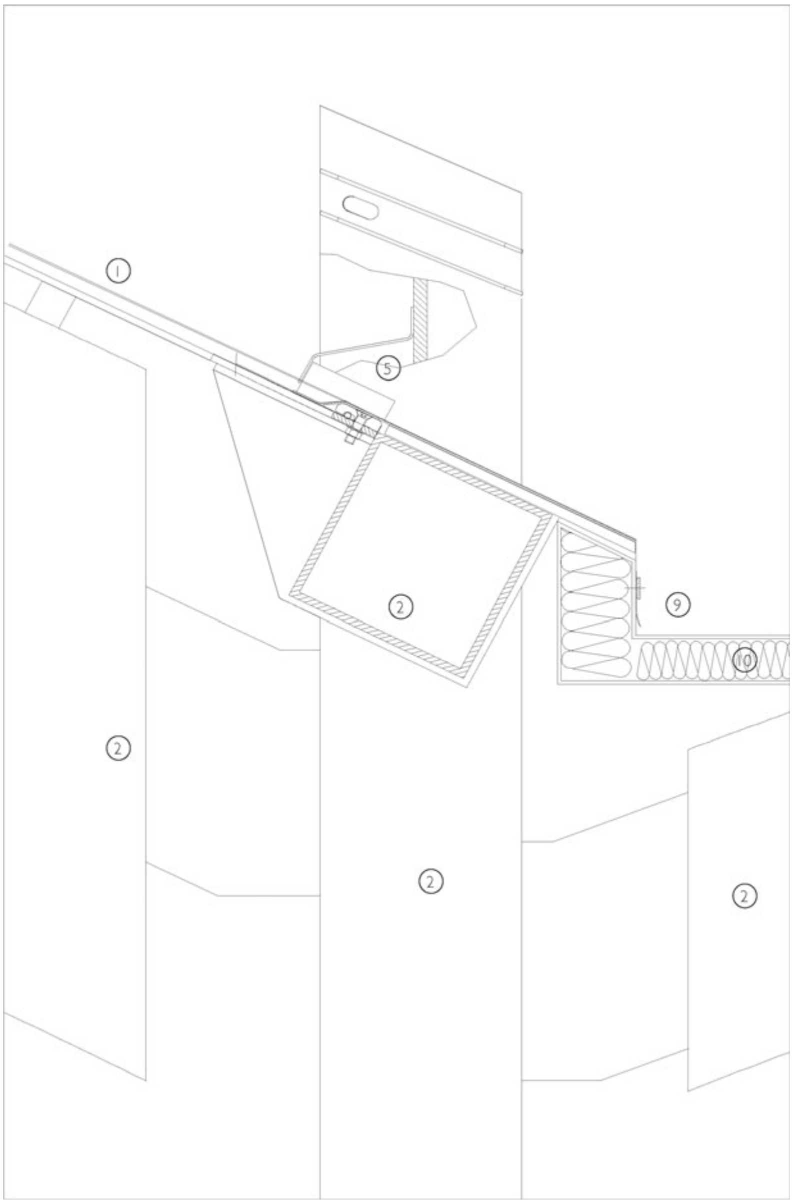
Details
1. Fabric membrane panel
2. Supporting mild steel structure
3. Extruded aluminium retaining profile
4. Plastic edge bead to fabric membrane
5. Extruded aluminium clamp assembly
6. Stainless steel cable
7. EPDM sealing tape
8. Membrane skirt
9. Gutter formed by membrane skirt
10. Thermal insulation
11. Welding seam
12. Wind up lift cable (above membrane)

Membrane roof edges

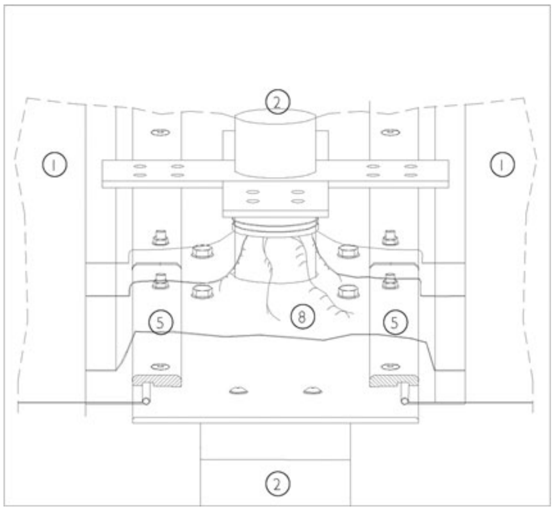
Edges of membranes are usually either gently curved or straight. Curved edges are formed with a cable held in a continuous pocket at the edges of the membrane. An alternative detail used in PTFE/glass fibre canopies is to have an exposed cable connected to the clamped edges of the membrane with a series 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, 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 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.

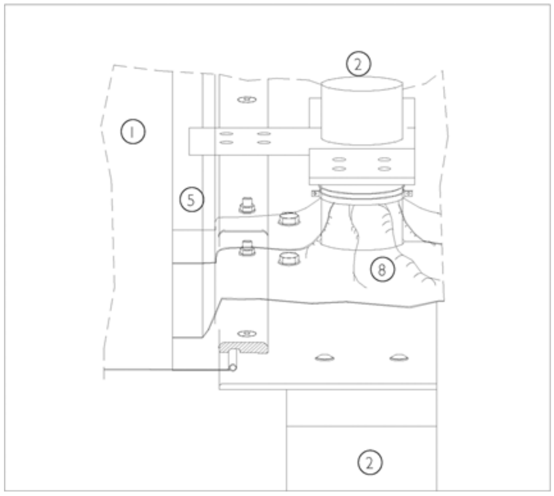
Straight clamped edges use clamping plates, around 100mm wide, set back to back and bolted together, which comprise two flat, grooved plates, rather than the clamping plate and supporting extrusion used at joints between panels. The clamping plates are fixed back to either a visible cable which is set around 100mm away from the edge of the



Vertical section 1:10. Edge of roof with penetration



Elevation 1:10. Roof penetration



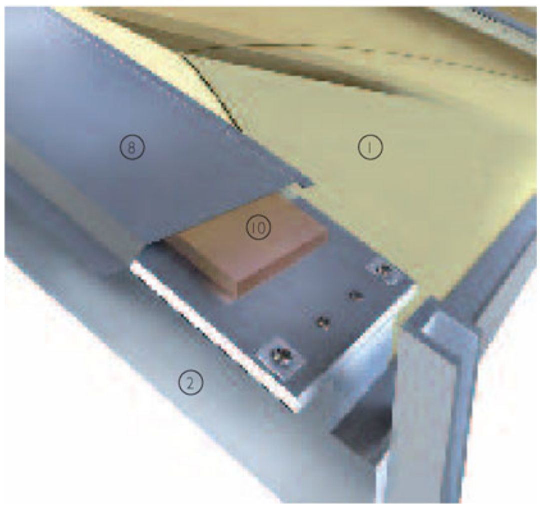
Elevation 1:10. Roof penetration

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.

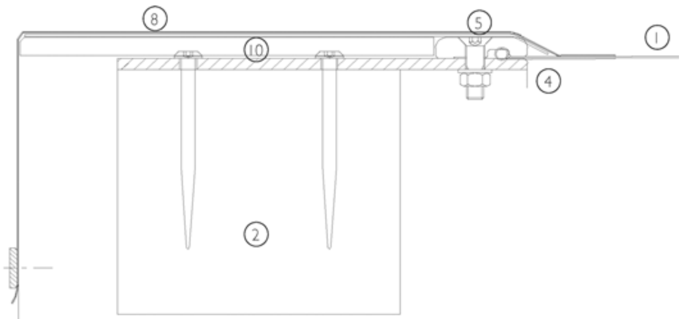
Clamping plates are also used at the junction between two areas of roof where the two parts are required to be fabricated and installed separately, usually where the membrane has reached a maximum size for either fabrication or installation. In both cases the clamping plates are positioned to ensure 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.

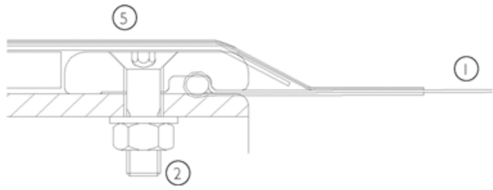
Rainwater can be directed along the edge of a membrane, rather than being allowed to fall directly off the edge, by intro-



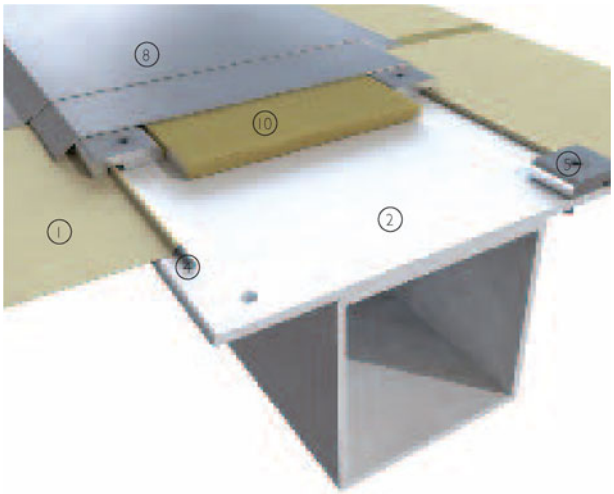
3-D view of junction between two fabric panels



Vertical section 1:10. Edge of roof

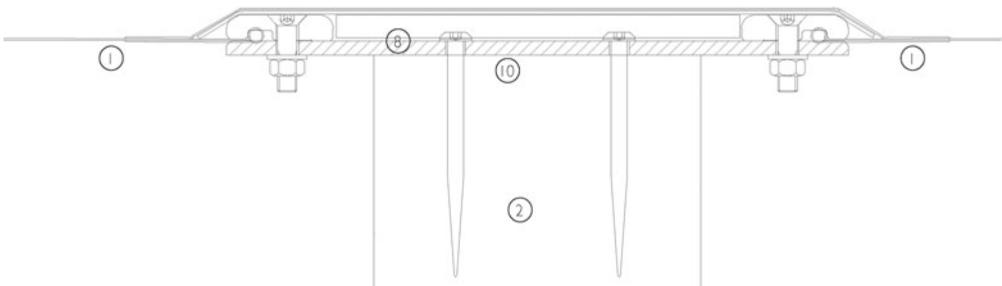


Vertical section 1:10. Edge of roof

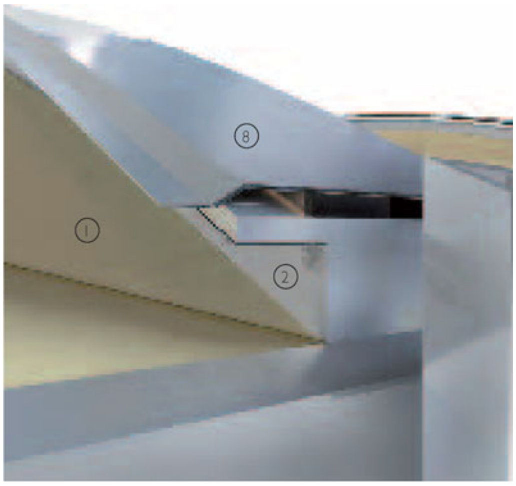


3-D cutaway detail of junction between two fabric panels

3-D detail view of junction between two fabric panels



Vertical section 1:10. Junction between panels



3-D view of junction between two panels

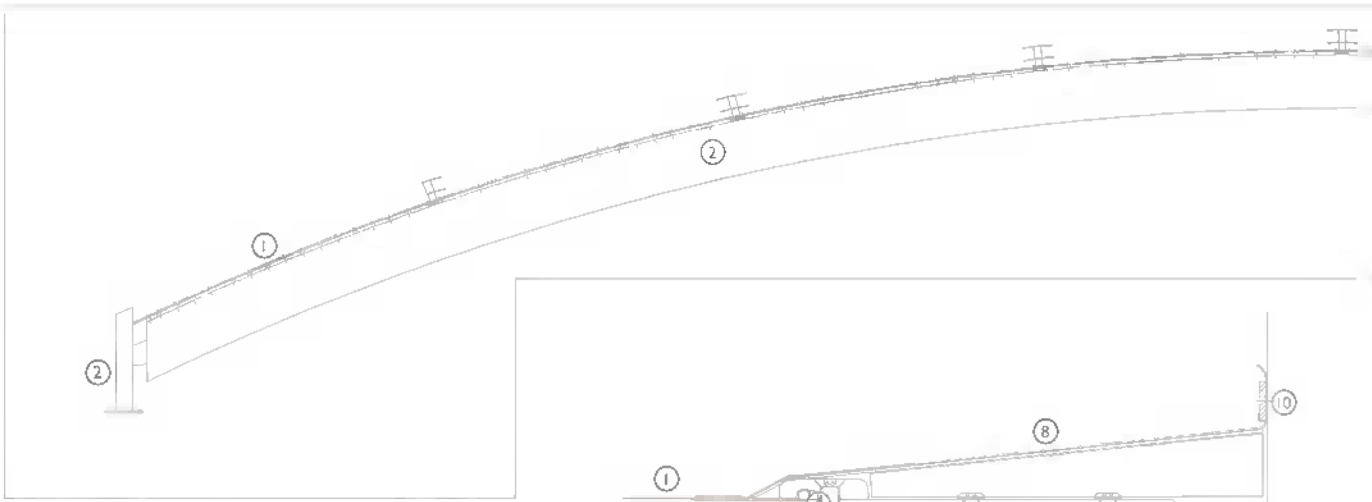
ducing a standing seam adjacent to the edge. A strip of membrane is rolled around a foam strip and is welded or stitched to the membrane. This is particularly useful where building users pass beneath, as when the fabric roof forms an external canopy. Junctions with vertically-set membranes beneath the roof, are formed as flexible membrane connections to allow for movement between roof and wall.

Suspension points

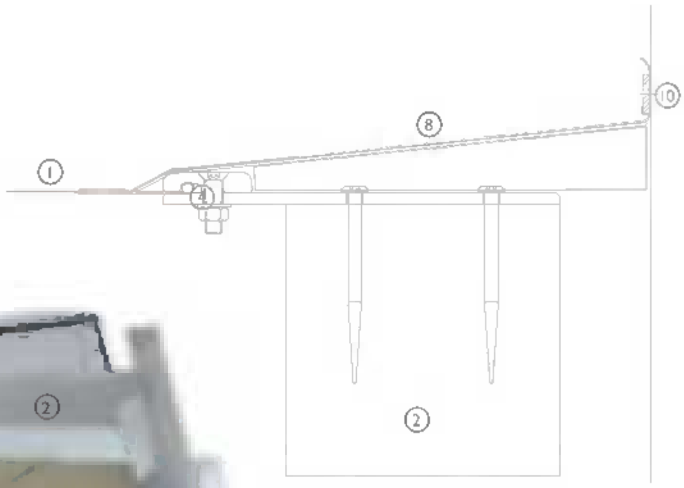
Suspension points at the top of a cone-shaped fabric roof are usually formed either by a metal ring, which is fixed back to a central mast by cables or cantilevered brackets or, alternatively, by a 'palm tree' arrangement of projecting curved metal brackets which serve to tension the continuous membrane 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.

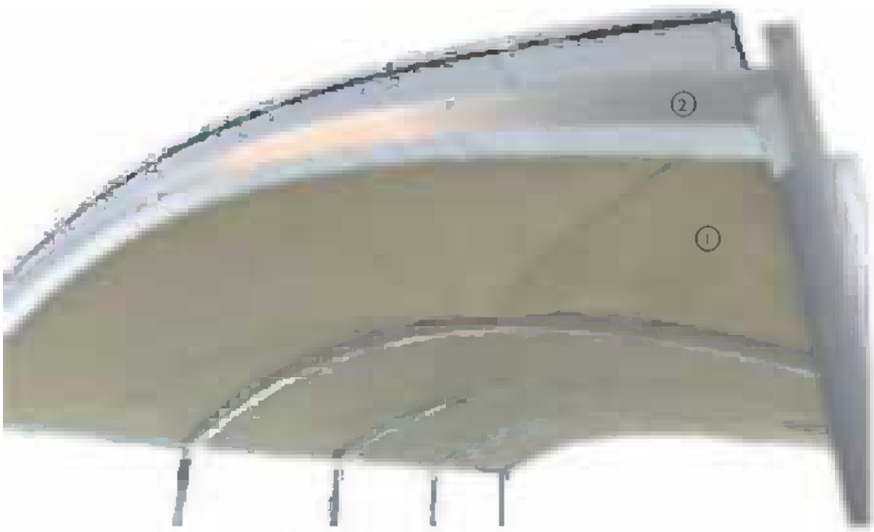
In the 'palm tree' supported solution, cantilevered brackets with a curved shape are set out radially in order to create a



Vertical section 1:200. Barrel-shaped fabric roof



Vertical section 1:10. Edge of roof at abutment



3-D view of underside of barrel shaped fabric roof

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 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. 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

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10. Thermal insulation
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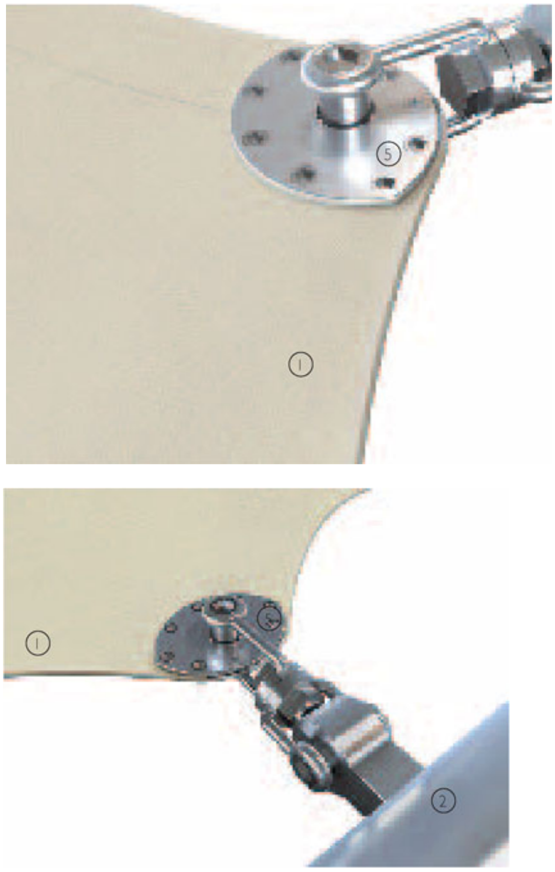
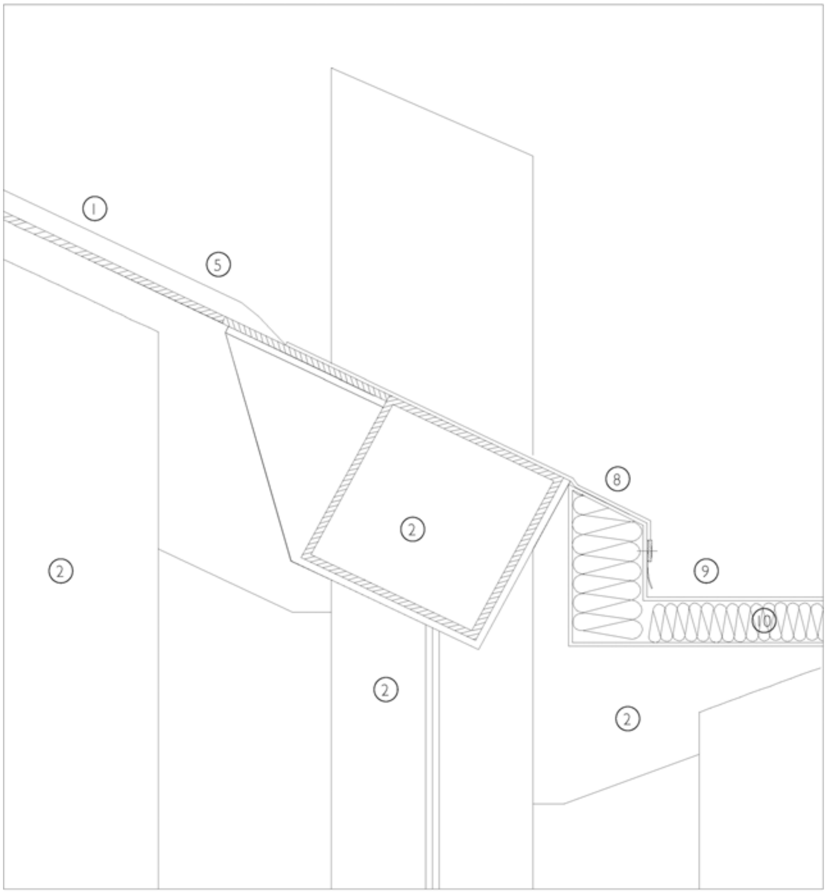
12. Wind up lift cable (above membrane)



3-D details of edge clamp



Vertical section 1:10. Edge of roof with penetration

above the level of the water that is drained, rather than being submerged in water. This would be the case where a single gutter is formed where the clamp holding the straps in place is lower than that shown.

Where two joining members form a continuous line, 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 on 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.

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, 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, and 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. The same principle is applied at the roof edge, 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. 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. The membrane skirt at the base of the roof is clamped to the side wall of an insulated gutter. Adjacent penetrations are closed with a specially formed membrane skirt that fits around the structural member which 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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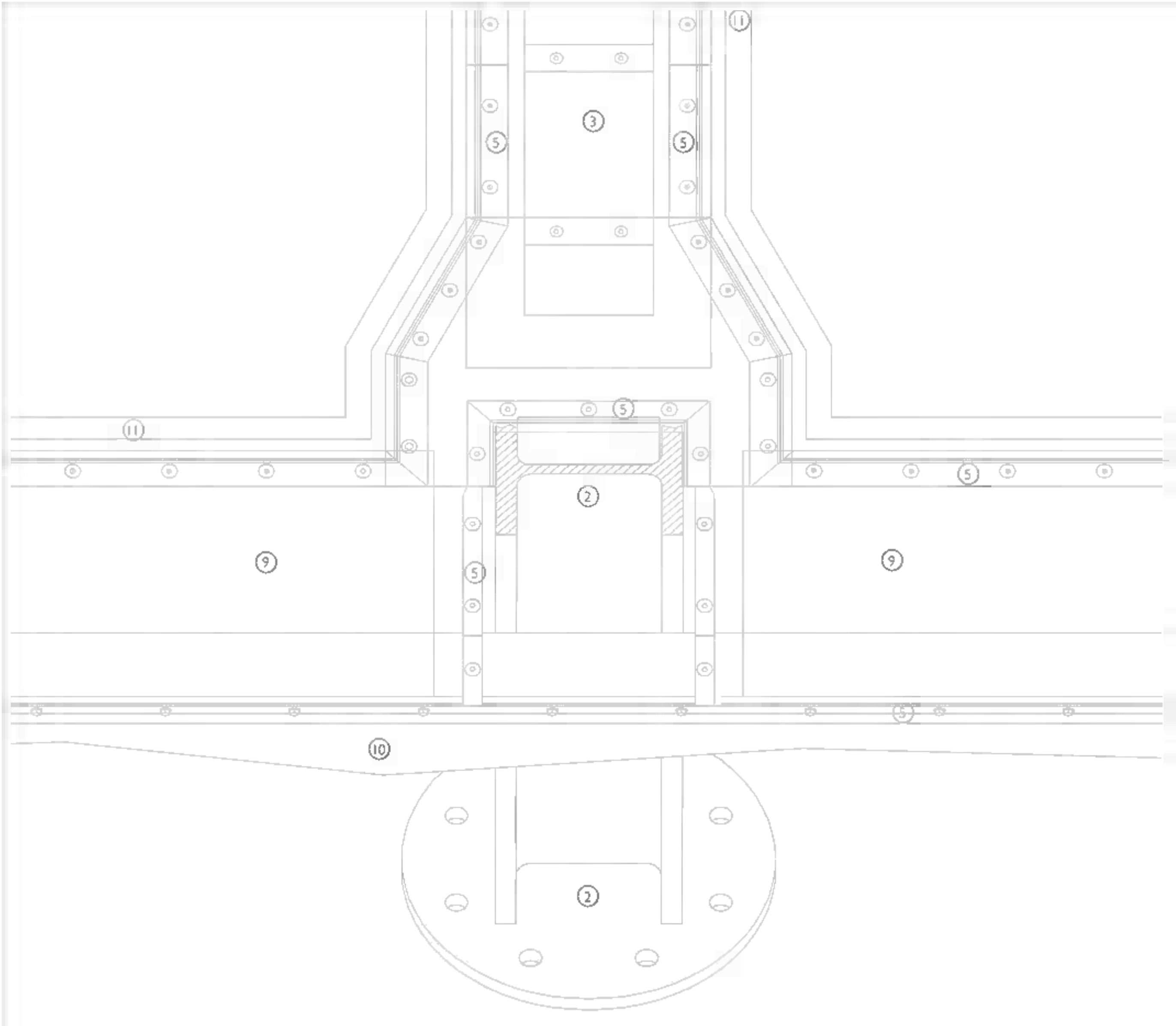
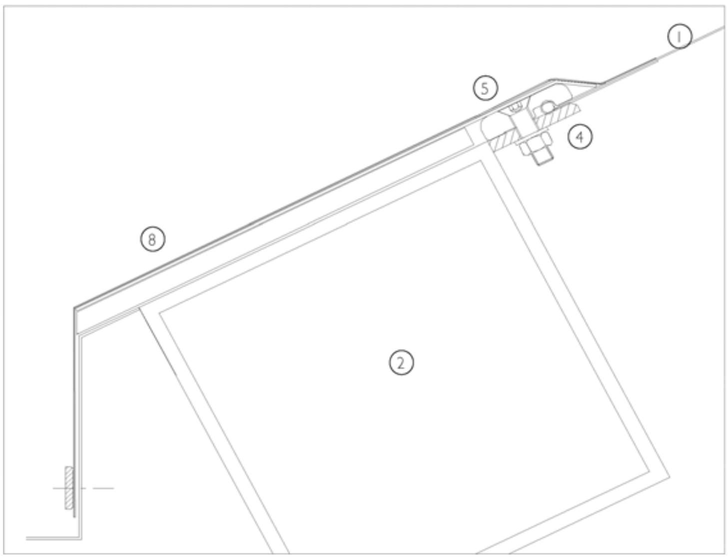
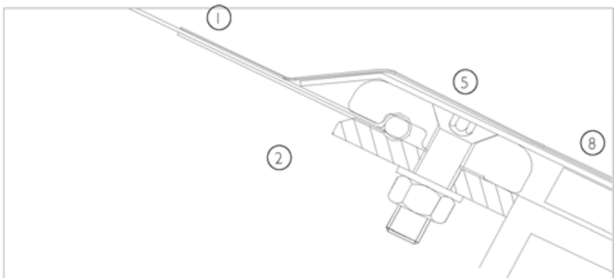


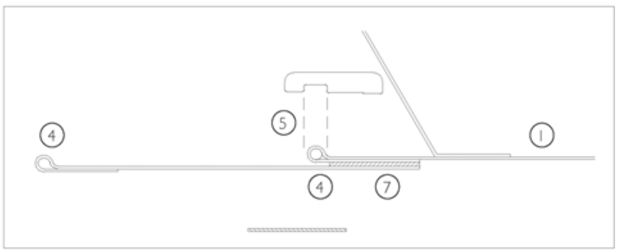
Horizontal section 1:10. Junction between membrane roof panels



Vertical section 1:10. Edge of roof



Vertical section 1:5. Edge of roof



Vertical section 1:10. Clamping plate assembly

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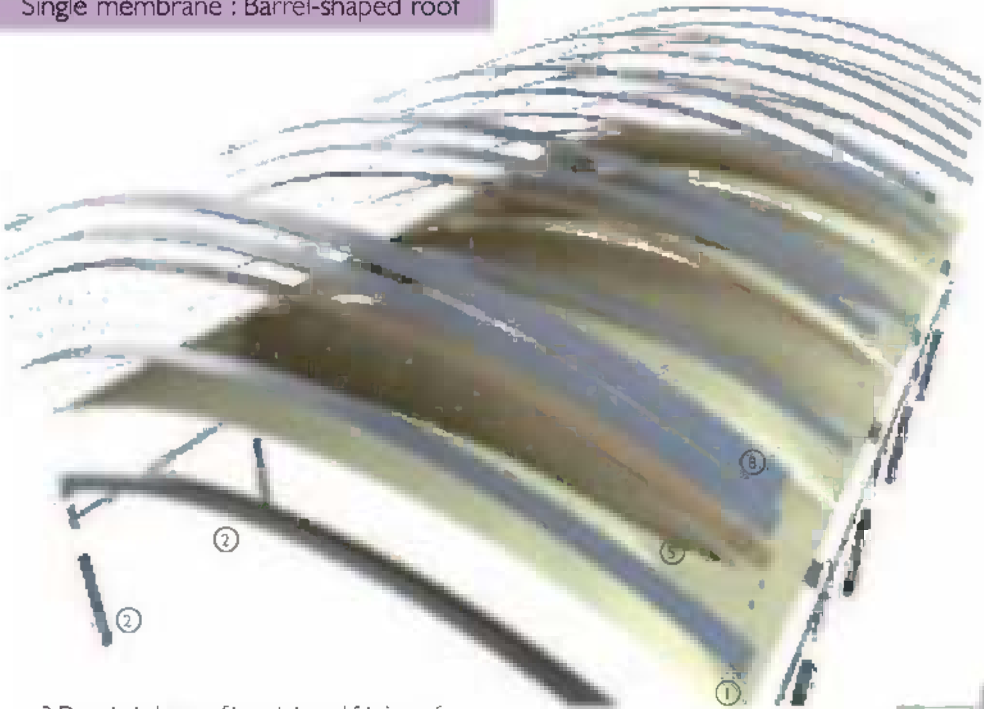
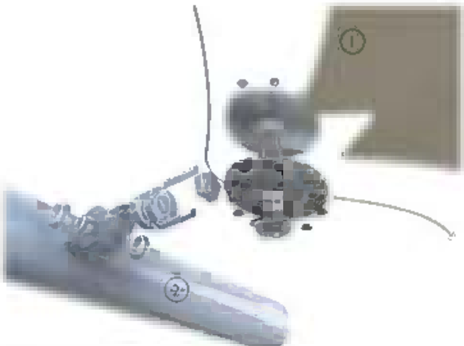


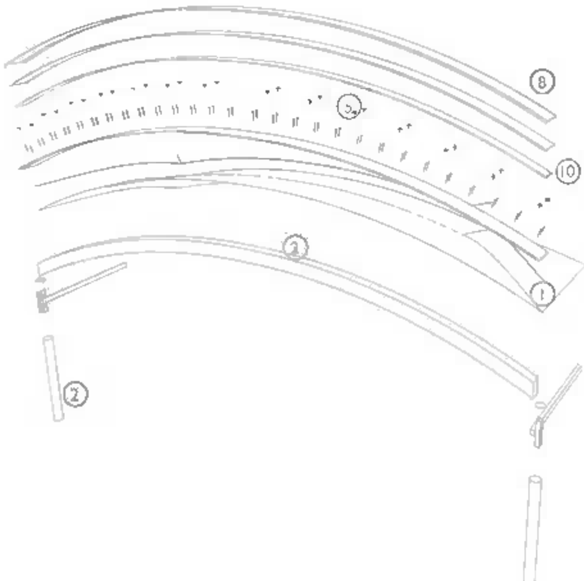
3-D exploded view of barrel shaped fabric roof



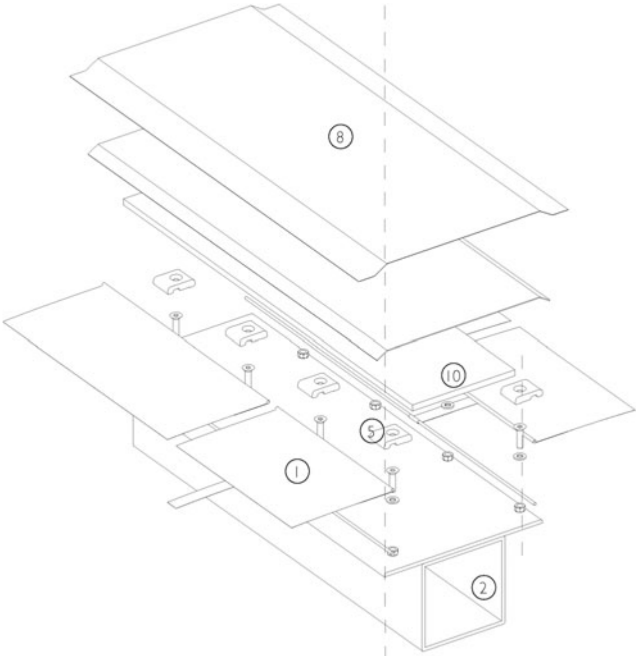
3-D exploded view of edge clamp

3-D exploded view of barrel shaped fabric roof

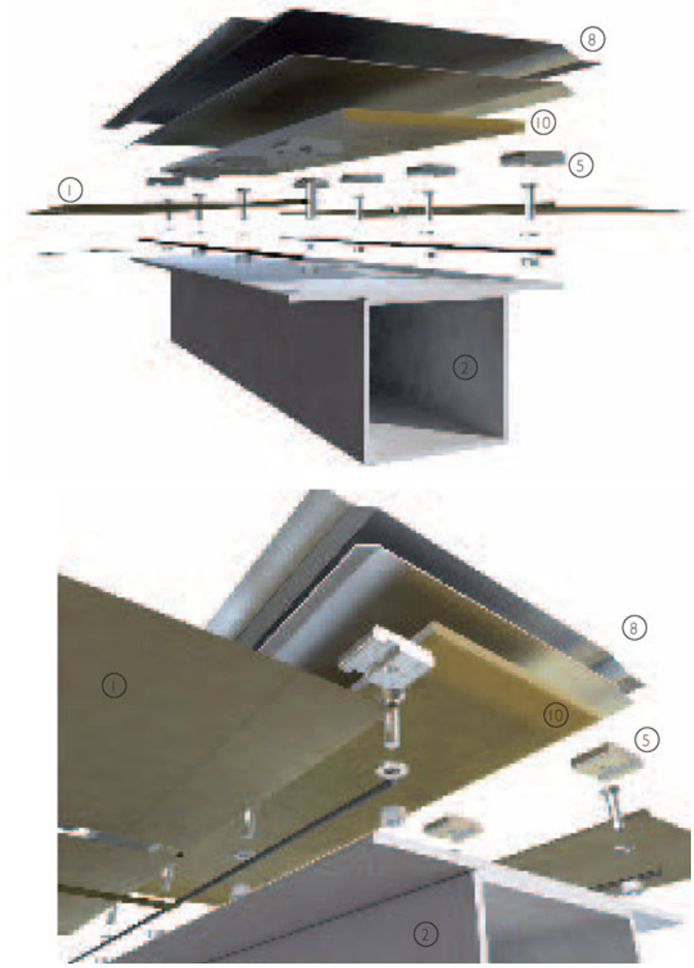
3-D exploded view of segment of barrel shaped fabric roof



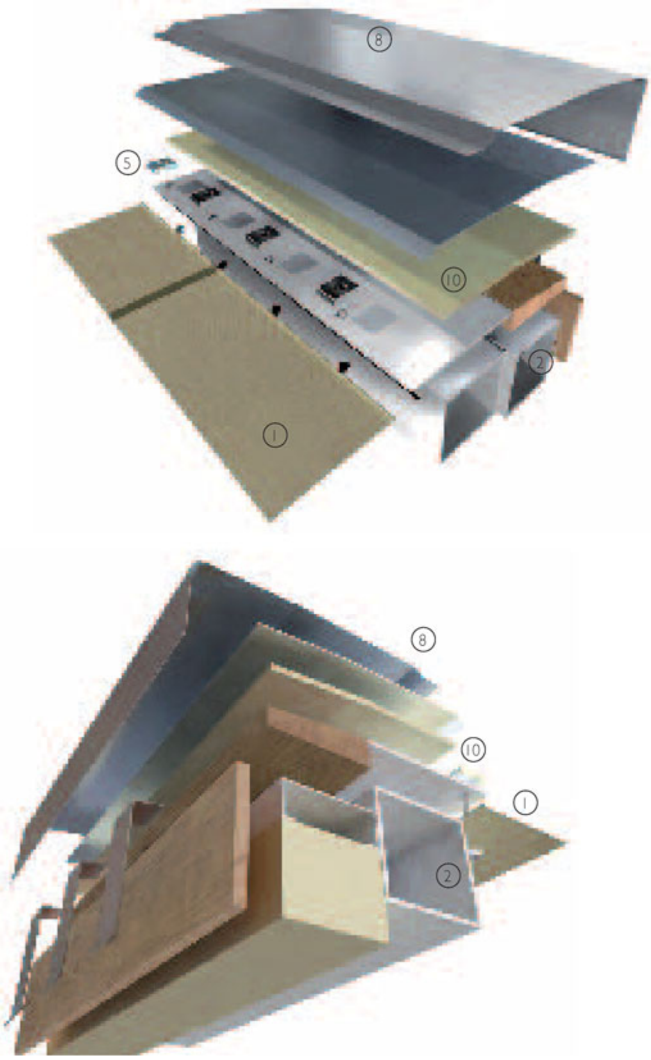
3-D exploded line drawing of junction between two segments of barrel shaped fabric roof



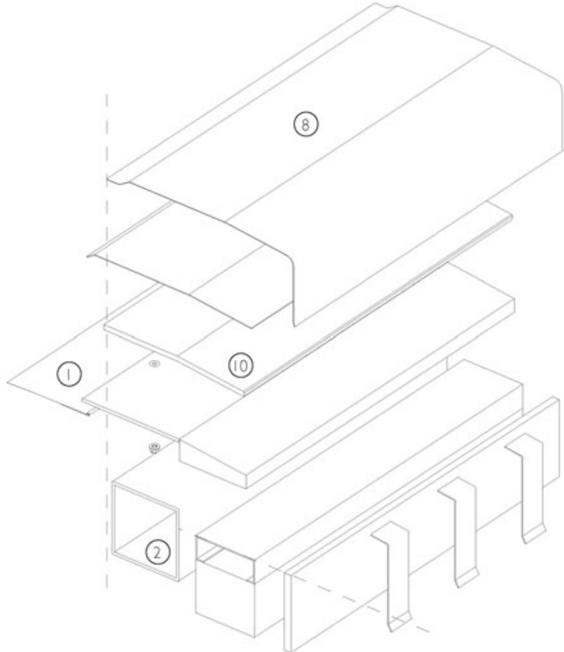
Exploded axonometric of junction between two fabric panels



3-D exploded view of junction between two fabric panels



3-D exploded view of fabric roof edge



Exploded axonometric of fabric roof edge

This book has been produced by the Newtecnic team: Ciaran Canavan, Julianne Cassidy, Nick Channon, Mike Clarke, Jenny Coppin, Sana Hasan, Alia Khonji, Rocky Marchant, Louise Scannell, Howard Tee, Leon Turrell, Andrew Watts, Yasmin Watts, Adam Willetts. The text is by Andrew Watts. Views of 3-D models for the book were set out and rendered by Julianne Cassidy and Louise Scannell. The layout was designed by Yasmin Watts. The cover image is by Michael Clarke.

David Marold is Editor for Architecture and Philosophy at Springer Verlag in Vienna. He has driven this book from a set of basic layouts to a completed book. He has a passion for books and their design, ranging from their wider content to the quality of print paper.

Before establishing their own practice specialising in facades, Newtecnic principals Andrew and Yasmin Watts worked extensively both in the UK and other countries. During this time they were involved in a range of significant projects including Federation Square, Melbourne with LAB Architects, the Millennium Bridge, London for Foster and Partners, Euralille and Institut du Monde Arabe, Paris for Ateliers Jean Nouvel, and Cite Internationale, Lyon and the New Caladonia Cultural Centre for Renzo Piano Building Workshop. They have produced a number of volumes on contemporary building technology which provide reference material for students. The *Modern Construction Series* is published by Springer Wien New York. In addition, the *Facades Technical Review*, from RIBA Publications was published in spring 2007.

Newtecnic is a firm of London-based specialist architects who create facades in collaboration with leading architects. The firm practices internationally as facade designers for architecturally and technically challenging projects and has a particular interest in developing new facade systems and in the use of complex geometries. Newtecnic follows principles of rapid prototyping as a method of developing facade systems that can be manufactured quickly and with a high degree of accuracy and precision. The office's current work ranges from large scale developments in Moscow, Dubai, Egypt, Kuwait City and St Petersburg to residential and commercial projects in London, where Newtecnic are working with design teams to develop innovative technical solutions and optimise complex designs for digital fabrication.

Much of Newtecnic's work is informed by a specific response to climate and to the technical performance of the external envelope. In projects where climate control and natural ventilation are primary design criteria for the facades in temperate climates, double skin facades are often used. Rather than follow rectilinear design, the outer skin of facades of projects where Newtecnic are involved are required increasingly to be shaped geometrically in response to specific environmental issues. These resulting facade forms are typically twisted, curved, tapered, or a combination of these forms. These pages aim to illustrate some of the research undertaken by Newtecnic in recent projects which exhibit these tendencies in terms of the possible solutions for the design of the cladding in both temperate and hot climates.

The Newtecnic team investigates material systems that are explored through 3-D modelling rather than 2-D drafting. The engineering aspects of the design, both structural and environmental, are developed through an investigation of the behaviour of construction systems when modifed geometrically. Rather than develop a series of options to solve a design, a single parametric model is used with fixed criteria and criteria which can be stretched and pulled until an optimum solution is found. This allows a single design model to provide a 'range' of solutions which can be explored through rapid prototype models, using a variety of modelling tools from 3-D printers to laser cutters. Strands of fabrication, context, site specificity, language of the base 'component' of the design and spatial organisation are developed in parallel for each project.

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