CWCT
CURTAIN WALL INSTALLATION HANDBOOK

This handbook was written by the Centre for Window and Cladding Technology (CWCT) as part of its training programme to improve the standard of curtain wall installation.

It will be of benefit to all those installing, or supervising, the installation of curtain walling and other glazed building elements.

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Introduction

The installation of facades and façade elements is one of the more complex site operations. It requires a range of skills and knowledge yet has not been recognised as a particular skill or trade. Façade failure, particularly water leakage, is the most common cause of failure in new buildings.

This handbook brings together advice on installation of curtain walling including all the major components: frames, gaskets, sealants, finishes, glass and fixings. It is based on experience gained by CWCT in setting up training centres for installers and in training main contractors' site supervisors.

The book explains why things should be done and highlights those things that are most critical to the success of curtain wall and window installation.

This handbook is a guide to achieving better curtain wall installation. However, it is not a substitute for care and diligence, nor should it be a substitute for proper training. Full details of CWCT's training programme are available at http://www.cwct.co.uk/installers.

1 The facade

- **Function**

The facade of a building has to exclude the weather, provide a comfortable internal environment, be safe during construction and use, and retain its appearance throughout its life.

Facades will only do these things successfully if they are correctly designed, planned and installed. This guide gives advice on the correct installation of facades and the components that make up a facade.

Modern facades are often highly technical involving the use of many materials, Figure 1.1.

- **Components**

Facades are made up of components or elements. These are factory-made to high tolerances and quality. However each is designed as a separate self-contained component without full regard as to how it may be built into most forms of facade construction. It is left to the facade designer and the installer to detail and fit the component on any particular contract. The different elements of the facade are each selected to serve a purpose and may not be chosen for ease of installation.

\- **Windows**
Window types are selected to provide ventilation, ease of cleaning, ease of operation, appearance, escape in case of fire, resistance to burglary and blast.

\- **Doors**
Door types are selected for security, appearance, emergency exits, fire performance, ease of operation, robustness.

- Glass
There are many types of glass to meet the requirements of particular buildings. Glass can provide security, resistance to blast loading, safe failure, strength, reduced sound transmission, reduced glare, reduced transmission of ultra violet, colouration and appearance.

- Panels
Infill panels in glazing frames and panels mounted as rainscreen are selected for their appearance, strength, resistance to abrasion and vandalism, fire rating, strength, ease of installation.

- **Types**

Facades take many forms ranging from heavy forms of construction; brickwork and precast concrete to the lighter forms such as profiled metal sheet, stick curtain walling and glass screens. The form of construction will have been chosen by the client and the architect having full regard for the purpose of the building, the image required, the design life of the building and whole life costing (energy and maintenance costs).

The basic forms of cladding are:

- **Brick and blockwork**

Load bearing masonry is the traditional method of building low-rise buildings without a structural frame. Masonry in medium and high rise construction is normally built as a non-load-bearing wall supported by the structural frame at floor levels. Windows and doors are fitted to holes left as the masonry walls are built. Masonry walls normally have cavities and it is important that factory made components are correctly sealed into the multi-layer masonry wall. The accuracy of construction is at odds with the accuracy required at joints.

- **In-situ and precast concrete**

In-situ concrete may be used to form the exposed surface of a façade but is more commonly concealed by an external cladding or rainscreen. Precast concrete is normally non-loadbearing and may be used to form cladding panels or backing wall panels clad with rainscreen.

Windows and doors may be installed into openings in in-situ concrete walls or precast panels, either at site or, for precast panels, in the factory. In other cases window openings may be formed as spaces between precast units. Components must be correctly sealed into the panels. If windows abut more than one panel then special care is needed to fix both panels and windows to prevent unintentional movement.

- **Panelized curtain wall**

Curtain wall may be constructed as large panels. Each the width of a structural bay and one storey high, they can weigh up to 15 tonnes, Figure 1.2. They may be precast concrete panels or steel trusses to which are attached outer and inner surfaces, insulation, and windows. Components are fitted onto the panels in much the same way that they are fitted into other facades. Panels of this size require very large fixings and anchors to hold them on the building. Special attention should be given to the large panel-to-panel seals that are required.

- **Unitised curtain wall**

Smaller factory-made panels are used in unitised construction. Typically one glazing bay in width and one or two storeys high the units are either:
- stick curtain walling frames that are factory assembled as ladders
- panels of concrete, gfrp, grc, metal skinned insulating composites that are factory assembled and include windows as required

Sealing the joints between units on site often depends on good workmanship and understanding of joint behaviour.

- **Stick system curtain wall**

Curtain wall can be formed from a stick system of site assembled framing members, mullions (vertical) and transoms (horizontal). Glazing and infill panels are fixed into the framing grid by clamping them in to a glazing rebate Figure 1.3. Panels may also be fitted as rainscreen, structural silicone glazing or bolted structural glazing.

Stick curtain walls are usually built from standard systems but they always have non-standard interfaces with adjacent elements (roof, structure, other wall elements). Stick curtain walls can be custom-designed to include accessories such as blinds and brise soleil.

- **Rainscreen**

Rainscreen is constructed as panels with a ventilated cavity between them and an inner air barrier. Rainscreen is either built by mounting support rails and panels on an inner wall of concrete, brick or blockwork (overcladding) or is part of a curtain wall (panelised, unitised or stick) that is self-supporting with integral cavity and air barrier (integral rainscreen) Figure 1.4. The panels may be of any material including metal, gfrp, stone, glass and ceramics.

- **Bolted glass assemblies**

Glass is either bolted directly to a supporting frame or a number of pieces of glass are bolted together to form a structural glass assembly. The installation of these walls may require greater knowledge and skills than are described in this book.

- **Profiled metal cladding**

Profiled metal normally spans between sheeting rails or purlins supported by the structural frame. It may be used in one of two basic forms: single skin and double skin insulated. The second form is used for cladding heated habitable buildings. The fitting of windows and doors requires attention to air and water sealing of joints with complex shapes.

- **Durability**

All facade components will deteriorate and age. This results from weathering, abrasion, staining, mechanical wear and tear. The useful life of a wall and the period to first repair may be reduced if any component is incorrectly installed or substituted with an inferior product.

Walls are generally required to last in excess of 20 years. A normal requirement would be for the primary framing members to last 40 or 60 years while other components such as hardware are required to last 20 years before refurbishment or replacement. Other components such as sealant joints may be designed to have a shorter life.

Poor installation can reduce the useful life of components to less than half of that intended. In particular inconsistent workmanship can lead to premature failure of a few components across the whole facade or complete failure of a small area of wall. With medium- and high-rise buildings the cost and difficulty of gaining access for remedial work will be far greater than any savings made by using inferior materials or modifying the design at site to simplify installation.

- **Interfaces**

A wide variety of components and wall elements are brought together in different combinations on every building site to create a unique building. Components are designed by manufacturers to fit into a number of construction forms but the interface between different manufacturers' components and constructed elements such as brickwork is the responsibility of the specialist contractor. Particular problems arise when the work of two contractors meet at an interface and design responsibility is shared.

Late substitution of one component for another, such as a window, will often require the design of an interface to be changed. This guide deals with the principles and practice of installation to ensure that interfaces are properly detailed and constructed at site level.

Cost	Materials	Performance	Quality	Appearance
- Capital cost	- Glass	- Weathertightness	- Methods	- Fit
….	*Annealed*	*Water*	….	….
- Running costs	*Toughened*	*Air*	- Standards	- Finishes
….	*Laminated*	….	….	*Gloss*
- Whole life costs	….	- Wind loading	- Inspection	*Colour*
Energy	- Metals	….	….	….
Maintenance	*Aluminium*	- Thermal	- Testing	- Shape
-	*Bronze*	*U-value*		*Flatness*
-	….	*Solar gain*		*Curvature*
-	- Plastics	….		-
	….	- Condensation		-
	- Stone	….		-
		- Ventilation		
	- Sealants	….		
	Silicone	- Acoustics		
	Polysulfide	….		
	Acrylic	- Fire		
	….	*Resistance*		
	- Gaskets	*Reaction*		
	….	….		
	- Finishes	-		
	….			
	-	-		

Figure 1.1 Some of the aspects of wall performance to be taken into account during design and installation

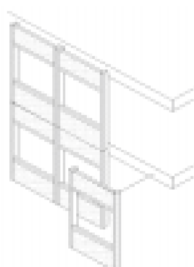

Figure 1.2 Unitised/panelised curtain wall

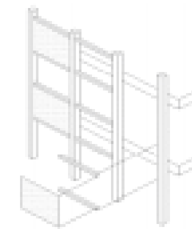

Figure 1.3 Stick system curtain wall

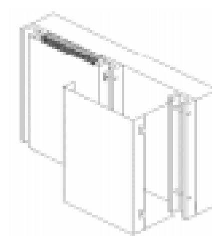

Figure 1.4 Rainscreen panels

2 Principles of weathertightness

- **Water and air tightness**

It is important that a facade keeps out the rain and the wind. Walls are designed to resist wind loading appropriate to the site and to provide water penetration resistance corresponding to that wind exposure.

Walls are designed to achieve the required low levels of air leakage. The allowable leakage is determined by the specifier and will depend on the use for which the building is designed, whether or not it is air-conditioned and the assumptions made when designing the heating systems. Excess air leakage gives rise to increased heating costs and possibly an inability to heat the building fully.

- **Water penetration**

Water should not penetrate the wall and reach the inner surface of the wall. It is also unacceptable for water to penetrate partly through the wall if it causes damage (rot or corrosion) to the wall or reduces its performance (reduction of thermal insulation).

A wall may be designed and constructed so that water can enter into the wall but is then drained safely to the outside. Water management rather than watertightness is the secret to constructing a good wall.

Water will penetrate the wall wherever there is an opening, water and a mechanism to take the water through the opening.

- **How water penetrates a wall**

Water may penetrate a wall or component in one of six basic ways:

- Gravity
- Wind pressure
- Air borne
- Kinetic energy
- Surface tension
- Capillary action

These are illustrated in Figure 2.1. Very often it is a combination of factors that causes leakage.

Incorrect installation can allow water to enter by any of these mechanisms even if the wall is designed to prevent water penetration.

Failure to lap components such as flashings, wrongly fitted gaskets and poor sealant joints will all create openings that allow water to flow into the wall under gravity. If drainage paths are blocked water will pond and overflow (often into the wall) under the effect of gravity.

Failure to seal openings that should be sealed and the incorrect fitting of gaskets leaves openings through which the wind can force water.

Failure to install air seals correctly allows air to pass through the wall and this may carry water into the wall.

Removal of drips and nibs from the underside of components can allow water to remain attached to the surfaces and run into the wall as a result of surface tension.

- **Leakage points**

Gravity is the most serious cause of water leakage followed by the effects of wind pressure. Both can allow large volumes of water to flow continuously. The other causes of leakage allow only intermittent flow or small flows.

The risk of leakage is greater at places on the wall where there is most water or greatest pressure. The points at which water leakage is mostly likely to occur are shown in Figure 2.2. Water is driven across the facade by the wind. It gathers at the mullions and runs down to the corner of each frame bay.

Wind passing a building moves around and over the building. This movement of the wind deposits more intense rain on the edges of the facade. Wind moving upwards on the wall can drive rain up the wall, particularly on the upper levels of medium and high rise buildings. Drainage openings can be designed to cope with this. Water may leak past gaskets and seals at the head of a frame if the joints are not correctly made.

It should never be assumed that a joint is in a protected position and that it is not an important joint.

The use of picture frame gaskets avoids the need to make mitre or butt joints of gaskets on site.

- **Forms of construction**

Walls have to be sealed against air leakage and water has to be prevented from penetrating the wall. In many walls and components the air seal is separate from the water barrier.

The outer water barrier, or rainscreen, prevents large amounts of water entering the wall or component. A cavity in the wall or component frame intercepts the small amount of water that passes the water barrier. An inner air barrier or air seal is provided behind the cavity to give the required low level of air leakage.

The water barrier is designed to prevent water leakage. It is the primary defence against water leakage and should be constructed with this in mind. Any small amounts of water that enter the cavity have to be drained to the outer face of the wall.

The outer layer may be impermeable such as an aluminium or glass panel or it may be porous such as brick or terracotta.

- **Drained facades**

With the exception of front sealed construction, all framing members and cavities behind rainscreen panels should be designed to be drained. This means that water passing the outer seal has to drain out through drainage openings to the outer face.

Drainage may occur at open joints between panels or through drainage paths in the framing members.

Window frames are normally drained through holes in the outer face of the frame. An opening sash may have drainage holes in its lower edge. These drain water from the glazing cavity into the cavity below. This in turn has to be drained to the outer face, Figure 2.3.

Stick curtain walling systems may be drained in the same way as windows. Each glazing rebate is drained to the outer face with holes in the front face of the lower framing member, Figure 2.4. Alternatively systems may be designed to drain water along the transom to the mullions, Figure 2.5. The drainage capacity of these systems is limited and water should be drained from the mullion at every third floor.

It is important that drainage channels are not blocked as the wall is installed. Badly placed glazing blocks, use of sealants in the wrong place, debris left in the glazing rebate or inadequate or missing drainage holes can all block the intended drainage paths.

Water will not drain freely from very small openings due to the effect of surface tension. Drainage holes should be at least 8mm diameter or 25mm x 6mm. Holes that are partially blocked or not properly deburred will not allow water to drain. Glazing blocks should bridge the drainage channel in the glazing rebate unless drainage holes are provided between all glazing blocks. Water will not drain for long distances along horizontal frames, particularly if they deflect under load. Many designs set a maximum distance between drainage holes.

- **Drained and ventilated facades**

Drained rainscreen and glazing frames have drainage holes at the bottom of each cavity to allow water out. Holes may also be provided at the top of the cavity to provide ventilation of the cavity. This allows air to pass through the cavity or frame to remove excess water vapour.

Holes for ventilation may be smaller than drainage holes. They are normally made the same size as drainage holes and placed in symmetrical positions so that transoms cannot be installed upside down. If transoms have holes for only one glazing rebate it should be assumed that they are drainage holes. The transom should be placed with the drainage holes uppermost so that they are at the lowest point of the glazing rebate they drain.

- **Pressure equalised facades**

Pressure equalised windows and walls are designed with openings large enough to allow the air pressure in the cavities to nearly balance that of the wind on the outside. This helps to prevent water from entering the cavity.

For a rainscreen the drainage and ventilation holes may be larger than for a simply drained and ventilated system. Pressure equalised window frames do not always need larger holes. It is not obvious on site whether a window is pressure equalised or only drained and ventilated.

Unless a seal is shown it should be assumed that all holes, including ventilation holes, are necessary to prevent water penetration into the wall.

If a glazing rebate is vented into the cavity between an opening frame and a fixed frame then the outermost vent or drain holes will be larger than the inner ones. This is because they have to allow pressurisation of the two cavities, Figure 2.6.

- **Windows**

Windows are tested to BS5368 Pt 1 for watertightness and BS5368 Pt 2 for airtightness. The test only proves the effectiveness of the window and its internal seals. The joint between the window and the surrounding wall is equally important if the wall is to function correctly.

The window should be sealed to the surrounding wall using either a wet applied sealant, a sealant impregnated sponge or, in the case of a window in a curtain wall, a gasket. The same principles apply to these seals as to all the other seals of the window:

- The seals should be well made.
- It should always be assumed that some water may leak past the outer seal and provision should be made to drain this to the outer face.
- An effective air seal should be made at the inner face, Figure 2.7.
- The sill should be sealed to both the surrounding wall and the window taking care not to restrict any drainage channels.

Particular attention should be paid to the sill detail. Sub sills are not tested as part of BS5368 and in any case are frequently made to suit a particular contract.

- **Curtain wall**

Curtain wall is tested to the CWCT 'Standard and Guide to Good Practice for Curtain Walling'. A representative sample of the wall is tested and for a custom wall the test will have included the flashings and typical interface with adjacent elements of the building envelope.

Flashings and interfaces must be constructed in accordance with the drawings as approved after test.

For proprietary systems it is normal to test the system once only. In this case the flashings and other interface details may not have been tested. It is important that these details are built according to the drawings.

The installer should be alert to any possible leakage paths as this is often the first time that complex details have been seen full size in three dimensions. If there is doubt about the detailing of the interfaces the designer should be consulted before work continues.

If a wall has been tested the design may have been modified as a result of early tests.

The wall should be constructed on site to exactly match the wall tested. The installer should be notified of any modifications or non-standard details. Even proprietary systems are modified from contract to contract and the installer should not assume familiarity with a system.

- **Rainscreen**

Rainscreen performance depends on the rainscreen panels and all components in the cavity. Design drawings and test reports should show details of the framing members, number and location of fixings, size and position of all openings, dimensions of all cavities, internal flashings and gutters, cavity closers and fire barriers.

Excess water may pass the rainscreen if:
- drainage and ventilation openings are the wrong size

- cavity closers are omitted or wrongly constructed
- baffles are omitted from joints
- the cavity is too wide

Water will fail to drain from the cavity if:
- drainage holes are too small
- drainage paths are blocked with debris
- the cavity is blocked with insulation material
- internal flashings and gutters are incorrectly fitted or missing
- drainage of components (windows and doors) is not linked with drainage of the rainscreen

- **Site testing**

Site testing may be carried out during construction to check for good workmanship and consistent performance. Testing may also be carried out after construction to identify the cause of water leakage.

The hose pipe test is used for routine site testing for water penetration. The test is described in CWCT 'Standard and guide to good practice for curtain walls'. A full description of site testing is given in CWCT TN10 'Site testing for watertightness'. Testing should be conducted using a standard nozzle, standard water pressure and motion of the nozzle.

The test was developed for use on sealed joints but it may be modified for use on opening joints. In this case it is good practice to vary the nozzle pressure and not the motion of the nozzle.

- **Air leakage**

Air leakage can lead to excessive heating bills, an inability to heat a building and uncomfortable draughts

Allowable air leakage rates are given in Part L of the Building Regulations.

High rates of air leakage are symptomatic of poor installation. Walls that leak too much air are also likely to leak water as poor air seals impair the pressure equalisation of many walls and components.

High rates of air leakage are associated with unintentional openings in the air barrier. These openings will impair the acoustic properties of the wall and allow more sound into the building.

The main causes of unintentional air leakage are:
- incorrectly fitted air seal gaskets
- failure to seal windows and other elements to the air barrier of the surrounding wall
- Opening windows and doors that are not correctly adjusted and do not seat correctly

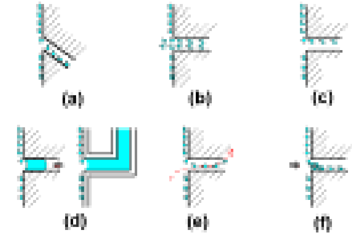

Figure 2.1 a) Gravity b) Kinetic c) Surface tension d) Capillary action e) Air driven f) Pressure difference

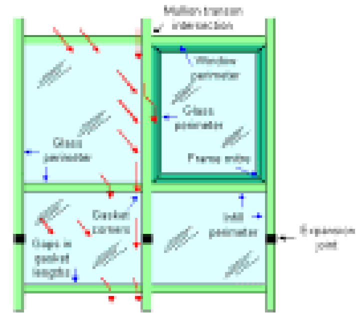

Figure 2.2 **Potential leakage sites**

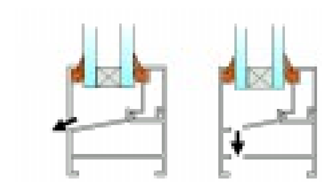

Figure 2.3 **Drainage of window frames**

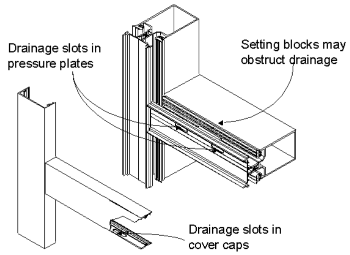

Figure 2.4 Transom drained curtain wall

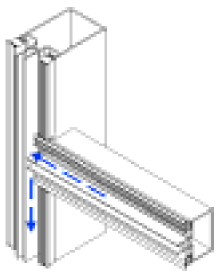

Figure 2.5 Mullion drained curtain wall

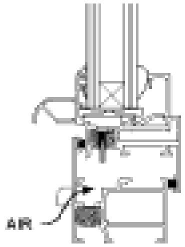

Figure 2.6 Pressure equalised frame

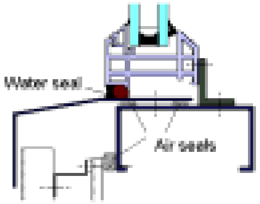

Figure 2.7 Air sealing of window to wall

3 Frames

- **Function**

Frames may be used for windows, glazing screens and curtain walls. In all cases the frame is composed of a series of profiles assembled to form the frame and designed to support glazing or other infill panels. For windows, assembly of the frame, and sometimes glazing, is carried out before delivery to site whereas for glazing frames and curtain walls at least some, and in some cases all, of the assembly work will be carried out on site.

- **Frame materials**

Framing materials are selected largely on the basis of individual or corporate preference. They are chosen because of the specifier's familiarity with the material or for reasons such as 'green issues'. Each material offers different benefits and this may determine the choice of material. The principal materials used to form glazing frames are:

\- **Timber**
Traditionally used as a framing material, today both hardwood and softwood are used. Timber suffers from rot but modern timber treatments combined with good design and workmanship give an acceptable life. However regular maintenance of finishes is required. Timber windows may be produced with a drained glazing cavity but many are undrained and rely on a single outer seal between glass and frame to keep out the water. Water ingress following failure of the seal can then lead to failure of the edge seal of double glazing units. Many windows have a limited depth of rebate restricting the width of glazing unit that can be accommodated.

Timber has been used for glazing screens but this is not common.

Timber is used as a solid section and is thus relatively stiff. It resists bending and torsion well and hardware can be attached to the frame with little difficulty.

\- **Steel**
Steel was introduced as an alternative to timber for window frames. Originally hot rolled sections were used but today steel is used as cold-formed sections to make window and door frames. Steel windows are galvanised and powder coated and may today be double-glazed. The hardware is usually an integral part of the window. Steel windows allow the use of slender sections yet are robust and are comparatively secure, if secure hardware is used. Steel has obvious advantages when making fire resistant glazing screens and windows.

\- **Aluminium**
Aluminium has been used as a framing material for some fifty years. Aluminium does not suffer badly from corrosion and is easy to form and finish allowing many different designs. Aluminium is used as hollow sections and is relatively flexible in bending and torsion. Hardware often has to be matched against a particular profile. Because of the hollow and complex profile cross sections achievable with aluminium it is easy to make drained and ventilated or pressure equalised windows.

Aluminium is a very good conductor of heat. To meet requirements for low thermal transmission aluminium profiles are thermally broken with either a polyamide or resin element between inner and outer aluminium sections. The latest proposals for improving the thermal performance of windows will require improved thermal breaks.

Aluminium is the most common frame material for stick system curtain walls, glazing screens and shop fronts. It is also commonly used as a framing system to support rainscreens.

\- **PVCu**
PVCu is a flexible material that is normally internally reinforced with steel or aluminium to give it the required strength and stiffness. As with aluminium it is easily formed to produce a wide variety of profiles. When first introduced it was generally used white without any finishes but it is now widely available in coloured form, either using coloured material, foil finishes or specialist paints. It is dependent on reinforcement for its strength and hardware should be fastened through to the reinforcement. Many PVCu profiles are multi-chambered and it is essential that they drain correctly.

PVCu is now used to construct glazing screens and low rise curtain walling. The structural elements are PVCu clad aluminium and these form the supporting grid for PVCu framed windows.

\- **Composites**
The use of composite frames allows the designer to use the advantages of different materials for the inner and outer parts of the frame. Common combinations are:

Aluminium - PVCu
Aluminium - Timber
Stainless Steel - Aluminium
Bronze - Aluminium

Composite frames are used to improve thermal performance (heat loss), reduce the risk of condensation, give a more durable outer weathering surface, give different appearances to the inner and outer finishes.

- **Window types**

There are many different types of window in use. Some of these are traditional designs, others are copied from traditional designs elsewhere and some have only become possible with the use of modern materials and hardware.

The window types commonly used in the UK are:

Fixed light	Vertical slider
Side hung vent	Horizontal slider
Projecting side hung	Horizontal pivot
	Vertical pivot
Top hung vent	Off-set vertical pivot
Projecting top hung	
Tilt-turn	

These are shown in Figure 3.1. The drawing notation used is in accordance with BS4873 in which the arrow drawn on the glazing points toward the hinges.

UK practice has been to use a solid line for open out windows and a dotted line for open inward windows. This is different from practice in some European countries and it should be clearly established which convention is being used.

- **Window selection**

The types of frame used on any particular contract will depend on a number of factors. These include:

- **Maintenance**
Windows that can be cleaned from the inside of the building may be preferred where it is possible to use a large proportion of opening windows. Framing materials that require little maintenance are also preferred.

- **Safety in use**
Windows have to be safe in use. They may have to meet any of these needs:
- be safe to clean and maintain
- provide a fire escape route
- prevent people from falling out
- not obstruct paths and passages when open

- **Ventilation**
Windows of different types give different ventilation patterns in a building Figure 3.2. The size of the opening sash will determine its weight and the hardware to be used.

- **Local custom**
Windows will often be selected to match those on nearby buildings. For refurbishment they are normally chosen to follow the style of earlier windows. On listed buildings and in conservation areas it may be a requirement that particular windows are used.

- Size of opening
The size of window opening will depend among other things on the lighting requirements, view, allowable heat loss and appearance of the window.

- Preferred material
Framing materials may be selected on the basis of cost, durability, strength, appearance. Increasingly whole life costs and environmental issues are being taken into account.

- Glazing material
The glazing or infill material may affect the choice of framing material. The frame has to support the weight of the glazing and accept glazing units of the required thickness.

- Appearance
This probably has the greatest influence on the selection of framing materials. Both the available finishes and the slenderness of the frame are factors.

• Window frame construction
Window frame construction is governed firstly by the type of framing material and secondly by the style of the window. The following are typical cross sections through window frames:

- **Timber**
There are no timber systems but there have been standardised designs. Timber is machined to a profile from hard or softwood and joined by tenon joints and finger joints to produce glazing frames. Today timber windows are available factory-painted and glazed.

- **Steel**
Hot rolled sections have traditionally been used to make window and door frames, Figure 3.3. They are of welded construction and are robust but the range of sections available is limited.

Cold-formed sections are available as proprietary systems Figure 3.4. The corners are normally cleated rather than welded. Care should be taken that frames are not racked or otherwise distorted during installation as the corner joints may be damaged.

- **Aluminium**
Aluminium can be extruded in an infinite number of complex shapes and to very close tolerances Figure 3.5. Window and wall framing systems consist of a number of profiles to facilitate extrusion and assembly.

Aluminium profiles are formed into frames by the use of mechanical joints. Window frames comprise a main framing member that provides the strength and stiffness and an extruded glazing bead that generally clips into place to retain the glazing in a drained glazing rebate.

Aluminium frames are thermally broken to make them more energy efficient and reduce the risk of condensation forming.

- **PVCu**
PVCu framing members are formed into window frames either by heat welding the members at mitred joints or by mechanical joints. Heat welded joints are more common and provide a clean seal that keeps water out of the frame. Window frames comprise a main framing member that provides the strength and stiffness and an extruded glazing bead that generally clips into place to retain the glazing in a drained rebate, Figure 3.6.

Many window suppliers are now able to supply an additional outer frame of galvanised steel. This can be built into a new wall allowing the window to be fitted sometime after the bricklaying has been completed.

- **Composite**
Frame construction depends largely on the material of the main or central element. For instance a timber window is made and then clad with plastic or metal. The jointing technology has to take account of the materials to be joined and the presence of different materials and is generally more complex than for non-composite frames.

• Doors
Doors are constructed from all of the framing materials. In general doors are made from larger sections. This is due to their size but also due to the robustness requirements, particularly for commercial buildings. The most commonly used framing materials are aluminium, hardwood and PVCu.

• Tolerances
Overall tolerances for windows and doors are set out in the British Standards for each framing material. Tolerances are defined in terms of height, width and difference between diagonals (or squareness). They are (in mm):

Material	Width	Height	Diagonal
Timber	± 2	± 2	3,5 or 10**+**
Steel	± 1.5	± 1.5	4
Aluminium	± 1.5	± 1.5	4
PVCu	± 3	± 3	4

+depending on size of window

Particular manufacturers will be able to make windows to greater accuracy. However they may not be able to do so for very large windows. The tolerance achieved with a composite frame should be the greater of the above when considering both materials.

The squareness of a fixed frame may change if it is fixed incorrectly to the wall. That of an opening frame may change as it is glazed. Squareness should be checked before and after installation.

The rigidity of a window frame depends on the presence of the glazing and the positioning of the setting blocks. The use of factory glazed windows can overcome this problem. However care is still required with the frames of doors and opening lights.

- **Curtain wall sections**

Stick system curtain walls comprise mullion (vertical) and transom (horizontal) framing members. Curtain wall frames act structurally to resist wind loading and to carry the weight of the wall. A typical profile is shown in Figure 3.7.

The profile comprises an outer section that serves to hold the infill material in place, prevent water penetration and form an air seal. The inner section comprises a hollow structural box the depth of which determines the strength and stiffness of the section.

Most curtain walls are constructed from aluminium profiles. Some walls are constructed as an assembly of windows with PVCu frames. These are supported in a structural frame the mullions and transoms of which are aluminium sections sheathed with PVCu.

Stick curtain wall members are delivered to site machined and cut to length. A high degree of accuracy is required in cutting to length. Slight variations in the length of members will result in the erected frames being out of square or distorted, whereas if all the elements are consistently over or under size the frame can be erected square, but the final bay may have to be manufactured specially to fit the remaining gap. The tolerance for these elements should be agreed at the design stage. Framing members may be pre-assembled as ladder frames or unitised walling.

Framing members may be designed to retain the infill panels in a number of ways:

- **Pressure cap**

The most common means of retaining glazing in a curtain wall frame is by using a pressure plate which secures the glass in the glazing rebate around the full perimeter of the glazing unit.

Pressure caps are secured in position by screws which must be either tightened to a required torque or to a stop where the pressure cap makes contact with the frame.

- Structural silicone glazing

Structural silicone provides a means of retaining glass without the need for external components. It is therefore possible to obtain a smooth façade.

It is important that the structural silicone should be applied under controlled conditions in a factory. This should ensure a clean environment and controlled curing times.

To achieve this the structural silicone is normally used to attach the glazing to a carrier frame that is then fixed to the curtain wall frame using mechanical fixings.

- **Bolted connections**

Bolted connections have been developed as an alternative means of achieving a smooth façade. Bolted connections can be used with glazing units and single glass.

- **Rainscreen frames and rails**

Rainscreen is a layered form of construction comprising an outer cladding or rainscreen, a cavity and a backing wall. Rainscreens may be constructed in various ways. Panels may be supported by a masonry or concrete backing wall via brackets or timber battens. Alternatively the rainscreen panels may be supported by rails spanning between floors or a frame consisting of vertical and horizontal members.

The frame may be of similar proportions to a curtain wall frame and span from floor to floor as a self contained, integral, rainscreen. Alternatively sections of lighter weight may be used attached to a background wall for support.

Frame members are made from aluminium profiles or cold formed steel sections. The tolerances on components are similar to those achievable for curtain walls.

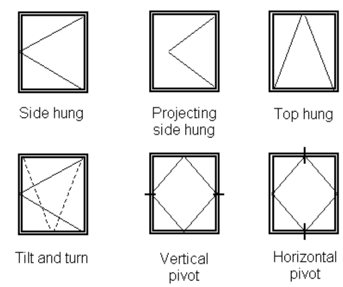

Figure 3.1 Window types

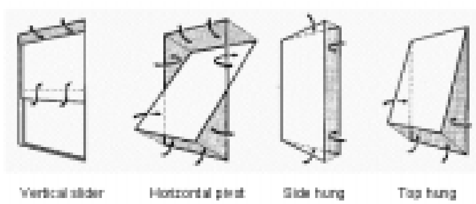

Figure 3.2 Window types

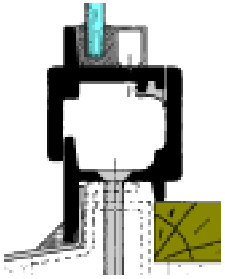

Figure 3.3 Hot rolled steel window frame

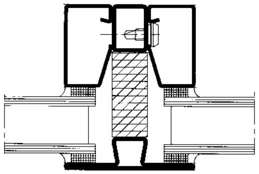

Figure 3.4 Cold formed steel glazing frame

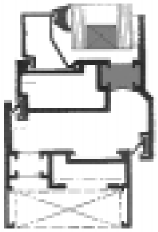

Figure 3.5 Aluminium window frame

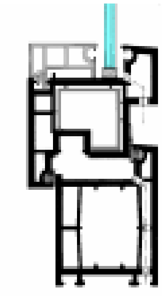

Figure 3.6 PVCu window frame

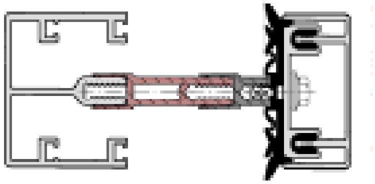

Figure 3.7 Aluminium curtain walling frame

4 Gaskets

- **Function**
  Glazing gaskets are required to:

- Limit air leakage and water penetration
- Allow relative movement
- Distribute and absorb loads
- Accommodate tolerances

- **Materials**

There is a very wide choice of gasket materials available to the designer. Materials are selected for their ability to:

- Retain their shape
- Resist weathering
- Work at extremes of temperature
- Resist tearing

Cost is also of course a consideration when selecting a suitable gasket material.

Materials used to make gaskets can be grouped into families but within each family a wide range of performance can be achieved. It is wrong to assume that all gasket materials are the same because they are in the same family. Gaskets from one supplier should not be replaced with those from another without considering the performance requirements given above.

The most commonly used gasket materials can be grouped into the following families:

EPDM		**Neoprene**	
Shape retention	Good	Shape retention	Average
Low temperatures	Good	Low temperatures	Average
Tear resistance	Good	Tear resistance	Very good
Weathering	Good	Weathering	Average
Cost	Average	Cost	Average

Silicone		**Butyl**	
Shape retention	Good	Shape retention	Poor
Low temperatures	Very good	Low temperatures	Good
Tear resistance	Poor	Tear resistance	Average
Weathering	Very good		
Cost	Expensive		

Thermos-plastic rubbers		**Hypalon**	
Shape retention	Poor	Shape retention:	Average
Low temperatures	..	Low temperatures	Average
Tear resistance	..	Tear resistance	Good
Weathering	..	Weathering	..
Cost	Average	Cost	…

- **Types**

Gaskets are made in a range of shapes and sizes as shown in Figure 4.1 and can be categorised in several ways as follows:

Type of seal
A weatherstrip is a gasket whose primary purpose is to prevent water entering a joint and which will normally be located on the exposed side of the joint.
A draughtstrip is primarily intended to prevent the passage of air through the joint and is normally located at the back of the joint.

Method of fixing
Three methods of locating gaskets are employed:

- Push-in gaskets are designed to be fitted into a groove in the mounting surface, prior to the formation of the joint.

- Drive-in or wedge gaskets are designed to be forced into the gap between the mounting surface and contact surface, usually as the last stage in sealing the joint. A drive-in gasket can usually be removed by pulling it from the joint, although it may be manufactured with a rigid strip that makes this difficult.

- Slide-in gaskets are designed to slide into a groove on the mounting surface, but must be installed from the end of the groove. A slide-in gasket can usually only be removed by sliding it out from the end of the groove.

- Slide in gaskets can only be installed as single lengths and corner joints have to be made after installation. Factory made joints perform better than site made joints.

Principle of operation
Most gaskets form a seal as a result of compression of the bulk material but some gaskets form a seal by deflection, either of a cantilevered arm or a hollow tube and others work by wiping contact with minimal deflection.

To seal effectively a gasket must remain in compression however the compression of the gasket will cause forces to be exerted on the contact surfaces of the joint. The joint must therefore be designed to ensure that when the joint is at its widest there is sufficient compression in the gasket to create an effective seal. However the gasket must also be capable of being compressed sufficiently to fit when the joint is at its narrowest in such a way that the forces on the contact surfaces do not damage the joint components or prevent movement.

Where a single gasket cannot accommodate the full range of possible joint widths due to manufacturing and erection tolerances, it may be necessary to have a range of gaskets available. The installer can then select the appropriate gasket by measuring the width of the joint gap.

The force exerted by a gasket in compression will gradually decrease over a period of time due to the effects of creep and stress relaxation. There will also be a reduction in recovery of compression when the load is removed.

Corners
Gaskets are either injection moulded or extruded. Most glazing gaskets and other gaskets used in the facade are extruded as continuous lengths. At corners the gasket has to be cut and joined.

The practice of bending the gasket around the corner is generally unacceptable as the cross section of the gasket distorts locally to the corner.

The following options are available for making corner joints:
- Cut extrusions to length and glue

- Cut extrusions to length and heat weld
- Cut extrusions to length and site vulcanise
- Mould corners and bond to extrusions
- Mould corners onto extrusions

All of these methods will produce a single gasket that forms a continuous seal around the infill panel or glazing. This is recommended for the inner (air) seal of a curtain wall, Figure 4.2.

For window glazing and for the outer (water) seal of a curtain wall it may be acceptable to mitre the corners of the gasket and make an unbonded butt joint at each corner.

- **Installation**

It does not matter how much effort is expended in designing the perfect joint and the perfect gasket if it is then installed by an untrained workforce with little appreciation of the performance requirements of a sealed joint.

Basic good practice includes:

- Careful handling of the gaskets to avoid damage
- Cleaning of joint surfaces including removal of swarf. Lubricants may be used to ease fitting of gaskets but must be compatible with the gaskets and adjacent materials.
- Leaving gaskets unpacked in a warm environment to relax and recover their natural shape prior to installation is also recommended although this may leave the gaskets prone to damage.
- The gasket should be inspected before installation and discarded if visible defects such as cuts and abrasions are found.

Temperature may affect the flexibility of the gasket and width of the joint. Generally it is not recommended that gaskets are installed at temperatures below 5°C and even at this temperature the joint may have opened up due to thermal contraction of the components, leading to the risk of crushing the seal at higher summer-time temperatures.

The correct gasket should be used. The size of gasket to be used depends on the frame dimensions and thickness of the glazing unit or infill panel. Different sizes of gasket may be available to accommodate different glazing types and tolerances.

Gaskets that are undersize and easy to insert will not be compressed and form a proper seal throughout the life of the wall. Gaskets that are too tight and are forced into position may crush the edge of the infill.

Gaskets that are stretched as they are fitted will return to their original length after installation leaving gaps at any butt joints. Gaskets should be cut slightly over size and compressed lengthwise as they are fitted. Fitting commences from the ends followed by the middle, Figure 4.3. Gaskets are available with co-extruded cords that prevent stretching of the gasket. Gaskets should not be twisted or folded during fitting.

Most glazing systems are designed to be dry glazed using only gaskets. However some systems require the use of a sealant with the gasket. This need arises with special systems such as blast resistant glazing. This should be done in accordance with the system designer's recommendations. The arbitrary use of sealants in combination with gaskets should not be allowed.

Like sealants, gaskets are a target for cost cutting. A fabricator will buy cheaper gaskets from another supplier just to save a few pence on the cost of each metre length, without any form of guarantee that the new gaskets will perform satisfactorily. The cost of even a small

amount of water leakage, in terms of problem rectification/damage repair never justifies the initial cost saving, but the capital cost saving is made by the fabricator, who rarely sees the clients' costs of repair.

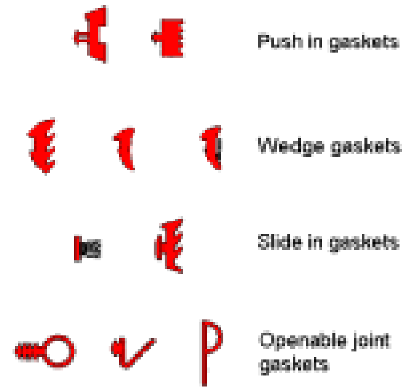

Figure 4.1 Types of gasket

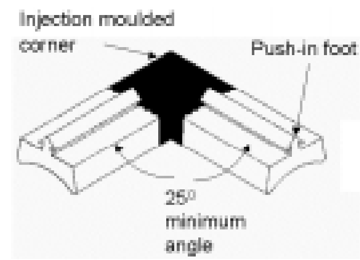

Figure 4.2 Moulded gasket corner

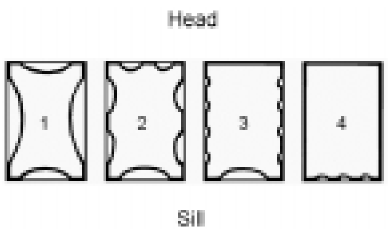

Figure 4.3 Sequence of fitting a dense gasket

5 Sealants

- **Function**

Sealants are used to make water seals, air seals, combined seals or to protect an internal seal. They have to adhere to the materials they connect, resist tearing and be durable. In movement joints they should not stress adjacent materials.

Many sealants are likely to have a shorter useful life than the design life of the building unless they are protected and provision should be made for replacing the sealants within the joints, or oversealing.

- **Sealant systems**

Sealants used in modern façade construction are wet applied materials based on synthetic polymers which cure to form flexible solids. Oil based mastics which gradually harden with time are not generally suitable for use in these applications.

Sealants should be used as part of a system comprising sealant, cleaner, primer and backer rod.

Sealant

There is a large range of wet applied sealants. Supplied in tubes or tins, they are either one or two part materials. One-part materials avoid the need for site mixing but generally take longer to cure as they cure from the surface.

Cleaners

Cleaners are used to prepare surfaces before a primer or sealant is used. They are used to degrease the surface and are normally solvent based.

Some cleaners are not suitable for use with all materials, particularly plastics. Cleaners should be chosen to be compatible with both the sealant material and the substrate. Cleaners should be tested on a small area of substrate before being used more widely.

Primers

Primers are used to prepare the surfaces the sealant has to bond to. They may seal the surface to prevent penetration of the sealant and improve bond or they may promote a chemical bond between the sealant and substrate material.

Primers used to seal porous materials serve to reduce seepage of the sealant into the substrate and possible staining of surfaces adjacent to the joint.

Backer rods

Backer rods are used with wet applied sealants to control the joint shape and to limit the waste of sealant material in joints that are too deep.

Sealing strips

An alternative to wet applied sealants is to use sealing strips. Sealing strips are flexible materials which are pre-formed in a range of sizes and sections and mainly rely on compression although some adhesion to a joint face may take place. They may be considered as a special type of gasket and are of two basic types:

- Mastic strips, usually manufactured from relatively soft, tacky synthetic rubber to which an easily removed backing paper is applied; and,

- Cellular strips, usually based on a synthetic polymer, which may also be edge-coated with an adhesive layer. They may be composed of closed cell material or open cell material impregnated with a sealant. They are supplied pre-compressed to about 20% of their normal thickness and expand after placing. They can either be inserted in a preformed joint or fixed to one side of the joint before placing the component forming the other side of the joint.

• Types of joint

Joints are made to join together elements of the building and may be used for two purposes:

Fixed joints
These occur where materials are joined because maximum panel or unit size requires the use of more than one element. Joints also occur where different materials or components meet.

At a fixed joint the adjacent components are fastened together to prevent movement between them. The joint then has a constant size and shape and the sealant does not have to move.

For fixed joints the materials used are selected to be durable, Figure 5.1 and to bond to the substrates.

Movement joints
These joints are provided to allow the building and the cladding to move. Movement occurs because of temperature change, wind loading and imposed loading amongst other things. Movement joints are made at the natural joints in the building where there would otherwise be fixed joints.

The shape and size of a movement joint will change daily and over longer periods of time. A sealant that can move in the required way is chosen for a movement joint and there is a wide range of performance available Figure 5.2. Sealants also have to be durable and bond to the substrates.

In a movement joint the stretching of the sealant will make greater demand on the bond to the substrate.

Joint size
The exact size of a movement joint gap, Figure 5.3 is important to its short and long term performance. If the width of a movement joint is made only half of the intended size then the forces within it will be double those intended and failure is almost inevitable. All joint designs should specify a minimum joint gap size to be achieved on site.

• Joint shape

There are three basic shapes of sealant joint:

Butt joint
This shape of joint occurs when two thick panels are joined edge to edge or where thinner panels are required to have a flush face Figure 5.4.

Thin panels should be formed with a return that gives an adequate bond area for the sealant.

It is important, particularly for a movement joint, that the sealant material can stretch across its full width. A backer rod or release tape is used at the back of the joint to prevent adhesion of the sealant at the back of the joint. If the sealant is not free to move then it will tear early in its life Figure 5.5.

It is important to control the depth of sealant within the joint. Too deep a sealant will cause high stresses and tear the sealant or adjacent material. It will also be wasteful of material. Too little sealant will not create a robust joint.

Lap joint
This shape of joint is most commonly used for fixed joints although it can be designed to move.

It is important that the gap achieved on site is not less than that intended, particularly for a movement joint. Otherwise the sealant will be overstressed leading to tearing or debonding.

Backer rods should be used to control the size of the sealant bead within the joint to avoid the wasteful use of material and to provide a robust joint Figure 5.6.

Fillet joint
This shape of joint is frequently used when components are neither lapped nor positioned to give a flush face. This is the joint commonly used to seal windows recessed in openings.

The joint should be constructed to give an adequate contact area between the sealant and the substrates. This should be not less than 6mm onto a non-porous surface and 10mm onto a porous surface. A fillet joint made in front of two components that are very close together will tear Figure 5.7 and a minimum gap of 5mm should be allowed.

Joints between windows and walls are not designed as movement joints but are not perfectly fixed and so some movement will occur.

Backer rods should be used to prevent the wasteful use of material and so that the joint can be properly tooled to form a good bond.

• Materials

Sealants are commonly classified by their base materials:

- Silicones
- Polysulfides
- Polyurethanes
- Acrylics

However the performance of a sealant is not only governed by the base material but also by additives such as plasticisers, retarders and fillers. The preferred practice adopted by recent British Standards is to specify sealants by performance.

The following classification system is given in BS ISO 11600:

Sealant type
Sealants may be classed as type G which are suitable for use in glazing and type F which are suitable for use in building joints other than glazing.

Sealant class
Four classes are given relating to the amount of movement the sealant can accommodate. The classes are 7.5, 12.5, 20 and 25 which give the allowable movement as a percentage of the unstressed width. Sealants can accept this movement in both compression and tension.

Although a class 25 sealant can accommodate more movement than a lower class sealant it would only be suitable for use in place of a lower class sealant if all the other properties of the sealant are also acceptable.

Some sealant specifications give movement accommodation as the total movement expressed as a percentage of the minimum joint width (the joint width when the sealant is fully compressed). This will give values about twice those given using the BS ISO 11600 definition. When selecting sealants for movement joints it is important to check the basis on which the movement characteristics sealant are given.

Sub-classes

Sub-classes relate to the elastic properties of the sealant.
Class 20 and 25 sealants are elastic and may be designated LM for low modulus or HM for high modulus.
Class 7.5 sealants are plastic
Class 12.5 sealants may be designated P for plastic or E for elastic

Test criteria are given in British Standards to establish compliance of the sealants with this classification system. This classification system gives a starting point for the specification and selection of sealants however other properties which must be considered include:

- Life expectancy
- Colour
- Compatibility with substrate
- Adhesion to substrate
- Stress relaxation

It follows that sealants should not be casually chosen or substituted at site. It will always be possible to buy a cheaper sealant but it will probably not be suitable.

• Storage and use

A successful sealant joint requires correct installation procedures.

All materials making up the sealant system must be compatible and should preferably come from the same supplier. The materials making up the sealant system must also be compatible with the substrate.

Materials must be used in accordance with the manufacturer's instructions. The provision of detailed site-specific method statements ensures that the applicator is aware of the correct procedures and allows co-ordination of sealant application with other work on site. Aspects to be included in the method statement are described below.

Storage

Sealants and associated materials including primers and cleaners may contain hazardous materials and require appropriate storage conditions. Materials may also require protection against frost and excessive heat or humidity during storage. Storage procedures should also ensure that materials are used before their expiry dates.

Inspection

Before sealant application commences joints should be inspected to ensure that their dimensions are within permitted limits and that the adjacent materials are of suitable quality. The inspections should be carried out in sufficient time to allow remedial work to be carried out where necessary.

Weather

Temperature will affect the properties of the sealant and the opening of joints. In cold conditions the sealant will be more viscous and take longer to cure whereas in hot conditions it will be less viscous and have a shorter working life.

Sealant application is normally limited to temperatures between 5°C and 40°C. These temperatures apply to the surfaces to be sealed not the ambient air temperature.

Frost may persist on shaded surfaces after the air temperature has risen to 5°C and surfaces subject to direct sunlight may reach temperatures as high as 80°C.

It is also necessary to consider likely temperature changes during the curing period of the sealant as excessive movement during this period may cause the joint to move while it is curing and pucker the cured surface of the joint.

Sealants should be applied in dry conditions although some primers are tolerant of damp surfaces. Wet surfaces can arise due to condensation in cold weather as well as rain. For this reason sealants should only be applied when surface temperatures are at least 5°C and rising.

Cleaning

Cleaning of the joint surfaces is always necessary. The cleaning methods to be used vary according to the type and condition of the surfaces.

Physical removal of dirt may require use of a dry brush, compressed air, wire brush or abrasive pads. The method chosen must ensure that the surface is not damaged.

Removal of grease may require use of a solvent. The solvent must be compatible with the substrate, primer and sealant and must be clean. Cloths used for application should also be clean and lint free: use of white or light coloured cloths is preferable so that soiling is evident. One cloth should be used to apply the cleaner and a second to wipe off.

Masking

Masking tape is useful on substrate surfaces where removal of excess sealant is difficult and may also be used to improve the appearance of the finished joint by giving a clean edge. Tape should be applied prior to application of primer and the tape should not touch surfaces cleaned for sealant application. Tape must be removed immediately after sealant application and tooling.

Priming

The need for a primer will depend on the substrate and sealant to be used. Non-porous surfaces usually use a silane type primer which must be applied sparingly using a cloth. Resin type primers are normally used for porous surfaces and may be applied by brush or cloth.

Primer should only be applied to the sides of the joint to which the sealant is required to adhere.

Care should be taken to avoid contamination of the primer both before application and between application of primer and sealant.

The primer must normally dry or cure before application of the sealant but if left too long may cease to be effective.

Back up material
Closed cell polyethylene or polyurethane foams supplied in rods, hoses or flat sheet, which may be cut to form rectangular sections, are commonly used as back up materials to control the depth of the joint. The back up material may have a surface skin which prevents adhesion of the sealant. If this is only present on one surface care is required to ensure that the material is inserted the right way round. If the back up material does not have a surface skin a bond breaker tape is required. Polyethylene and PTFE are commonly used for bond breaker tape.

The back up material may be applied before or after priming. In the former case care is required to ensure the primer is not removed or damaged during installation of the back up material and in the latter care is required to avoid application of the primer to the back up material.

Foam back up material should be compressed by 25 to 50 % when installed to ensure that it is held securely in place during sealant application. The backer rod must be placed carefully to avoid distortion or twisting and it must be at the correct depth as it controls the depth of the sealant.

If the backer rod is damaged during installation gases can be released and as a precaution a period of 30 minutes should be left between installation of the backer rod and application of sealant to allow gasses to disperse. If severe damage to the backer rod occurs replacement is necessary.

Mixing
Two part sealants require mixing. Mixing is normally carried out using a paddle in a low speed drill.

Mixing needs to be thorough, indicated by a uniform colour, but if too vigorous air can be trapped in the sealant.

Curing of the sealant will commence as soon as it is mixed hence it should be mixed in quantities which can be used within the pot life.

Sealant application
Sealant is normally applied from a hand-operated gun.

The nozzle should suit the width of joint and the rate of extrusion and movement of the gun should be such that the joint is filled with sealant in a single pass Figure 5.8.

For very wide joints it may be necessary to use several passes of the sealant gun building up from the back corners of the joint.

Tooling
Tooling removes voids, improves adhesion by compacting the sealant against the sides of the joint and gives a neat finish. A slightly concave surface reduces movement stresses but overtooling can leave the sealant too thin at the centre.

Tooling must be carried out before the surface forms a skin which may be damaged. The available time for tooling varies from a few minutes to several hours depending on the type of sealant and ambient conditions.

Tooling is usually carried out using a wooden or metal spatula which may be wetted with water or a dilute detergent solution. Water should be used sparingly and applied to the tool rather than the joint. Excess water should be shaken from the tool.

Protection
During the curing cycle dirt may adhere to the tacky surface of the sealant and become embedded. The sealant should therefore be protected from dirt and debris. The sealant may also require protection against inclement weather. However sealants may require the presence of air, moisture or UV to aid curing and protection should not interfere with the curing process.

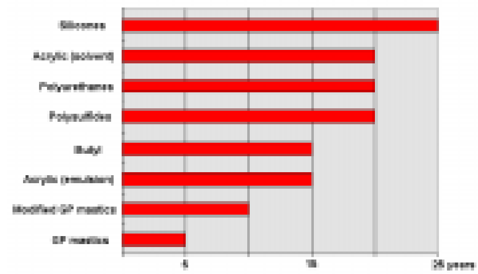

Figure 5.1 Durability of sealants

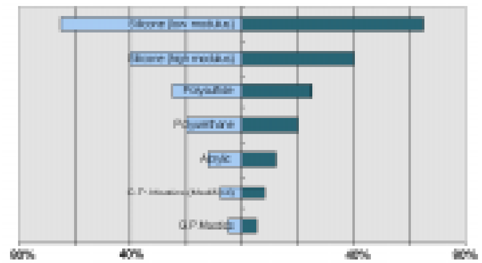

Figure 5.2 Movement accommodation of sealants

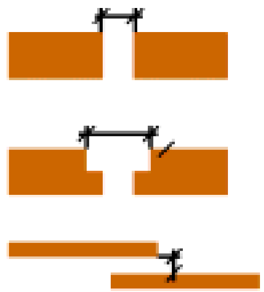

Figure 5.3 Joint width

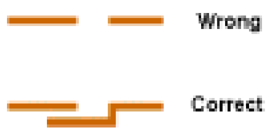

Figure 5.4 Joints between thin panels

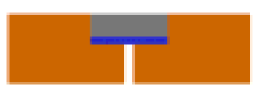

Figure 5.5 Use of release tape

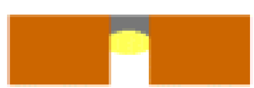

Figure 5.6 Use of backer rod

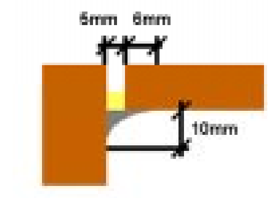

Figure 5.7 Fillet joint minimum dimensions

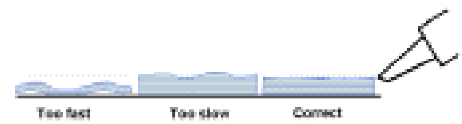

Figure 5.8 Use of sealant gun

6 Finishes

- **Function**

Many facade materials have to be finished or coated to protect them from the environment and give the required appearance. The quality of the finish may be the greatest factor affecting the useful life of the wall and is likely to be a contentious issue if the appearance is not acceptable to the client.

Materials may rot, corrode and suffer other forms of degradation in the presence of moisture, UV, salt laden air and air borne pollutants. The materials most in need of protection from these atmospheric conditions are metals and timber. Plastics and other materials may be painted for reasons of appearance.

- **Aluminium**

Mill finish

Aluminium may be left uncoated as 'mill finish' aluminium. In this form the surface oxidises to form a stable coat. However the oxide coating appears as a slightly white bloom that may not be visually acceptable.

Although the oxide coating is stable it will penetrate under adjacent paint and powder finishes allowing them to blister and separate.

Coatings

Coated aluminium is a durable material and a useful life of 25 years or more can be achieved. The quality of the paint or powder finish depends on the materials used and the cleaning and pre-treatment of the aluminium prior to painting.

Paints and powder coatings are applied to closely controlled thicknesses in the range 40-100 microns. The coating is then oven baked to achieve a uniform and durable surface.

Finished aluminium is a quality product that cannot easily be repaired on site. It should be treated with care and protected as necessary during construction.

The commonly used coatings are:

- Polyester powder coating
- PVDF (Polyvinylidene Fluoride)
- Wet applied paints

Anodising

Aluminium may be anodised to form a hard resistant oxide coating. This coating is integral with the aluminium but should be treated with the same care as painted and powder coated surfaces.

Anodised aluminium may be coloured or clear. Clear finishes are used to give corrosion protection and should be treated with the same care as coloured surfaces.

Cut edges

Aluminium is often finished in lengths prior to cutting and fabrication. Cut edges can be the starting point for corrosion and some contracts do not allow the use of pre-finished (post-cut) aluminium.

The risk of corrosion occurring at cut edges depends on the quality of cutting, standard of pre-treatment and coating. The use of hand held saws and drills is unlikely to give a satisfactory edge quality. Factory machining uses separate drills and blades for working aluminium and steel.

Protection

All significant surfaces should be protected from abrasion, scuffing and other damage during transportation and installation.

Protective tapes are used on coated aluminium surfaces but they are no substitute for careful handling. Additional methods such as protective boards may be used to protect against damage by following trades.

Only low tack tapes should be used as agreed by the manufacturer. Tapes should not be left in place for more than six months or difficulty may be experienced in removing them.

Tapes should be removed by peeling. If this is difficult a soft tool should be used. Sharp blades and solvents should not be used.

Products such as windows may be protected during transport to site by using bubble wrap, shrink-wrap or card. Tape should still be applied to protect significant surfaces during and after installation.

Mortar drops and similar alkaline materials are particularly damaging to coatings and paint finishes which should be appropriately protected.

Remedial work

Site repairs to finishes should be agreed with the Client's agent. It is seldom possible to achieve a repair that looks good and the Architect may ask that the component be replaced. This decision must depend on the extent of damage and any disruption that may arise.

Repairs to coated surfaces should be carried out in accordance with the suppliers instructions. This often requires the use of specialist paint contractors.

- **Steel**

All steel has to be finished to protect it from corrosion. Steel may be coated in the same way as aluminium but these finish coats are applied over a protective treatment. For use in facades steel sections are hot dip galvanised, or equivalent. This is done after machining to avoid edge corrosion. Paint or powder coat is then applied to give the required appearance.

Galvanising deposits a zinc layer on the steel, which protects the steel by forming a barrier between the environment and the steel surface. The zinc layer will corrode unless protected by a coating but corrodes more slowly than steel.

Zinc also provides protection to the steel by corroding preferentially to the steel at breaks in the zinc layer. This process is a form of cathodic protection but is only effective when a sufficient area of the zinc is exposed.

Where there is a paint finish on the zinc surface, protection only occurs at small scratches. Larger areas of damage to the galvanising should be made good with zinc paint.

Protection of finishes and repair of any damage should be dealt with in the same way as damage to finishes on aluminium.

Steel may also be plastic coated. This finish is used for metal coil that is subsequently formed into profiled metal sheets or flat cladding panels. The plastic coating is applied at the steel mill before the metal is shaped and cut and no attention is given to machine cut edges.

Holes and cut edges made with hand held tools will not have such clean-cut edges and may be sites for early corrosion.

- **Timber**

Timber is treated and then finished to prevent the onset of rot and provide a good appearance. The finishes most commonly used are paints and micro-porous stains. Timber windows are often pre-finished at the factory but may be supplied primed for painting on site.

Exposure of untreated timber to sunlight will adversely affect the durability of paint finishes hence untreated timber should be painted, or at least primed, as soon as possible.

Most timber finishes can be repaired by site painting but it is difficult to conceal heavy damage to stained timber. Timber frames should be treated with the same care as other finished materials.

- **Plastics**

Many plastic components are made from self-coloured plastic, predominantly white although brown and other colours are available. These plastics cannot be refinished. They should be protected and treated with care. Components may be coloured by co-extruding a coloured outer layer of the required colour. Damage to this layer may allow the base material colour to show.

Low tack protective tapes should be used on all significant surfaces even if they are only self-coloured plastic surfaces. Tapes should be peelable and used in accordance with the manufacturers' instructions. Plastics are easily damaged by solvents and some adhesives.

Plastics can be finished by painting or applying foil to the surface. Adhesive foil is commonly used to achieve a wood grain effect on domestic windows. Repairs to painted and foiled surfaces are difficult to achieve with any degree of success and the manufacturer should be consulted before any remedial work is started.

- **Appearance**

Finishes determine the appearance of the completed building and this is a subjective issue. It is little wonder that the appearance of finishes is so often questioned. Appearance depends on:

- Colour match
- Level of gloss
- Texture

On larger contracts it is common practice to make samples showing the acceptable colour range and level of gloss. All oven-baked finishes will suffer some orange peeling and this texture is to be expected. Samples will show the acceptable limits of this texturing. In some cases an independent inspector will be employed to acceptance test the finishes.

In either case it is advisable to gain acceptance for the finishes before they are delivered to site or at least as the components are installed.

When inspecting finishes for appearance they should be viewed from a distance of one metre using normal, corrected vision in diffuse daylight.

- **Cleaning down**

Protective tape and other protective measures should be left in place as long as possible. If tape is removed for inspection it should be replaced, if necessary with new tape of the same type.

On completion surfaces should be cleaned down using water containing a mild detergent. Neither abrasives nor solvents should be used on any finished surfaces.

7 Glass

- **Types**

Glass is available in many types, thicknesses, patterns and finishes. The glass is selected for reasons of safety, appearance and the way it controls the internal environment of the building.

Glass may be grouped into categories by considering:

- Strength and safety
- Appearance
- Environmental control

Strength and safety

Glass in a building will be subject to mechanical loads in the form of wind load and impact. It may also be subject to stresses due to environmental conditions such as temperature changes. The strength properties of glass can be varied by increasing the thickness, heat treatment and combining the glass with other materials to form composites. The strength of glass must be sufficient to resist the loads it is likely to be exposed to. Safety of glass is related to its strength but also takes into account the risk of injury from the failed glass.

- Annealed glass

Annealed glass is the basic form of glass produced in float glass plants. It has no special properties of strength or safety and on breaking it forms large shards with sharp edges.

- Heat strengthened glass

Annealed glass may be strengthened by controlled heating and cooling. Heat ***strengthened glass is not a safety glass*** but is roughly twice as strong as annealed glass. When broken it behaves like annealed glass and breaks into large shards with sharp edges.

- Wired glass

Wired glass fractures in the same way as annealed glass but remains in place with the shards held together by the wire mesh. Wired glass is not stronger than annealed glass before failure. After failure the strength of the pane will depend on the thickness of the wires. Wired glass is available as ordinary wired glass and safety wired glass which contains stronger wires.

- Toughened glass

Annealed glass is toughened by heating it to 650^{o}C and rapidly cooling the surfaces. This compresses the surfaces and increases the strength of the glass. Toughened glass is roughly five times as strong as annealed glass.

An important property of toughened glass is the way in which it breaks. Any cracking of the glass leads to a rapid release of the surface compression and toughened glass always breaks into small pieces of glass Figure 7.1. Toughened glass complying with BS6206 is a safety glass.

Toughened safety glass should be kitemarked and installed with the kitemark visible.

Toughened glass cannot be cut or drilled after toughening and must therefore be cut to size before toughening.

- Heat soaked toughened glass

Toughened glass may fail due to the presence of nickel sulfide crystals in the glass. To reduce the risk of nickel sulfide failure, the glass may be subjected to a process known as heat soaking. To be effective the heat soaking process must be strictly controlled.

- Laminated glass

Annealed, heat strengthened or toughened glass can be laminated in any combination to make a safety or security glass. Two or more pieces of glass are laminated together to give the required properties. The glass may be laminated as a sandwich with a layer(s) of polyvinyl butyral (PVB) between the sheets of glass. Glass can also be laminated by pouring a resin between two sheets of glass. PVB laminates are best suited to flat glass while poured resins are best suited to curved glass.

Laminated glass is not as strong as a single pane of glass of the same type and thickness but after failure the broken pieces of glass will be held together by the interlayer.

The performance of a laminated glass depends on the type of interlayer used. Some are designed to resist penetration and others solely as safety glasses.

- Tempered glass

Tempering is the American term for strengthening and toughening. Tempered glass is roughly equivalent to heat strengthened glass and is not a safety glass. Only fully tempered glass has similar properties to toughened glass. Fully tempered glass used as a safety glass should conform to BS6206.

- Plastics

Polycarbonates are sometimes used as glazing materials. They are used for safety glazing as they are less prone to breakage. Plastics are more flexible than glass of the same thickness. They may be sprung out of a glazing frame and are not always suitable as security glazing. Plastics are less scratch resistant than glass.

Appearance

- Patterned

Glass may be patterned by rolling a relief onto one surface while it is still hot and soft. This is done to obscure vision or to change the appearance of the facade. Patterned glass has the same strength and safety characteristics as annealed glass and is not normally a safety glass however it is possible to toughen patterned glass. Some patterned glasses - those that do not have deeply embossed surfaces - may also be laminated.

- Printed

It is possible to print patterns on to glass. This may be done to make people aware of the glass for safety reasons. In this case the patterning has to be in the correct position. Note that company logos and other signage may be used for this safety purpose.

- Fritted and etched

The surface of glass may be etched or otherwise altered to achieve the same effect as printing. Again this may be done for safety reasons.

Environmental control

Environmental control glasses are used to limit the heat and light passing through a window.

- Tinted
Glass may be tinted to reduce light transmission and prevent glare within a building.

- Coated
Glasses are coated to change the properties of the glazing. Coatings are used to reflect light and/or heat. Increasing the amount of reflected light may be required for aesthetic reasons (giving a mirror effect) or to restrict the view into the building. Reflection of heat may be required to reduce solar gain or to retain heat within the building. The type of coating will differ depending on its purpose.

Low emissivity (low-E) coatings are among the most widely used and are provided to reflect heat from inside the building back to the inside and therefore reduce heat loss. They do not reflect solar radiation in the same way due to the different wavelength. They are not visible to the eye.

- Printed
Patterns may be printed or etched onto the surface of the glass to obscure vision or prevent glare.

- Double and multiple glazing
Glass is frequently used as insulated glazing units (double glazing). This is normally done to reduce heat loss from the building but it can also help to reduce noise levels inside a building. In some cases triple glazing is used to reduce noise levels or further reduce heat loss.

Insulated glazing units may be made using any of the glasses described above and different glasses may be used for the inner and outer panes. The panes are separated by a spacer bar. The units may be constructed with a primary airtight seal between the spacer bar and the glass and a secondary structural seal outside the spacer bar holding the glass panes together Figure 7.2. Alternatively a single structural and air tight seal may be used Figure 7.3.

- Gas filled
Insulated glazing units may be gas filled to reduce energy loss through the window. Any units that are broken or damaged should be replaced with equivalent units.

• Safety glazing and fire rated glazing

The Building Regulations make specific requirements for the use of safety glazing and fire rated glazing under certain circumstances. The design of the facade will have taken account of these requirements. It is essential that safety glazing and fire rated glazing are installed as specified.

Safety glazing
Glass in critical locations (adjacent to doorways and pedestrian areas and in windows with low sills) has to comply with part N of the Building Regulations Figures 7.4 and 7.5.

The glass has either to break in a safe manner or resist impact. It is normal to use toughened, laminated or wired glass in these locations. Plain annealed glass may be used provided no single pane exceeds 0.5 m^2 in area, the smaller dimension is no more than 250mm and the thickness is not less than 6 mm.

Substitution with glass of different performance in a critical zone may be unsafe and should only be approved by the specifier.

Fire rated glazing systems
Fire rated glazing systems will have been tested to show that they can resist fire for the required period of time.

The performance of a fire rated screen depends on the exact replication of the test sample on every contract. No substitution of any framing, glazing or other components is permitted.

In the UK FIRAS maintain a register of trained installers and approved specialist contractors.

CDM Regulations
The Construction, Design and Management Regulations require all people involved in the construction of a building to ensure that it is safe during construction and use. Glass is a potentially hazardous material and care will be required to ensure the safety of the workforce, occupants of the completed building and any future maintenance workers.

• Terminology

The following terms relating to glazing are illustrated in Figure 7.6.

- Sight size
- Pane size
- Tight size
- Edge clearance
- Rebate depth
- Edge cover
- Back clearance

• Condition

The performance of glass is highly dependent on its condition. The use of damaged glass or insulated glazing units will impair the performance of the facade.

Glass should be inspected for:

Size
Glass that is undersize will not have sufficient cover in the glazing rebate. This can lead to an inadequate seal at the gasket and in the extreme loss of glass retention.

Glass that is oversize will reduce the clearance between the glass and frame which will limit the accommodation of relative movement of the glass and frame.

If thinner setting blocks are used to accommodate oversize glass this will reduce the cavity in the glazing rebate so that the lower edge of the glass is wetted. This may lead to the breakdown of seals of glazing units.

Ultimately the glass may not fit into the frame if it is too large.

Surface defects
Surface defects are uncommon with float glass. However when they do occur they are clearly visible. Surface defects are an obvious source of irritation to the client.

It is good practice to check all glass for surface defects at the time of installation. It is far easier to replace glass at this stage while the access scaffold is still in place.

Toughened glass may have a slightly rippled surface as a result of the toughening process. This is generally accepted but if particularly bad it may be unacceptable and the glass may have to be replaced.

If the cavity of an insulated glazing unit is at a different pressure to the surrounding air, the glass will dish and give distorted reflections.

Pressure differences can be caused by sealing the units at too high a temperature or at a different altitude from the site. This results in dishing of the glass as the cavity volume changes. Visual effects can be quite pronounced and unacceptable.

Changes in weather conditions will have a smaller effect that is normally acceptable.

Edge defects
Edge defects include:

- Feathering where the edge of the glass is not exactly square to the face and may not be plane
- Venting where the edge of the glass is clearly chipped to leave sharp edges around a depression

Feathering of the edge is acceptable up to a point. Venting is never acceptable Figure 7.7.

Edge defects cause stress concentrations which weaken the glass if it is subject to load. Thermal fracture of glass takes place if there is a large temperature difference between different parts of the glass. This can occur when most of the glass is heated by solar radiation but the edge is kept cool by shadows or the insulation of the frame. Stress concentrations at edge defects increase the risk of thermal cracking.

An edge tape may be used but this is not recommended as it provides little protection, hides edge damage, prevents inspection of the seal(s) and can even trap moisture causing breakdown of the seal.

Laminated glass
Laminated glass should be visually and optically acceptable. There should be no damage to the edge of any sheet of glass in the laminate.

Edge seals
Sealed units are made with either single or double edge seals to comply with BS5713.

Double edge seals are used to give a longer life to the unit. Any units replaced on site due to breakage or the presence of defects should be replaced with units of the same construction.

Edge seals should be free of any visible air bubbles.

- **Identification**

Identification of glass on site can present difficulty if it is part of a glazing unit, has invisible coatings or particular strength properties. The main methods of identifying glass are:

- Visual inspection with a gauge card held against the surface will identify the glass thickness using the reflection from the back face of the glass. A reflected flame will appear differently on coated surfaces.

- **Marking** of glazing units at the time of manufacture assists identification. Labels should show: type of glass, size, manufacturer, glazing position and orientation. Toughened safety glass should be kitemarked to BS6206. Glazing units may be kitemarked to BS5713.

- Gauges or meters may be used to determine glass thickness. Several commercial systems are available.

- DSR (differential surface refractometer) equipment can be used to determine the surface stresses in glass and the degree of toughening. This equipment is expensive and is unlikely to be available on site.

- **Ultrasonic** test equipment can be used to identify laminated glasses. These also sound differently when tapped.

Suitable methods of identification:

Glass types	***Methods***
Clear float	Visual or meter
Patterned	Visual
Wired	Visual
Tinted	Visual
Coated	Visual or meter
Heat-strengthened	DSR
Toughened	Mark, DSR or polarised light
Bent	Visual
Laminated	Mark, ultrasonic
Glazing unit	Mark on spacer
Printed	Visual
Off-line coated	Visual, meter, reflections

- **Glass installation**

The following standards apply to glass installation:

BS6262	Code of practice for glazing of buildings
BS8000 Pt 7	Code of practice for glazing on building sites
BS5516	Code of practice for design and installation of sloped and vertical patent glazing
BS8213 Pt 4	Code of practice for the installation of replacement windows and doorsets in buildings

Glazing materials should be installed in accordance with the manufacturer's instructions and BS6262. BS6262 gives general guidance applicable to most windows.

Where manufacturer's instructions differ from BS6262 the manufacturer's instructions should be followed.

Positioning
It is important that glazing units are correctly positioned. Units that include safety glass should be used in the correct openings and not swapped with non safe units.

Units that have different glasses for the inner and outer panes should be positioned with the correct face outermost. This may be required for reasons of safety, appearance or the effectiveness of energy efficient glazing.

Each glazing unit will contain two or more pieces of glass that will be of slightly different size due to manufacturing tolerances. Good quality glazing units are constructed with all glass aligned on two edges of the unit that are labelled 'bottom'.

Glass should be installed with the correct edge resting on the setting blocks so that all sheets of glass are equally supported.

Setting blocks and spacers
Setting blocks are used to support the glass and must support both panes of a glazing unit. They prevent glass to frame contact and centralise the glazing in the frame, Figure 7.8.

Setting blocks should support the glazing clear of any water that enters the glazing rebate.

Setting blocks should not block any drainage paths. Some systems require setting blocks that bridge the drainage channel. Use of sealant to locate setting and location blocks may also block drainage paths.

Setting blocks may be made from the following materials:

- Neoprene with Shore Hardness 80 to 90
- Plasticised PVC with softness of 35 to 45
- Extruded unplasticised PVC

Hammered lead is sometimes used in undrained systems and sealed hardwood may be encountered in some windows but should not be used in curtain walls.

Location blocks are used to prevent lateral movement of the glazing and give rigidity to opening lights and factory glazed products. They are made from the same materials as setting blocks.

Distance pieces are used to maintain the distance between the glass and the frame when using wet applied sealants Figure 7.9. They are made from the same materials as setting blocks.

Glass and frame support
The glazing material stiffens the frame of opening lights and doors and prevents them distorting or sagging in use. The setting block positions are selected to correctly stiffen the frames as well as support the glass. For windows that pivot on a horizontal axis the setting blocks at the top of the frame also support the glass.

The recommended positions for setting blocks for windows are shown in Figure 7.10 but the manufacturer's instructions should also be read.

Setting blocks should be at least 30mm and no more than 100mm from the corner of the glazing frame.

Curtain walling and glazing screens have to move to accommodate movement of the primary structure. Location blocks in curtain walling should be placed near the bottom of the glass to prevent lateral movement of the glass but allow racking of the frame Figure 7.11.

Edge clearance
Glass should be fitted into the frame with adequate edge clearance. This is necessary so that:

- The glass and frame can move without stressing the glass
- Water entering the frame can drain freely

Minimum edge clearances for glass are:

- 3mm for glass sizes up to 2m
- 5mm for glass sizes over 2m
- 6mm for all drained systems

Minimum edge clearances for plastic glazing materials are:

- 3mm for plastic sizes up to 1m
- 5mm for plastic sizes between 1 and 2m
- 7mm for plastic sizes between 2 and 3m

Drainage
Drain holes in the bottom or face of the frame must not be blocked by setting blocks, swarf or sealants.

- **Storage and Handling**

Glass weight
Typical glazing units are heavy and larger units require special consideration. It is always preferable to glaze windows at the factory. However for larger windows the completed weight is too great to be lifted manually and these windows have to be site glazed. Some windows have to be deglazed for fixing into the opening.

Glass weighs 2.5kg/m^2/mm. Weights of typical glass products are shown below;

6mm glass	15 kg/m^2
6 - 12 - 6 glazing unit	30 kg/m^2
7.3 - 12 - 6 laminated glazing unit	32.5 kg/m^2
15mm glass	37.5 kg/m^2

Consideration should be given to mechanical handling and lifting of larger glazing units and complete glazed windows.

Glass storage
Glass should be stored:

- In the dry
- Out of direct sunlight
- Stood on edge
- Protected from impact
- Protected from dirt

Glass should be stored on site in a protected location where it will not be damaged and does not become marked or unduly dirty.

If glazing seals become wet, particularly if water becomes trapped behind edge tapes, the seals will start to break down. If water is trapped between two pieces of glass for too long then the glass surfaces may be permanently marked.

If glass is stored in direct sunlight then heat passes into the stack and cannot escape. The glass within the stack can become very hot causing fracture.

Glass should be stored stood on edge and inclined against a rest to prevent it from falling. With glazing units both edges should be supported to reduce the risk of edge damage. A suitable arrangement is shown in Figure 7.12.

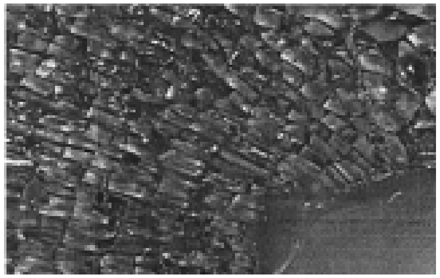

Figure 7.1 Fractured toughened glass

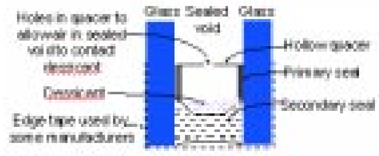

Figure 7.2 Dual seal edge detail

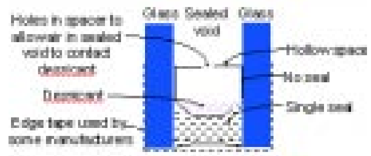

Figure 7.3 Single seal edge detail

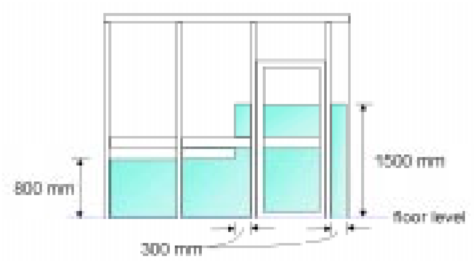

Figure 7.4 Critical areas in a glazed screen

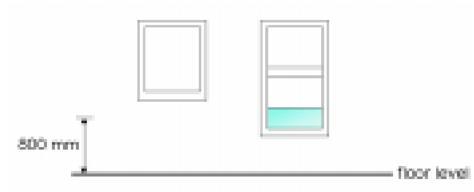

Figure 7.5 Critical areas in windows

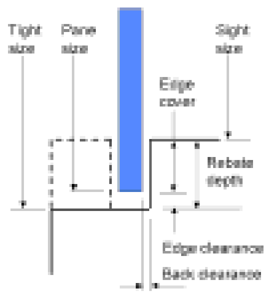

Figure 7.6 Glazing terms

Figure 7.7 Edge damage to glass

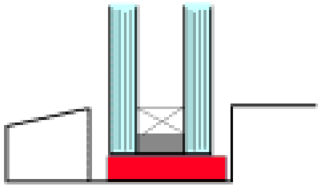

Figure 7.8 Setting block

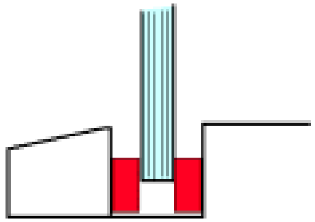

Figure 7.9 Distance pieces

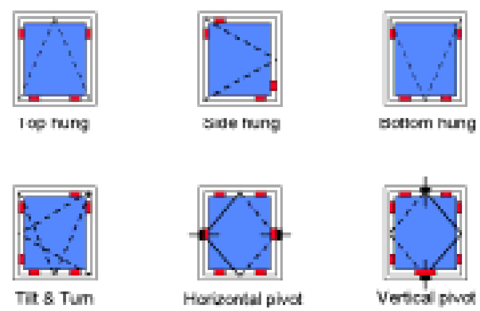

Figure 7.10 Setting and location block (windows)

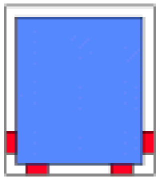

Figure 7.11 Setting and location blocks (curtain wall)

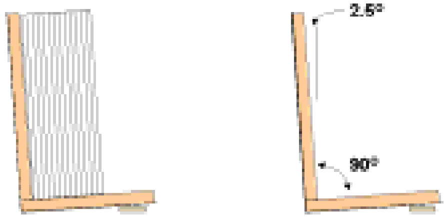

Figure 7.12 Storage of glass

8 Brackets and fixings

- **Function**

Brackets and fixings are used to attach curtain walling and windows to the supporting structure.

Windows are normally located within the supporting wall so that vertical loads are transferred to the structure by bearing at the window cill. Fixings are required to hold the frame securely in position and resist horizontal loads. Fixings may pass directly through the frame into the supporting structure. Alternatively a strap or lug may be attached to the frame and fixings pass through the strap into the supporting structure, Figure 8.1. The use of lugs or straps is essential for factory glazed windows. When through fixing care is needed to avoid crushing or distortion of the frame.

Curtain walling is normally positioned in front of the supporting structure and brackets are required to connect the curtain wall to the structure. Fixings are then required to attach the brackets to the structure.

- **Performance of Brackets**

Brackets are required to perform a number of functions as described below.

Loads

Vertical forces due to dead loads and horizontal forces due to live loads are transferred to the structure by the brackets. To transfer these loads two types of connection are required:

a) Support brackets are required to carry dead loads and these will prevent vertical movement of the mullion relative to the supporting structure. Only one support bracket is necessary for each length of mullion and provision of additional supports is undesirable as movement will be restricted (see below).

b) Restraint connections are required at both top and bottom of mullions to resist wind loads.

Two possible bracket arrangements for a single storey height mullion are shown in Figure 8.2. The top hung arrangement is more common but the bottom-supported arrangement may be used, particularly for low-rise construction. Where mullions span more than one storey restraint connections are usually provided at the intermediate floors.

Adjustment

All brackets should provide adjustment in three directions to overcome dimensional variations.

Means of adjustment include:

- Slotted holes for fixings
  These may need to be combined with serrated surfaces to prevent further movement after adjustment or low friction surfaces to permit movement by sliding after installation;

- Site-drilling or welding after positioning of components
  This may be used for final fixing after initial fixing with slotted holes.

  It is likely to be less successful for fixings into concrete as the required hole positions may coincide with reinforcement.

- Shims, packing pieces or washers
  If excessive thicknesses are used nuts may not engage fully with bolt threads and bending stresses may be induced in bolts.

  Packing pieces may also reduce the contact area between components increasing stresses and inducing additional bending.

- Sliding connections;

- Channel fixings - Comments for slotted holes apply:

Movements
Design of brackets needs to take account of movements of the curtain wall and structure to avoid:

- Imposing loads on the curtain wall for which it has not been designed

- Breakdown of seals due to large movements being transferred from the frame to the curtain wall

For stick curtain walls, vertical movements are usually accommodated in the splices between mullions which allow the sections of mullion to slide vertically but transfer horizontal load.

Movements which cause shear of the curtain wall can usually be accommodated by rotation of the mullion/transom joints provided there is sufficient clearance between the frame and the infill.

Although vertical movements will normally be greater than horizontal movements, horizontal movements must also be considered.

All brackets should allow the required amount of movement after fixing. Movement accommodation should not be sacrificed to achieve fit of incorrectly sized elements and components.

Resistance to corrosion
Two forms of corrosion warrant consideration:

- General corrosion of individual components including brackets, fixing bolts and curtain walling
- Bi-metallic corrosion resulting from contact between components made from different metals.

Requirements for corrosion resistance also apply to fixings and are described in the materials section below.

Buildability
Cladding is often erected at height in inclement conditions. Connection details should therefore be simple to construct, to improve safety and reduce the risk of poor workmanship.

Brackets which are capable of being lined and levelled in advance of cladding erection can produce overall cost benefits.

- **Fixings**

Fixings are required to attach curtain wall brackets and windows to the structure. A wide variety of proprietary fixings is available.

The selection of suitable fixings for a particular application depends on a number of requirements including the magnitude of the loads to be carried, the nature of the loads (shear, tension or compression), thickness of the fixture (including provision for packing or shims), the substrate and the required life of the fixing. Substitution of a specified fixing by an alternative type requires a reappraisal of all these factors.

The load which fixings are required to carry varies greatly. Window frames will normally be secured with a number of fixings at intervals around the perimeter, Figure 8.3, giving fairly small loads at each fixing. A fixing for a curtain wall bracket will carry the total wind load for a larger area of cladding, Figure 8.4. The curtain wall fixing will also have to carry the dead load.

The load from the curtain wall bracket may be carried by one or two fixings giving little scope for load redistribution in the event of failure whereas failure of a single window fixing may be accommodated with little difficulty.

The performance of curtain wall fixings is therefore more critical to the safety of the installation.

Fixings may be required to connect to steel, concrete or masonry. Brackets for curtain walling are commonly fixed to concrete floor slabs but can be fixed to the structural steel frame. Window frames are commonly fixed to masonry but may be fixed to concrete.

Steel
Fixings to steelwork are normally bolts which may connect directly to structural steel sections or to cleats welded to the sections.

Any welding should normally be carried out by the steelwork fabricator prior to delivery to site.

Concrete
Fixings to concrete may be cast-in place or post installed. Cast-in place fixings are positioned in the formwork prior to casting the concrete and usually take the form of channels with T-head bolts or internally threaded sockets, Figure 8.5. There are three forms of post-installed fixings related to their method of load transfer as follows:

- Expansion anchors in which a metal cone is drawn into a metal sleeve or shield causing friction against the sides of the hole, Figure 8.6. In torque controlled fixings the expansion occurs as the fixing is tightened. In displacement controlled fixings the sleeve is forced over the cone using a hammer and a separate operation is required to connect the fixture to the installed fixing.

- Undercut anchors in which the end of the hole is enlarged allowing the end of the anchor to expand without inducing stress in the substrate, Figure 8.7. Mechanical interlock then provides resistance to pullout.

- Bonded anchors in which the anchor is held in the hole by resin which may either be introduced in the form of a glass capsule or may be injected from a cartridge, Figure 8.8.

Resin anchors transfer the load over the whole of the bonded length giving lower contact stresses than other types of fixing.

The performance of fixings in concrete depends on the strength of the concrete and density of aggregate. The choice of appropriate fixings will also take account of the practical problems of either securing the fixings to the formwork or alternatively drilling holes in the hardened concrete.

Masonry
Masonry can be a difficult material to fix into due to the wide range of strength of masonry materials, the presence of voids within the masonry units and the presence of mortar joints. Fixings should normally be located within the masonry unit rather than the mortar joint. Fixings for use in masonry include expansion anchors, bonded anchors, screws and specialist fixings designed for use in low strength materials, particularly aerated concrete

Some expansion anchors with metal sleeves and cones are suitable for use in masonry but similar anchors with plastic sleeves and plastic wall plugs are also available. These may be standard wall plugs were the plug is embedded fully within the masonry and expands when a conventional screw is inserted, Figure 8.9, or frame fixings where the plug extends through the fixture into the masonry and may be expanded by a screw or nail, Figure 8.10.

When perforated masonry units are used it may be necessary to use longer fixings which will pass through several webs of material to provide a secure fixing.

Bonded fixings may be used in solid masonry in the same way as they are used in concrete. However where hollow masonry units are used it may be necessary to use a net sleeve to contain the injected resin, Figure 8.11.

Screws which will cut their own thread in predrilled holes in masonry materials are available, Figure 8.12.

Specialist fixings for use in aerated concrete include plastic plugs with fins which are hammered into predrilled holes, Figure 8.13, and anchors which are grouted into an enlarged hole using a cement grout, Figure 8.14.

Materials
Brackets may be manufactured for a particular installation requiring the specifier to select the appropriate material. Brackets may be made of aluminium, steel or stainless steel. In most cases proprietary fixings will be used and the choice of material depends on what is available. Fixings are commonly available in stainless steel or zinc plated and passivated steel. Most stainless steel fixings are available in grade 1.4401(316) but some are also available in other grades. Fixings may also be available in hot dip galvanised steel and unprotected carbon steel.

Aluminium and stainless steel are durable in most conditions but stainless steel is available in different grades and an appropriate grade should be selected. Carbon steel components require protection which is commonly provided by galvanising or zinc plating. Galvanising gives greater protection than zinc plating but is less durable than stainless steel.

Aluminium, zinc-coated steel and stainless steel are generally compatible in situations which are likely to occur in practice. Although there is an increased risk of corrosion of aluminium when it is in contact with stainless steel the risk depends on the relative areas of the materials.

Stainless steel fixings for aluminium components are therefore acceptable whereas aluminium fixings for stainless steel are not.

The specifier should have taken into account the durability of the materials used and the specified material and finish must not be changed without his agreement.

Installation

General
- Before installation all fixings should be checked to ensure that they are of the specified type, size and material. Fixings must be installed in accordance with the manufacturer's instructions.

- Setting out is required before fixings can be installed. Setting out should be related to the site datum rather than local features such as the slab edge or nearby column.

- The correct equipment is required. Some fixings require special tools supplied by the fixing manufacturer and may not operate correctly it alternative tools are used.

Cast in fixings in concrete
- Fixings should be securely fixed in place before placing the concrete
- The concrete should be allowed to cure before applying load to the fixings

Post drilled fixings
- Drill hole to correct diameter. Drills become worn with use and need to be replaced at intervals. Percussive drilling is normally required for concrete but when drilling into weak materials rotary drilling may be required to prevent enlargement of the hole.

- In all cases the hole must be deep enough to allow the fixing to be inserted to its full depth.

  For some fixings a greater depth of hole will not affect the fixing performance. However, for some types of fixing, for example bonded fixings with resin capsules and some displacement controlled expansion anchors, an overlong fixing hole may prevent the correct operation of the fixing.

- Ensure holes are square to the surface.

- Ensure minimum edge distance and spacing is provided. Reducing the edge distance and spacing reduces the strength of the fixing.

- Ensure reinforcing steel is avoided and agree procedures to be adopted where holes conflict with reinforcement. Reinforcement should only be cut with the agreement of the structural engineer and when the cut reinforcement will not affect the operation of the fixing.

- Where holes are aborted, due to hitting reinforcement or for any other reason, procedures for filling aborted holes and minimum spacing for replacement holes must be agreed.

- Clean hole thoroughly; blowing is usually sufficient for mechanical anchors, brushing is required for bonded anchors.

- For bonded fixings ensure temperature and moisture conditions are suitable and allow resin to cure before applying load.

- Position fixing correctly.

- Tighten to specified torque using calibrated torque spanner.

  If too low a torque is used the anchor may not clamp the fixture securely when subject to tensile load and expansion anchors may not give the required pullout strength. Too high a torque may damage the fixing material or may break the bond of resin anchors.

- Fixings should be marked for example by spraying with paint to indicate that the correct torque has been applied.

Packing and shims

- Shims should be made of material with suitable strength and durability. Plastic shims may be used when fixing window frames but metal shims should be used when fixing brackets. When metal shims are used the metal must be of sufficient inherent durability for the exposure conditions and be compatible with other metals with which it may come in contact.

- Shims should be of sufficient size to prevent concentrated loads.

- Use of shims will lead to increased bending stresses in fixings subject to shear load. The maximum thickness of shims should be specified and not exceeded.

Slotted holes

- Where slotted holes are used to provide adjustment it is important to use washers which are sufficiently thick to bridge the slot without deformation.

- Where slotted holes are used to provide adjustment but additional movement is to be prevented during the service life a means of locking the fixing is required. Friction under the clamping action of the fixing is not sufficient.

- This is usually achieved by the use of serrated surfaces. The pitch of the serrations must be selected to give sufficiently fine adjustment.

Testing

- In most cases proprietary fixings can be used in situations covered by the manufacturer's test data however occasionally testing may be required to check the suitability of fixings. This is most likely to occur when fixing to an existing structure and the properties of the substrate are unknown.

- To check the quality of installation a proportion of the installed fixings may be tested. The test load must be sufficiently high to give a meaningful test but not so high that correctly installed fixings are damaged. Testing is more likely to be required for curtain wall fixings than for window fixings.

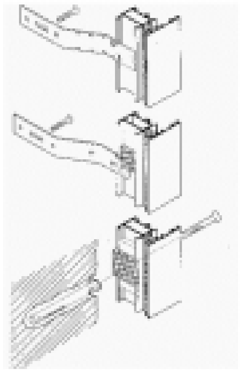

Figure 8.1 Fixings for windows

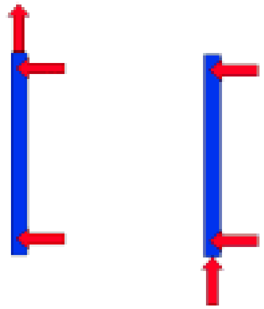

Figure 8.2 Support and restraint of curtain walling

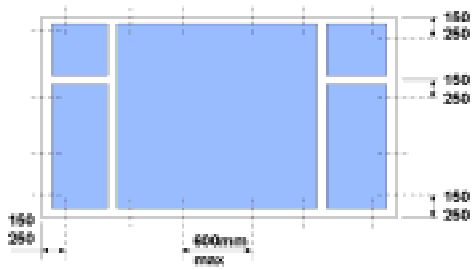

Figure 8.3 Fixing points for PVC-u windows

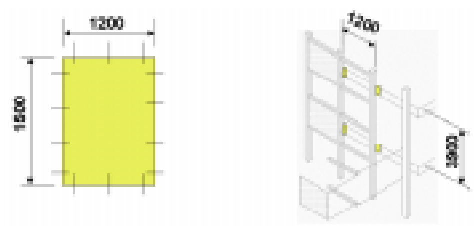

Figure 8.4 Spacing of fixing points

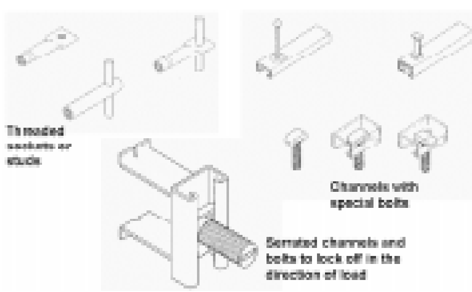

Figure 8.5 Cast-in place fixings

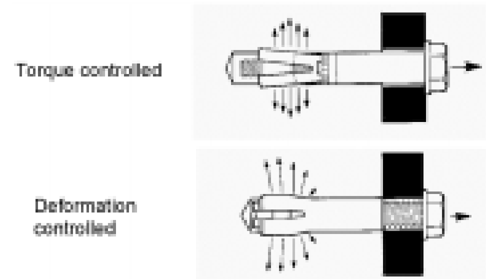

Figure 8.6 Expansion anchors

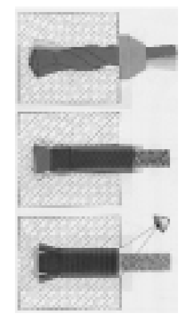

Figure 8.7 Undercut anchors

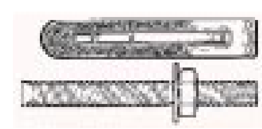

Figure 8.8 Resin anchor

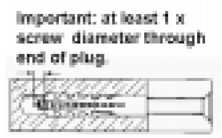

Figure 8.9 **Wall plugs**

Figure 8.10 **Frame fixings**

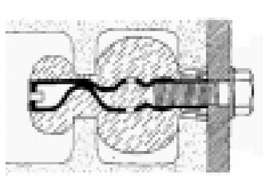

Figure 8.11 **Resin fixing with net sleeve**

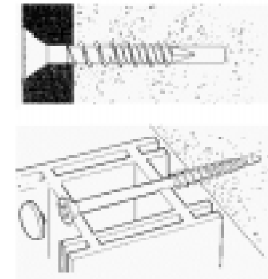

Figure 8.12 **Self drilling masonry fixings**

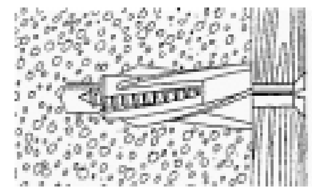

Figure 8.13 **Plastic plug with fins**

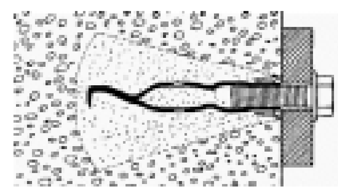

Figure 8.14 **Grouted in anchor**